Augmenting safe system of working: a systems thinking approach with leading indicators embedded within

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DECLARATIONS

I declare that no material contained in the thesis has been used in any other submission for an academic award.

I confirm that the thesis submitted is entirely my own work and based on my own research; that all sources used are appropriately acknowledged and that where the words of others are used these are clearly placed in quotation marks.

I have published material relating to this research previously and reference is made to any such publications in the body of the thesis and referenced accordingly.

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I am of the belief that the contributions and outcome we have managed to achieve with the continuous support and guidance of supervisory team will have lasting positive effect on people's lives and inspire generation of academics and problem-solvers for continuous improvement and pursuit of knowledge.

DEDICATIONS

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ABSTRACT

Complex and evasive phenomenon such as safety requires a holistic, multifaceted and intricately monitored and managed approach as opposed to current fragmented and reductionistic methods predominating in safety management. Such gestaltism of combining componential elements of complexly integrated systems can be achieved through the adoption of systems thinking and via the use of weak but early signals known as leading indicators. Therefore, this current doctoral study seeks to engender a novel theoretical basis in the form of conceptual model for the promulgation of proactive and holistic safety management, which is founded on continual and iterative learning from past and current safety activities. Such a conceptual model is inductively developed through analysis of existing knowledge in the literature and is tested with real life case study data.

To achieve the research aim, the research philosophies of interpretivism and critical realism were adopted to study the phenomenon under investigation and develop new theoretical insights. Within this overarching epistemology, the research strategy of sequential mixed methods was employed by combining a systematic literature review and case study using combination of data analysis methods such as thematic analysis, content analysis, cross-comparison analysis and framework analysis. The research process follows two phases *viz.,* in phase 1 pertinent literature is systematically reviewed with inductive reasoning and in phase 2 the research outcome from the preceding phase is tested with real case data using abductive and deductive reasoning. Consequently, the phase 1 of the study engenders a novel conceptual model for leading indicators' development and implementation. To test this research outcome, a proof-of-concept is designed at phase 2 by adopting the development step of the conceptual model *viz*., by seeking to develop leading indicators from a combination of case study data and their relevant normative documents. In addition to testing the conceptual model, this step engenders a novel analytical framework which provides the systematic development of leading indicators from the qualitative dataset. As a result, a total of 484 new leading indicators were identified by using the analytical framework. Subsequently, all these three research outcomes (i.e. proof-of-concept model, analytical framework and examples of leading indicators) are validated through focus group interview of experts.

Consequently, the study has developed multiple research outcomes, *viz.*, main contributions such as proof-of-concept model in Figure 7.9; analytical framework in Figure 8.3; as well as

other research contributions such as guidance note for training efficacy assessment in Figure 7.4; Safety-in-cohesion model in Figure 7.7; and Dynamic theory of incident evolution in Figure 8.5. These research findings generated create the groundwork for: proliferation of systems thinking in understanding safety, its management and maintenance; propagation of proactive and pre-emptive stance in development of safety countermeasures; and promulgation of a dynamic and adaptable approach in the generation of safety intelligence for continuous improvement. Therefore, these emergent theoretical and practical contributions stemming from this current doctoral work will become instrumental in mitigating asset and personal risks related to frontline workers' interaction with operating vehicles and construction machinery on highway work sites as well as in other safety critical industries and sectors. Moreover, the work will be influential in continuously monitoring safety status of complex systems and simultaneously preventing unfavourable events from taking place and learning from both failures and successes.

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ACRONYMS AND ABBREVIATIONS

AE	Academic expert
AHP	Analytic Hierarchy Process
AI	Artificial intelligent
ALIs	Active leading indicators
ANP	Analytical Network Process
BBS	Behaviour-based safety
BCU	Birmingham City University
BIPV	Building-integrated photovoltaic
BP	British petroleum
CAQDAS	Computer assisted qualitative data analysis software
Chat GPT	Chat Generative Pre-Trained Transformer
CII	Construction Industry Institute
CPCS	Construction Plant Competence Scheme
CSLIs	Case study leading indicators
DEMATEL	Decision-Making Trial and Evaluation Laboratory
EMR	Experience modification rate
FRAM	Functional Resonance Analysis Method
GPS	Global Positioning System
HFACS	Human Factor Analysis Classification System
HFST	Human factor safety training
HOP	Human and organisational performance
HRO	Human Reliability Organisations
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
ICE Planner	Intelligent Construction Equipment Planner
IE	Industry expert
IoT	Internet-of-things
LANTRA	Land and Training
LIs	Leading indicators
LRLIs	Literature review leading indicators
LWDR	Lost workday rate
MA	Major accidents

MCDA	Multi-criteria decision analysis
MCDM	Multi-criteria decision making
MIC	Methyl isocyanate
MS Teams	Microsoft Teams
NHS	National Health Service
NM	Near misses
NPfIT	National Programme for information technology
NPORS	National Plant Operators Registration Scheme
NVQ	National Vocational Qualifications
OECD	Organisation for Economic Co-operation and Development
OSHA	Occupational Safety and Health Administration
PFSS	Pay for Safety Scheme
PLIs	Passive leading indicators
POWRA	Point of work risk assessment
PPE	Personal protective equipment
PQS	Productivity, quality and safety
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analysis
PTSD	Post-traumatic stress disorder
PUWER	Provision and Use of Work Equipment Regulation
RAMS	Risk assessment methods statement
RE	Resilience engineering
RFID	Radio Frequency Identification
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations
SA	Severe accidents
SD	Safety differently
SMART	Specific, measurable, achievable, relevant and time-bound
SMS	Short message service
STAMP	Systems Theoretic Accident Modelling and Processes
STS	Sociotechnical systems
SVM	Support vector machine
SVQ	Scottish Vocational Qualifications
VR	Virtual reality
WAD	Work-as-done
WANO	World Association of Nuclear Operators

WAP	Work-as-planned
WMS	Workers, machinery and sites

LIST OF APPENDICES

CONTRIBUTIONS OF THE STUDY

As resulting from this doctoral work, following research papers and academic awards were accomplished. **The research papers are:**

- Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2021). Embedding training and competence within an organisation's safety culture: a systematic literature review, *Quantity Surveying Research Conference*, pp. 48-60. Nelson Mandela University, virtual, 10th November.
- Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2023). Enhanced safety in complex socio-technical systems via safety-in-cohesion. *Safety Science*, 164, 106176. pp. 1-14. DOI: https://doi.org/10.1016/j.ssci.2023.106176
- Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2023). Constructs of leading indicators: A synthesis of safety literature. *Journal of Safety Research*, 85. pp. 469–484. DOI: https://doi.org/10.1016/j.jsr.2023.04.015
- Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2024). Unravelling the Gordian Knot of Leading Indicators. *Safety Science*, 177, 106603. pp. 1-14 DOI: https://doi.org/10.1016/j.ssci.2024.106603
- Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2024). Uncovering the Genome of Leading Indicators from Lagging Indicators and Normative Documents: A Proof-Of-Concept Study. *Journal of Safety Research*, 91. pp. 230–244. DOI: https://doi.org/10.1016/j.jsr.2024.08.015

Other additional research papers:

- Bayramova, A., Edwards, D.J. and Roberts, C. (2021). The role of blockchain technology in augmenting supply chain resilience to cybercrime. *Buildings.* 11(7). DOI: https://doi.org/10.3390/buildings11070283
- Golzad, H., Teimoory, A., Mousavi, S.J., Bayramova, A. and Edwards, D.J. (2023). Mental Health Causation in the Construction Industry: A Systematic Review Employing a Psychological Safety Climate Model. *Buildings. 13* (10). 2442. DOI: https://doi.org/10.3390/buildings13102442
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- **Best Overall First Time Presenter Award-**issued by Nelson Mandela University in '*Quantity Surveying Research Conference 2021*' virtual conference-10.11.2021
- **Best Overall Youth Presentation U/35 Award**-issued by Nelson Mandela University in '*Quantity Surveying Research Conference 2021*' virtual conference-10.11.2021
- **Best Youth Woman Presentation Award**-issued by Nelson Mandela University in '*Quantity Surveying Research Conference 2021*' virtual conference-10.11.2021
- **Buildings 2021 Best Paper Award** (paper entitled 'The Role of Blockchain Technology in Augmenting Supply Chain Resilience to Cybercrime')- issued by Buildings MDPI-21.03.2023.

CHAPTER ONE – INTRODUCTION

1.0. INTRODUCTION

General awareness about health and safety of the workforce has exponentially increased in tandem with the unprecedented economic and technological growth of companies over recent years (Han *et al.,* 2019). This awareness comprises concerns over occupational health and safety of staff in all work sectors of an economy given the frequently occurring work-related accidents and incidents (Budzynski *et al.,* 2017; Choe and Leite, 2020), alongside other health conditions such as stress, anxiety and musculoskeletal disorders (Jackson *et al.,* 2013). The construction industry is not an exception, in fact, the sector is berated for having an infamously high record of workplace illnesses, injury and fatality (Müngen and Gürcanli, 2005; Thakur, 2018). These accidents occur, despite the best practices and safety countermeasures applied on construction worksites, causing life-changing injuries to workers, increasing costs (e.g. fines and legal fees) and stalling ongoing project progress while accident investigation commences (Swuste, 2013). A number of these accidents involve interaction of workers with heavy machinery, occurrences that are described as caught-in-between, struck-by incidents (Guo *et al*., 2012) or contact with moving machinery and trapped by a collapsing or overturning object (HSE, 2023). These accidents: involve large and heavy machinery such as mobile and tower cranes (Li *et al*., 2013; Zhong *et al*., 2014; Sadeghi *et al*., 2021), different types of excavators (e.g. hydraulic, tracked 360˚) with various attachments (Edwards and Holt, 2008; Coggins *et al*., 2010) or other equipment such as bulldozers, graders or material handling equipment such as loaders or rough terrain telescope handlers (Lee *et al*., 2018). Many of these accidents occur predominantly due to nonvisible-to-equipment-operator areas that are called blind spots (Guo *et al*., 2012; Li *et al*., 2013; Azar and Kamat, 2017). To improve all round visibility of those accident-prone zones or blind spots, various sensing technologies that are complemented with artificial intelligence (AI) based cameras are retrofitted to heavy equipment (Zhong *et al*., 2014; Azar and Kamat, 2017). These technologies are intended to timely detect human or worker entrance into the prohibited or risk/danger zone (also called safety zone) and to warn the operator and the intruding or unauthorised worker about potential collusion or hazardous proximity (Li *et al*., 2013). However, such innovative technologies are not a panacea *per se*, as their accuracy or efficiency can be compromised by impaired visibility due to inclement weather conditions (e.g. density of foggy weather or frost on camera lens in frosty weather) machinery overload or by poor maintenance or update of the detection system itself (Riaz *et al.,* 2011).

One prominent government company that is currently tackling such safety challenges in the civil engineering and construction sector is National Highways; a UK government-owned company that operates to manage and maintain major trunk roads and motorways of England (Tezel and Koskela, 2023). By building, operating, maintaining and improving the strategic road network in England, the company connects the country, providing reliable, safer and faster road network that is infused with new technological advancements (Prakash *et al*., 2023). However, delivering these services to users in a safe and efficient way can be problematic, particularly because operations on the highway are carried out in different weather conditions, both daytime and night-time, with the worksite being close to high-speed traffic flow (Smith *et al*., 2023; Tezel and Koskela, 2023). These conditions create elevated safety risks that have inherent potential to cause harm not only to assets and the working environment, but also workers and members of the public who may be affected by life-threatening and occasionally fatal injuries. Therefore, National Highways collectively with their supply chain members (such as major civil engineering contracting (tier 1) organisations) are taking measures to alleviate the impacts of latent risks in the worksites. Such collaboration is not therefore limited to a one single company or organisation but is rather based on cooperation of the entire supply chain to collectively ensure safety on all tiers and stages of managing, maintaining and prioritising safety. Regardless of joint attempts to eradicate such risks, accidents involving workers using construction machinery or working alongside operating vehicles, continue to occur (Cuerden *et al.,* 2008).

1.1. RESEARCH PROBLEM AND RESEARCH QUESTIONS

Industry and government have significantly invested in: reviewing, revisiting and adjusting multiple regulations and procedures for reducing inherent risks at worksites (Choudhry, 2014); developing and adopting cutting edge technologies for enhancing visibility difficulties associated with heavy vehicles and machinery (Zhou *et al*., 2012); creating worker training and assessment regimes and providing grants to support the attainment of qualifications for strengthening competency of workers (Albert and Hallowell, 2013). Yet, all these preventative measures appear unable to prevent accidents' occurrence in complex and intractable systems (*viz*. workplaces of safety critical industries in a less predictable environment) (Choudhry, 2014). The current process of safety management commonly involves: predicting or measuring the likelihood of unfavourable events during the planning stage (Sarkar and Maiti, 2020); and studying past events to learn about them during or after the operations stage (Alruqi and Hallowell, 2019; Hallowell *et al*., 2020). Such practices, in turn, form the foundation of health and safety knowledge and wisdom that inform the creation of preventative countermeasures for future work (Harms-Ringdahl, 2009; Alexander *et al*., 2017). However, most post-incident investigations undertaken typically conclude that 'human error' represents the root cause of incidents' occurrence, which then triggers the implementation of additional safety controls and stringent regulations for managing work process (Wang *et al*., 2020). Such a reductionistic approach to explaining a phenomenon (i.e. accidents) occurring in complexly interrelated environment fails to incorporate systems elements' (i.e. workers, machinery and sites): *holonic nature*, since events in complex systems occur as a result of interaction of its constituent elements (Baxter and Sommerville, 2011); and *dynamic character*, since changing disposition of elements obfuscate their predictability (Mohammadi and Tavakolan, 2020). Therefore, the following research question is framed: ***Why do current attempts to reduce accident occurrences fail and what approach will facilitate desired efficiency?***

Furthermore, the success of gathering safety knowledge about the states and outcomes of complex systems is dependent on the: 1) accuracy of the knowledge obtained through accident analysis (Quigley *et al*., 2012; Xu *et al.*, 2021); and 2) timeliness of the knowledge (e.g. closer to real time) (Teizer, 2016). Accuracy of knowledge refers to capturing the particulars of an occurred event itself by including any preceding event or status of the system as accurately and comprehensively as possible (Hopkins, 2009; Oswald *et al*., 2018). Typical activities include recording and reporting safety actions and events which generate information known as lagging indicators (*ibid*). Lagging indicators are after-the-fact information that are often associated with negative occurrences (Lingard and Wakefield, 2011; Quaigrain and Issa, 2021). Studying lagging indicators enables the identification of '*what went wrong'* in the system, so that past failures, errors and mistakes can be prevented in the future (Erkal *et al.,* 2021). Examples of lagging indicators include: recordable injury rate (Floyd, 2021); employers' liability compensation costs (Costin *et al*., 2019); lost work day rate (LWDR) (Falahati *et al*., 2020); experience modification rate (EMR) (Jazayeri and Dadi, 2017); and fatality rate (Hinze *et al*., 2013). Whereas timeliness of knowledge can be achieved through monitoring different sources of information known as leading indicators (LIs) (Costin *et al*., 2019). LIs are defined as the predictive and proactive measurement of safety that enables safety status monitoring without waiting for a system to fail and reveal its weaknesses (Eaton *et al*., 2013). LIs seek to measure an organisation's safety status by monitoring organisation's long term, safety related practices and short-term, current (negative or positive) manifestation of such practices in real time (Falahati *et al*., 2020). This ensures that relevant actions can be taken to prevent negative outcomes or continue positive actions leading to success (Patriarca *et al.,* 2019). However, despite the popularity and potential advantages of LIs, its definition, types, applications, functions and examples (i.e. measurements adopted to be a LIs) described in extant literature are mostly equivocal and inconsistent (cf. Guo and Yiu, 2015; Sheehan *et al.,* 2016; Alruqi and Hallowell, 2019). Moreover, the distinctiveness of every organisation's safety management system(s), safety culture maturity level as well as different capacity and resources allocated to develop, measure and record the LIs make the elements and application of LIs non-generalisable and unique to every organisation and individual project (Xu *et al*., 2021). For these aforementioned reasons, the following research question is constructed *viz*.: ***What are the main constructs of LIs that enable elucidation of such concept and facilitate their wider adoption for proactive safety management?***

In addition to these inconsistencies and ambiguities associated with LIs' constructs (i.e. characteristic, structure or specification), their use, development method and development source are portrayed differently in the pertinent literature (Guo and Yiu, 2015; Sheehan *et al*., 2016; Xu *et al*., 2021). These incongruities are compounded further by the notion that the nature and function of LIs are deemed overlapping with their counterpart *viz*. lagging indicators (Sheehan *et al*., 2016; Patriarca *et al*., 2019). This obscurity and the fine nuances existing between leading and lagging indicators has drawn attention of numerous safety experts and academics (Podgórski, 2015; Swuste *et al*., 2016; Santos *et al*., 2019). In addition to publications that contrast and extrapolate leading and lagging indicators (e.g. a theoretical debate discussed in a special issue (4 of 2009) of the 'Safety Science' journal), the Bowtie and Safety pyramid (also called Process Safety Indicator Pyramid) models also provide some explanation of the relationship that exist between these two indicators (Hudson, 2009; Samuel and Das, 2015; Zhen *et al*., 2022). For example, the Bowtie model describes LIs as information occurring prior to the event, which is at the centre of the bowtie shape and lagging indicators are denoted as the outcomes of the event (Mearns, 2009; Hudson, 2009; Schmitz *et al*., 2021; Bayramova *et al*., 2023). However, this conventional distinction between leading and lagging indicators does not universally apply to all examples of indicators (Lingard *et al*., 2017; Oswald, 2020). For instance, there is a convergence in identification and use of an indicator such as near miss events, which in some cases can be referred to as leading and in other cases they are described as a lagging indicator (Knijff *et al*., 2013; Haas and Yorio, 2016). For example, a near miss event such as slip or trip can be classified as a lagging indicator which occurred as a result of poor housekeeping at the worksite or it can serve as a LI informing about potential occurrence of a much more severe accident (*ibid*). Consequently, this thesis poses the following research question: ***What is the relationship or contrast between leading and lagging indicators and what is their role in safety management?***

1.1.1. Research focus and scope

As the research problem describes, understanding the underlying constructs behind health and safety incidents represents the first step towards designing effective and pre-emptive countermeasures that incorporate workers, machinery and sites (WMS) holistically (Costin *et al*., 2019). Accordingly, preventative countermeasures grounded on such holistic and proactive approach will enable accident prevention before they arise (Loosemore and Cheung, 2015). However, knowledge and understanding gained from the study of one unfavourable event occurrence cannot be neatly applied to another occurrence (*ibid*). This is because safety or absence of safety (i.e. unfavourable events such as accidents or near misses) occur due to multifaceted and nuanced interplay of multifarious elements (i.e. WMS) (Leveson, 2015; Mousavi *et al*., 2018). LIs enable collation of such knowledge and insights about complex interactions and interdependency of WMS elements (of construction workplaces) in a proactive manner. Consequently, this study focuses on developing a deeper understanding of LIs in safety management use (across the safety critical organisations as well as construction and civil engineering sector).

1.1.2. Aim and objectives of the study

Accordingly, a knowledge repository with safety intelligence derived from continuous study and monitoring of complex systems and their elements (i.e. through leading and lagging indicators) should be generated for a continual improvement and maintenance of health and safety (Pettinger, 2013). Therefore, with the ultimate goal of promulgating dissemination of holistic and proactive safety management and extrapolation of safety analytics' adoption by a continuous learning organisation, this doctoral research seeks to generate a novel theoretical base which is derived from pertinent literature and tested with real life case study data. Such novel theory will become instrumental not only in mitigating asset and personal risks related to frontline workers' interaction with operating vehicles and construction machinery on highway work sites, but also will be influential in continuously monitoring safety status of complex systems and simultaneously preventing unfavourable events from taking place and learning from both failures and successes. Therefore, in achieving the study's aim, following objectives are delineated:

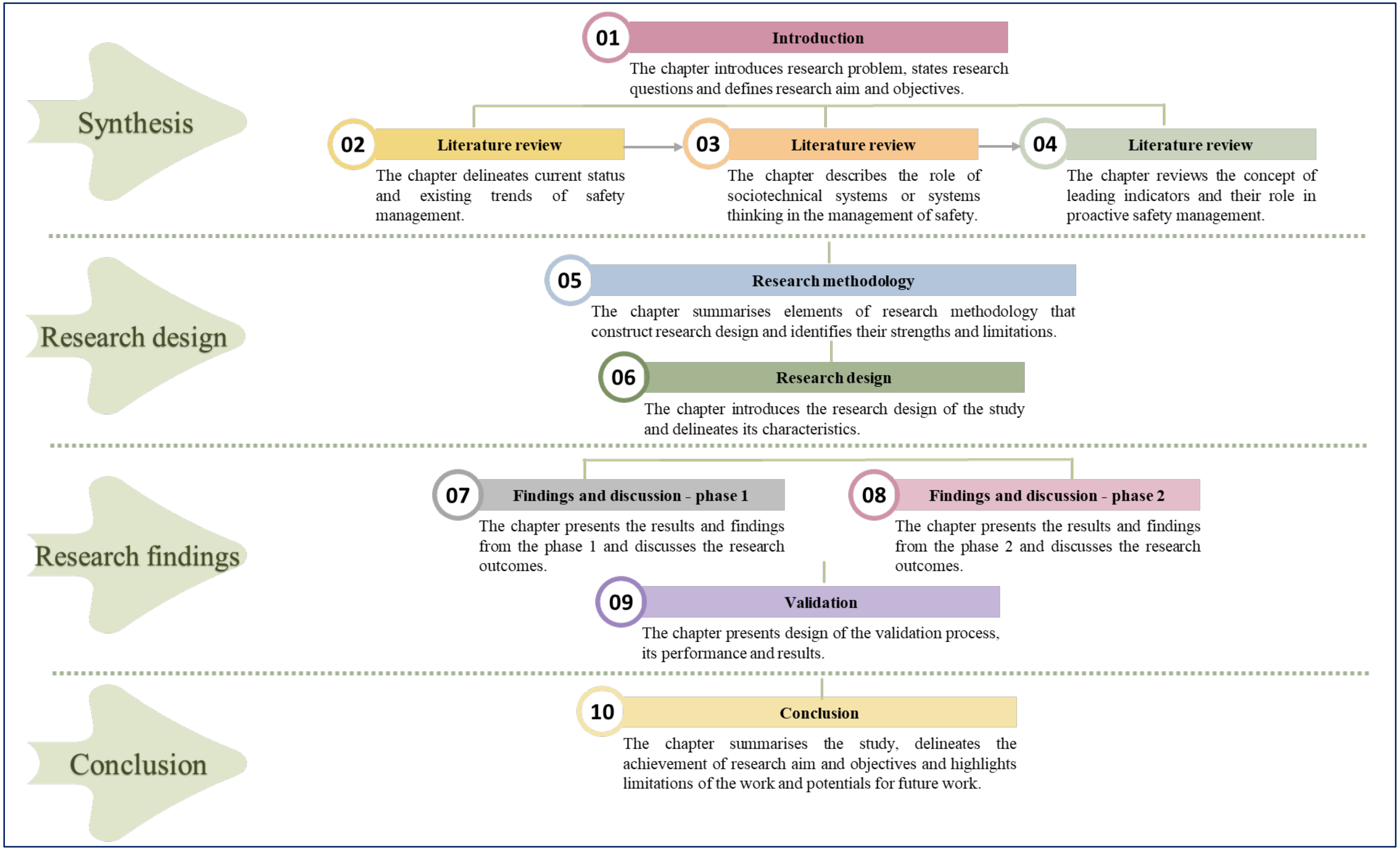
1. To identify apposite methodology or approach for proactive and holistic safety management through the systematic review of pertinent literature.
2. To generate a conceptual model (through systematic literature review) which allows design/development of systemic countermeasures and preventative steps for a continuous safety improvement and maintenance.
3. To develop an analytical framework (via framework analysis of pertinent literature) to systematically identify LIs from qualitative dataset.
4. To test the proposed conceptual model with real life case study data (in combination with relevant normative documents) to determine its potential impact and identify further considerations and recommendations for future work.

Based on research problem and research questions delineated and research aim and objectives constructed to address these research questions and research problem, the current study will scrutinise the literature of safety training programmes, construction safety management and LIs in order to respectively develop theoretical basis for understanding: the key elements for design and development of effective safety training programmes, holistic safety management practices and constructs of LIs for their extrapolation in theory and practice of safety management. This will be followed by the phase in which theoretical development around LIs (in the form of conceptual model) will be tested with case study materials in order to determine its feasibility for practical use. Such qualitative data-rich approach towards research design for addressing the research phenomenon poses a constraint of being overly reliant on interpretation of the researcher (which reflects interpretivism philosophical stance adopted). However, to address such limitation, critical realism philosophical perspective is added to enable critical reflection and objectivity to research process. In addition, to maximise the transparency in the decision-making in terms of data inclusion, selection and analysis, the work will provide detailed description via text and via illustrative infographics and tables.

1.2. THESIS STRUCTURE AND SUMMARY OF CHAPTERS

The thesis work constitutes ten consecutive chapters. The first chapter entitled 'Introduction' presents research problem domain and defines the research questions that the study seeks to address. Additionally, the research aim and research objectives are introduced in this chapter. The flow and content of all ten chapters are described in Figure 1.1. The figure provides the structure of current doctoral research work and presents a brief summary of each chapter that are enumerated from one to ten accordingly.

Figure 1.1 – The structure of the thesis work and the content of each chapter.



1.2.1. Synthesis of literature

The first four thesis chapters are grouped and represented as a synthesis of literature in Figure 1.1. Three chapters after the first introduction chapter are designated to review literature extensively to: 1) determine the existing status of safety management; 2) identify the importance of managing safety with sociotechnical systems thinking; and 3) critically explore the role of LIs in proactive and pre-emptive safety management.

1.2.2. Research design

Two chapters are incorporated into this section to elucidate upon the research methodology and design adopted within this thesis. Chapter 5 provides an in-depth study of research methodology elements and explicates their strengths and limitations. Insights generated contributes to the construction of research design and the selection of appropriate research methodology elements. Chapter 6 explains the research design adopted and characterises its elements based on the insights obtained from the preceding chapter. This chapter also introduces the structure of upcoming chapters on research findings and discussion that are presented as phases 1 and 2 (refer below).

1.2.3. Research findings

Contrary to a conventional structure of separately presenting findings and discussion parts of a thesis, the current work blends these sections in one chapter but presents in phases 1 and 2 as two separate chapters. These two phases and their process are explained in detail in Chapter 6. Subsequently, Chapter 7 describes research findings followed by the discussion of the corresponding findings from the phase 1 of the study. Similarly, Chapter 8 explicates the research findings and the discussion of research outcomes from phase 2 of the study. ‘Chapter 9 is the validation chapter and outlines the design of validation process, its performance and the associated results.

1.2.4. Conclusion

The final conclusion chapter consolidates the research work and summarises the study’s implications by highlighting conclusions reached. Chapter 10 also: addresses the study’s limitations and potential for future work; discusses achievement of research aim and objectives; and presents responses to the research questions posed at the outset of the study.

1.3. SUMMARY OF CHAPTER 1

Due to its tightly coupled structure, intractable and unpredictable workflow and complex interaction of its elements (WMS), the construction industry's work environment (i.e. vertical, horizontal or underground construction projects) is acknowledged as a complex sociotechnical system (STS) (Leveson, 2015; Bayramova *et al*., 2023a). STS theory studies the interrelationship of components within a complex system rather than inquiring about its integral components in isolation. Moreover, due to its dynamic and unpredictable nature, such complex systems require a proactive and flexible approach (i.e. safety management through early signals such as LIs) that can foster the application of adaptive solutions and countermeasures as events occur (Baxter and Sommerville, 2011; Davis *et al.,* 2014; Woolley *et al.,* 2019). However, despite a plethora of publications on safety management in the construction industry (cf. Chan and Chan, 2011; Lee *et al.*, 2014; Li *et al*., 2015; Oswald *et al.,* 2018; Swallow and Zulu, 2019), there is a dearth of studies that focus on concurrently combining all three construction worksite components (i.e. WMS) and their interrelationship. Furthermore, incipiency and existing ambiguity around LIs use equally hinder adoption of proactivity in safety management.

This current chapter introduced the study's research problems and delineated the research questions formulated to address the problem domain. The research aim and research objectives are also stated together with delineating the structure of the thesis and broad content of each chapter.

CHAPTER TWO – CURRENT STATUS OF SAFETY MANAGEMENT

2.0. INTRODUCTION

The focus of concepts, theories, tools and mechanisms that underpin safety management have been disparate over time in the history of safety science. ‘Taylorism’ in the 1910s focused on process improvement, while accident proneness studies in 1920s and ‘Behaviourism’ studies in 1930s emphasised control over workers (Dekker, 2019). Prominent concepts such as ‘Human Factors’ in 1940s and 1950s and ‘Cognitive Systems Engineering’ in 1980s and 1990s have revolutionised the previously existing ‘human blaming’ culture and promoted systems safety thinking that fosters adapting technology(ies), tool(s) and environment(s) according to human strengths and limitations (*ibid*). These early developments in safety science history (i.e. ‘Taylorism’ and ‘Behaviourism’) provide a foundation for the existing safety management construct known as Safety-I (Hollnagel *et al*., 2015; Sujan *et al.,* 2019). Safety-I defines safety as the absence of negatives (namely, accidents and risk), where an environment constituting fewer ‘*things going wrong*’ is deemed a safe workplace (Sujan *et al.,* 2019). However, the opposing Safety-II concept (which derives from ‘Human factors’ and ‘Cognitive Systems Engineering’ theories) advocates monitoring and learning from ‘*things going right*’ and measuring positives and success (Hollnagel *et al*., 2015). The literature of safety management is replete with studies criticising Safety-I, challenging Safety-II and indeed, proposing Safety-III (Leveson, 2020). Therefore, any existing best practices of both concepts (i.e. Safety I and II) which safety management can benefit from should be reviewed. Furthermore, a focal point in most of these different approaches predominating in different period of safety science involve human aspect, whether through: targeting human behaviour, motivation; studying human factor; or developing measures that focuses on human aspect. Consequently, the notion as to whether humans are a problem or a solution in managing and maintaining safety must be explored.

2.1. SAFETY MANAGEMENT

Safety management involves the systematic administration of health and safety risks using policies, practices, processes and technologies designed to effectively eliminate, prevent or control inherent workplace risks and hazards (Vinodkumar and Bhasi, 2010; Hughes and Ferrett, 2020). Safety management and risk management are often used interchangeably; however, risk management involves the process of assessing, controlling and preventing risks only. Whereas safety management entails other activities and initiatives (apart from risk analysis and assessment) such as: accident investigation, which is the inquiry and analysis of contributing factors to establish causes of accidents (Harms-Ringdahl, 2004); creating safety culture, which involves promotion and development of safety behaviour (of individuals in organisations) that generates shared norms of safety prioritisation (Mearns *et al*., 2003); and generating countermeasures which aims to prevent accident occurrence via elimination, mitigation or control of potential source of negative occurrence (Woolley, 2020).

Current methods and models of safety management are primarily predicated on three control measures: 1) increasing regulations and rules to reduce deviations of pre-planned work process (Choudhry, 2014; Qiao *et al*., 2021); 2) targeting workers' behaviour through training, incentives and sanctions to enhance their compliance and risk-aversion (Albert and Hallowell, 2013); and 3) reinforcing preventative measures (e.g. technology) to avoid adverse events and accidents in work environment (Zhou *et al*., 2012; Li *et al.,* 2020). These control measures originate from the history of safety science when the application of procedural safety management (rule and regulation-based control), behaviour-based safety management control and system safety-based control predominated in 1910s, 1930s and 1940s respectively (Dekker, 2019). Proponents of Safety II concepts (Ball and Frerk, 2015; Dekker, 2015; Hollnagel *et al*., 2015; Costella *et al*., 2021), refer to current predominating practices of safety that are founded on Behaviourism and Taylorism as Safety-I and propagate to avoid such anachronistic approach in understating complex systems the elements of which are intrinsically interconnected. Conversely, Safety-II approach to safety management is known to promulgate a holistic view that is centred around interrelationship of system components to identify underlying factors, systemic vulnerabilities and shortcomings (Costella *et al*., 2021).

2.1.1. Safety-I

As a concept, Safety-I postulates that accidents' occurrences stem from a failure of componential parts of a complex system that incorporates technology, procedures and people – where the latter constitutes the most variable of these three components (Dekker, 2015; Wang *et al.,* 2020). Therefore, the Safety-I approach to safety management involves imposing stringent control measures over workers because it posits that the human behavioural aspect is a major cause of accidents (Dekker, 2019). Specifically, post-accident investigations often attribute incidents to human error(s), unsafe behaviour(s) and unsafe act(s) (*ibid*). However, according to myriads of scholars (Hollnagel *et al*., 2015; Dekker, 2019; Cooper, 2020) this reductionist approach to safety management (otherwise known as Safety-I) is insufficient to resolve the complexity and unpredictability of dynamic workplaces. The reductionist approach, elucidated upon here, denotes a practice of separating each element of complex systems and attempting to address and tackle challenges of every element in isolation (Dekker, 2019).

According to the Safety-I concept, safety is the absence of negatives (i.e. accidents, risk, error and deviation from work-as-planned) and hence, risk management is based upon a reactive post-incident response (Jones *et al*., 2018). Similarly, risk assessment processes are contingent upon an analysis of accident records and measuring '*things going wrong*' (Hollnagel *et al*., 2015) whilst implementation of preventative measures are founded on rigidly following pre-planned work process without deviation (Sujan *et al.,* 2019).

2.1.2. Safety-II

In contrast, a relatively recent emerging concept of Safety-II posits an opposing view for managing health and safety of workers, that is premised upon monitoring and learning from '*things going right'* and advancing workers' adaptive capacity (Dekker, 2019). Safety II approach is also referred as a part of a group known as 'New View' which comprises other concepts, *viz.*: 'Resilience Engineering' (Hovden *et al*., 2010); 'Human and Organisational Performance' (Conklin, 2012); and 'Safety Differently' (Dekker, 2015). Resilience Engineering (RE) is a safety management approach that focuses on improving human adaptability to cope with complexity and to create a foresight for anticipating the changing shape of risks in high-risk organisations (Woods *et al.,* 2012, Costella *et al.,* 2021). According to RE, resilient organisations must have four potentials to adjust organisational operation before, during and after disruptions (i.e. dangerous occurrences or accidents) to sustain its daily work (Costella *et al*., 2021). Costella *et al*. (*ibid*) describe these four potentials as: 1) responding to regular and irregular changes; 2) monitoring potential positive and negative external influences; 3) learning from what went right (success) and what went wrong (failure); 4) anticipating threats and opportunities for future improvements. With the similar standpoint to RE, Human and Organisational Performance (HOP) proposes a proactive approach by using LIs to minimise negative consequences before accidents occur (Agnew, 2018). HOP is contrasted and related to what is known to be one of the Safety-I concepts' foundations – Behaviour-based Safety (BBS) (Haavik *et al*., 2019). Williams and Roberts (2018) describe HOP (similar to Safety-II approach) and BBS (similar to Safety-I approach) as two complementary approaches that focus on improving safety in workplaces. Safety Differently (SD), on other hand, advocates that humans are the solution to the problem, not the problem to be controlled, by pointing that humans are key to adaptive capacity and source of resilience in an intractable complex STS such as dynamic workplaces (Gantt, 2017; Dekker, 2019). Collectively, all these new concepts (in 'New View' group) aim to shift the paradigm from the narrow explanation that addresses a 'human error' as a sole root cause of accidents to the broader perspective which manages systemic vulnerability and shortcomings (Hollnagel *et al.*, 2015; Dekker, 2019). Therefore, all alluded key principles of 'New View' approaches are intertwined in Safety-II concept.

2.1.3. A comparative analysis of Safety-I and Safety-II

Safety-I and Safety-II can be differentiated from each other in the context of: definition of safety, purpose, role of human, risk management, business focus and performance variability (as outlined in Table 2.1). As Table 2.1 demonstrates, there are more differences ($f = 16$) than commonalities ($f = 4$) between Safety-I and Safety-II concepts, where concepts overlap four times only. Cooper (2020) states that Safety-II is a replication of Safety-I, only with diametrically contrasting philosophy. Similarly, Busch (2019) raises the issues of possible side effects of emerging new approaches (referring to Safety-II) and warns against the assumption that 'new is better'. Other scholars criticise the Safety-II concept for: its ambiguity and absence of definitive measurement of positives (*things going right*) (Wang *et al.,* 2020); lack of empirical studies to support the viability of such an approach (Cooper, 2020); and advocating the insights that reduces accountability and shared responsibility (*ibid*). However, proponents of Safety-II theoretical stance disapprove of the Safety-I concept for its: bureaucratic control towards safety management (Dekker, 2015); reactive approach to risk management (Albert and Hallowell, 2013; Jones *et al.*, 2018); and stringent consequences involved for breaching safety requirements (Albert and Hallowell, 2013).

Table 2.1 – Cross-comparison of Safety-I and Safety-II.

	Safety I	Safety II
Definition of safety	Absence of adverse outcomes and unacceptable level of risks (Hollnagel *et al*., 2015; Sujan *et al*., 2019).	Presence of resilience abilities (Patterson and Deutsch, 2015; Sujan *et al*., 2019).
	Freedom from danger, risk and injury (Dekker, 2019; Cooper, 2020).	Ability to succeed under expected and unexpected conditions alike (Cooper, 2020; Wang *et al*., 2020).
Measuring and monitoring	Things going wrong (i.e. negatives) to prevent failure occurrences (Jones *et al*., 2018).	Things going right (i.e. positives) to promote learning from success (Hollnagel *et al*., 2015; Sujan *et al*., 2019).
	Lagging indicators (Versteeg *et al*., 2019; Wang *et al*., 2020).	Leading indicators (Hallowell *et al*., 2013; Guo and Yiu, 2016; Wang *et al*., 2020).
Purpose	To manage implicit risk (Cooper, 2020) *.	To manage implicit risk (Cooper, 2020) *.
	To reduce injury/incident and to prevent harm (e.g. through workers training cf. Edwards and Holt, 2008; Biggs and Biggs, 2013; Wang *et al*., 2021).	To create more resilient systems (e.g. by balancing productivity with safety through adaptable business model(s) cf. Patterson and Deutsch, 2015; Leveson, 2020).
	To understand the impact of work systems on behaviour (Cooper, 2020).	To focus on the presence of success (Dekker, 2019; Cooper, 2020).
Role of people	Employee engagement (Jones *et al*., 2018; Cooper, 2020) *.	Employee engagement (Jones *et al*., 2018; Cooper, 2020) *.
	People are the solution (Dekker, 2019; Cooper, 2020) *.	People are the solution (Dekker, 2019; Cooper, 2020) *.
	People can be the problem (Cooper, 2020).	-
Business focus	Promote relationships not transactions (Dekker, 2019) *.	Promote relationships not transactions (Dekker, 2019) *.
	Focus on root causes and contributory factors (Hollnagel *et al*., 2015).	Focus on understanding work as done (WAD) and trade-offs (Hollnagel *et al*., 2015; Jones *et al*., 2018)
	Safety structures (e.g. emphasis on compliance and stringent conformity with WAP cf. Jones *et al*., 2018; Cooper, 2020).	Decentralise decision-making power to workers (Dekker, 2019).
	Bureaucracy of safety (e.g. division of safety management between 'blunt end' and 'sharp end' worker groups cf. Hollnagel *et al*., 2015; Jones *et al*., 2018; Dekker, 2019).	Reduce complexity (e.g. by streamlining work processes cf. Dekker, 2019).
	Safety culture (Lu *et al*., 2016; Cooper, 2020).	Organisational culture (Patterson and Deutsch, 2015).
	Learning from incidents and adverse outcomes (Dekker, 2019; Wang *et al*., 2020).	Learning from everyday clinical work (Hollnagel *et al*., 2015; Sujan *et al*., 2019).
	Zero accident goals (Sherratt, 2014; Cooper, 2020)	Lean management systems (Cooper, 2020).
Risk management	Reactive, following incidents (Hollnagel *et al*., 2015; Dekker, 2019).	Proactive, prior to incidents (Dekker, 2019).
	Control of risk through barriers (Winge and Albrechtsen, 2018).	Continuously anticipating changes (Patterson and Deutsch, 2015; Dekker, 2019).
	Risk-based (Wang *et al*., 2020).	Achieving success through trade-offs and adaptation (Patterson and Deutsch, 2015; Wang *et al*., 2020).
Performance variability	Potentially harmful, constraining performance variability through standardisation and procedures (Jones *et al*., 2018; Wang *et al*., 2020).	Inevitable and useful, source of success and failure (Jones *et al*., 2018; Wang *et al*., 2020).

*Commonalities of Safety-I and Safety-II.

Whilst these polarised studies (cf. Dekker, 2019; Busch, 2019; Cooper, 2020) serve as a cornerstone for open and critical debate that generates awareness of possible pitfalls of both concepts (Safety I and Safety II), another separate group of researchers (cf. Hollnagel, 2014; Patterson and Deutsch, 2015; Chuang and Wears, 2015; Sujan *et al.,* 2017; Jones *et al.,* 2018; Wang *et al.,* 2020) attempt to deduce and link best practices from each concepts. For example, Patterson and Deutsch (2015) and Chuang and Wears (2015) describe benefits of combining principles from Safety-I and Safety-II that focus on improving patients' safety in the field of healthcare. Jones *et al.* (2018) conclude that integration of both concepts is more appropriate in examination of procedural violations in community pharmacies. Their work (*ibid*) suggests that sole reliance upon Safety-I makes procedures over-restrictive at times, while integrating Safety-II allows staff to adopt a tailored and appropriate approach to patients' safety.

2.2. HUMAN ASPECT IN SAFETY MANAGEMENT

Although with a different approach, both Safety-I and Safety-II concepts aim to protect humans from accidents, risks and hazards and equally seek to protect plant, facilities, machinery as well as environment, sites from damage (Patriarca *et al*., 2018). Unequivocally, the human element of STS (i.e. workplaces of safety critical entities) is pivotal for both Safety-I and Safety-II concepts; whether this element is being addressed as a problem to control for system's safety or it is considered a catalyst of a system's success despite varying conditions (Patterson and Deutsch, 2015). The human aspect (or workers) is exposed to various hazards and risks due to inherent hazardous nature of their workplaces. Hughes and Ferrett (2020) differentiate terms hazard and risk as: hazard being articles, substances, plant and machines, working methods or working environment with the potential to cause harm; whereas risk is defined as the likelihood of potential harm from that hazard being materialised. Therefore, employers-organisations are legally bound to ensure employees' health and safety as far as reasonably practicable; which includes provision of safe place of work and adequate welfare facilities, safe plant and systems of work, establishment of written safety policies, instruction, relevant training and supervision (*ibid*). Organisations' risk assessment, preventative and protective measures, health and safety arrangements must be adequately rigorous and effective to protect employees from not only accidents, but also from illnesses, diseases, stress and other psychological problems as well as indirect hazards. Examples of indirect hazards to workers' lives are: noise - with potential cause of acute or chronic ear damage (Li *et al*., 2016), vibration - that causes hand-arm vibration, whole-body vibration (Edwards *et al*., 2020), radiation - that might lead to somatic or genetic effect (Kerur *et al*., 2013). Whereas examples of mental ill health issues are: work-related stress (depression, anxiety, panic attacks or post-traumatic stress disorder (PTSD)) (Härmä *et al*., 2006); fatigue (due to job design and long shift hours) (Williamson and Friswell, 2013); and substance abuse (alcohol or drug abuse) (Kava *et al*., 2019).

2.2.1. Worker training

To address human factor in complex STS, a plethora of studies (cf. Albert and Hallowel, 2013; Bhoir and Esmaeili, 2015; Başağa *et al*., 2018; Albert and Routh, 2021) frequently highlight the importance of training programmes on an individual level and culture definition on organisational level. Training is described as a systematic effort to advance knowledge, skill and behaviour of participants with the end goal of improving their work performance (Salvendy, 2012; Reiman *et al.,* 2017). The end goal of training can differ depending on the context, e.g. for accident prevention, service improvement or creating better products (*ibid*). Mandatory or otherwise, safety training (with the end goal of accident prevention) aims to enable trainees to discharge their roles and duties safely and efficiently through improving their confidence, resilience and adaptation (Bahn and Pugh, 2012; Taylor, 2015).

Unfortunately, a number of challenges that are inherent in the construction industry (subsequently in civil engineering sector) preponderate the benefits that can be achieved through training programmes. For example, Jeelani *et al.* (2019) outline a number of industry-related barriers that hinder gaining desired outcomes from training interventions *viz.*: the lack of interest amongst fellow workers; the transient nature of construction projects; and deficiency of data or evidence about tangible benefits of using training intervention(s) to preclude accidents occurrence. These same barriers impede employers from investing in an impactful training programme and compel them to prioritise productivity and cost-savings over provision of optimal training for their workers (Albert and Ruth, 2021). Moreover, according to Namian *et al.* (2016) traditional training programmes tend to be unengaging and poorly designed and therefore, ineffective to achieve higher learning gains. Despite these alluded barriers organisations are impelled to invest in training programmes due to high cost associated with accident occurrences (described in Table 2.2) and industry-wide unfavourable reputation those high accident records can cause to organisations (*ibid*).

Table 2.2 - Two types of accident costs.

Tangible (direct) costs of accidents	Intangible (indirect) costs of accidents
Sickness payment for employee (Başağa *et al.*, 2018; Mollo *et al.,* 2019; Reiman *et al.,* 2020).	Decreased human productivity due to low morale (Oliveira and Pais, 2018; Reiman *et al.,* 2020).
Increased insurance premiums (Mollo *et al.,* 2019; Reiman *et al.,* 2020).	Lowered company reputation (Oliveira and Pais, 2018; Reiman *et al.,* 2020).
Administrative and legal fees (Hughes and Ferrett, 2020; Reiman *et al.,* 2020).	Production disturbance and delay (Vahdatikhaki *et al.,* 2017; Oliveira and Pais, 2018; Reiman *et al.,* 2020).
Damaged equipment (Hughes and Ferrett, 2020; Reiman *et al.,* 2020).	Recruitment and training of replacement staff (Hughes and Ferrett, 2020).
Environmental hazard (Reiman *et al.,* 2020).	Resources for accident investigation (Mollo *et al.,* 2019).
Production loss (Hughes and Ferrett, 2020; Reiman *et al.,* 2020).	

2.2.2. Types of safety training

Training designs for accident prevention are myriad but include induction training, job specific training, supervisory and management training, and specialist training (as described in Figure 2.1).

Figure 2.1 – Training types and their descriptions.

Employees are legally required to undertake these training types depending on the nature of their job, career stages and different project life cycles (Taylor, 2015; Nykänen *et al.*, 2020).

Examples of legislations mandating health and safety training in the UK are: Management of Health and Safety at Work Regulations 1999; Health and Safety (Safety Signs and Signals) Regulations 1996 and Confined Spaces Regulations 1997 etc., all of which stem from Health and Safety at Work etc. Act 1974 (HSE,2009; Hughes and Ferrett, 2020). Another such regulation (part of the six-pack) is the Provision and Use of Work Equipment Regulation (PUWER) 1998 which states that employers are bound to provide operators of vehicles at work an adequate training and obligates employers to ensure that operators are competent to operate the machinery (PUWER, 1998). Some examples of training programmes and accrediting bodies for plant and machinery operators are: the National Plant Operators Registration Scheme (NPORS) 1992 who serve to train and test skills of mobile plant and equipment operators, lift truck operators and users of powered work equipment (NPORS, 2024); Land and Training (LANTRA) who provide training and qualifications for the skills required in land-based industries (such as forestry, food production, pest management or plant maintenance) (LANTRA, 2014); and The Construction Plant Competence Scheme (CPCS) 2003 who provide training or retraining of plant operators (on wide range of plant and equipment) and other associated operations for slingers, signaller and planner or controller of lifting operations (CPCS, 2024).

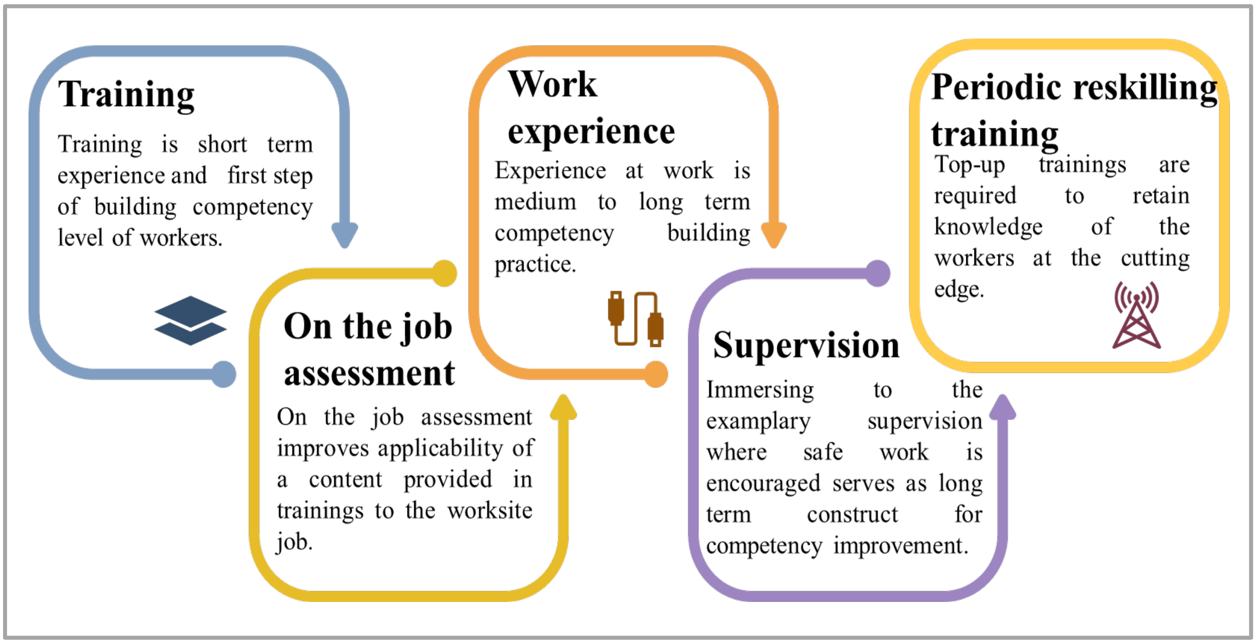
An earlier study by Wilkins (2011) identifies the tendency amongst industry leaders to increase the frequency and content of training programmes to attain high efficiency. Yet, this approach is deemed inefficient based on the survey study of 121 participants in an Occupational Safety and Health Administration (OSHA) 10-Hour Construction Safety Training Course. The study (*ibid*) concludes that failure to incorporate trainees' characteristics and the lack of participation-centred, andragogy-based approach in trainings are the main reasons of training inefficiency.

2.2.3. Competency

Efficacy of training intervention is contingent upon tangible benefit it yields, namely: level of knowledge retention of trainees (Perlman *et al*., 2014); qualification based on competency assessment (Dingsdag *et al*., 2008; Eggerth *et al.,* 2018); level of transferability of knowledge into an actual practice (Namian *et al.,*2016); and post training superior safety performance (*ibid*). According to many academics (Edwards and Nicholas, 2002; Albert and Hallowell, 2013; Schwatka *et al*., 2019; Ismail *et al*., 2021), training programmes, that are constructed to enhance trainees' competency, lead to a higher knowledge retention and subsequently superior safety behaviour during their daily performance at job sites. An example of the competency-centred training programme is the National Vocational Qualifications or the equivalent Scottish Vocational Qualifications (S/NVQs) (Edwards *et al*., 2002; Riaz *et al*., 2011). This programme provides work-based qualifications and has five levels of competencies (two of which mandatory units and other three are additional units) (Training Hebrides, 2023).

Edwards and Holt (2008) elucidate upon competency as a learned and retained knowledge of construction workers that has been obtained from both experiential and formal learning. Antonia *et al.* (2013) define competency as a permanent characteristic of a person that manifests when performing specific work (which is usually associated with a successful outcome) – a definition that was premised upon an analysis of previous definitions proffered by Boyatzis (1982), Spencer and Spencer (1993), Woodruffe (1993), Rodríguez and Feliú (1996). However, impactfully designed and developed training programmes are not the sole solution to building up the competency of workers, rather it is the first stage for competency growth. Figure 2.2 depicts other following stages of competency generation starting from early training intervention step.

Figure 2.2 – Competency building process.



The '*training*' stage is followed by application of '*on-the job assessment'* step to test trainees' competency level. Furthermore, '*work experience'* stage highlight the significance of exposure to real life work operations and aidant role of organisational safety culture for a long-term competency building (Woods *et al.,* 2012; Chen *et al.,* 2017; Mazzetti *et al.,* 2020); whereas '*supervision*' stage emphasises the importance of leaders in enhancing safety behaviour and competency as well as to recognise and anticipate dangerous occurrences at worksites (Bahn, 2013; Mazzetti *et al.,* 2020). Finally, to sustain the level of competency grown through previous four stages, a periodic reskilling training must be implemented. This final stage refers to '*periodic reskilling training*' in Figure 2.2.

2.3. SUMMARY OF CHAPTER 2

Safety science which involves managing safety in workplaces has evolved through its history by focusing on processes of work, on performers of work and most recently on all elements altogether. Both Safety-I and Safety-II concepts attempt to attain the same goal (i.e. safety) but with a different approach and methods (Jones *et al*., 2018; Sujan *et al*., 2019; Cooper, 2020). The studies reviewed in the current chapter highlight that the practice of contrasting Safety-I and Safety-II is advantageous not only to uncover the flaws and shortcomings in each concept (Leveson, 2020) but also to unravel a Gordian knot of potentials and benefits of both concepts for safety management. Therefore, this chapter contrasted and cross compared the distinctive features of both concepts in order to unravel positives and strengths of both Safety-I and Safety-II and to leverage their best practices and opportunities to improve safety management practices. Safety-II is known for: its focus on presence of success and '*what went right*'; measuring and monitoring safety through LIs; viewing people as a solution rather than a problem; and emphasising development of resilient systems and adoption of lean management. However, Safety-I serves as a complementary contrast which balances the approach to safety management by: focusing on negative events and analysing shortcomings and failures; and measuring safety through lagging indicators.

Whether described as a solution or problem, both concepts (Safety-I and Safety-II) convey that the human aspect plays pivotal role in systems safety (Hollnagel *et al*., 2015; Dekker, 2019; Sujan *et al.,* 2019). The view of both concepts about human aspects are diametrically opposed; Safety-I positioning that the human aspect is a problem to be controlled, whereas Safety-II regarding the human aspect as a source of solution. However, a new growing awareness, states that humans can be both a problem or solution depending on their competency level and experience, along with other social aspects such as: safety culture existing in organisation;

social norm and shared safety behaviour; and presence of goals conflict stemming from invisible pressure for production, expedient completion etc. Hence, efficacy of training programmes that are directed towards building and maintaining competency during and after the training becomes primary objective. Consequently, the chapter discussed different types of training programmes that are appropriate for various purposes and stages and delineated on competency building process which involves post training requirements such as supervision, mentorship and periodic reskilling. Therefore, to fulfil the existing gap - *viz*. lack of understanding about how training programmes can influence the safety performance of human element - the study will review the literature of safety training programmes in order to generate a guidance note on design and development of efficient safety training programmes that enables development of required skills and knowledge for continuous learning of human aspect.

CHAPTER THREE – SAFETY MANAGEMENT IN SOCIOTECHNICAL SYSTEMS

3.0. INTRODUCTION

Current systems' complexity and interdependence are increasing with the introduction of cyber-physical units, evolvement of digital communication technologies and ever-growing demand for cost-effective, expeditious and high-quality outcomes (Sujan *et al.,* 2019; Cooper, 2020). Likewise, construction projects are referred as a STS consisting of the social aspect (i.e. human aspect) and technical element (i.e. machinery, facilities and equipment used in project) and the environment (i.e. the site where the project takes place) (Leveson, 2020). All three dynamic elements, namely WMS (system's elements of construction) collectively create a system that is complexly interrelated to the point that negative occurrences (failures and accidents) in the system cannot be reduced to one single element (Dekker, 2019). However, the current approach to safety management relies to such oversimplification where elements or componential parts (WMS) of the system are studied in isolation and tackles their intrinsic challenges and risks separately (Raza, 2021). Such reductionistic approach prevalent in safety management of safety critical organisations is equally prominent in safety management of construction workplaces. While studies on the individual aspects of these three elements in separation might be advantageous in terms of granularity, they fail to recognise and omit the factors occurring in the complex interrelationship of those elements. This interdependence and complexity are particularly attributable to the construction industry (i.e. vertical, horizontal or underground construction projects) the projects in which are commonly described as a complex and tightly coupled STS (Arslan *et al*., 2019). Owing to its complex and interdependent nature, safety management of construction works requires the use of an STS approach (Zhao *et al.*, 2016; Kiwan and Berezkin, 2021). The STS approach to safety management supplies a holistic view where all componential parts are cumulatively considered and their interaction becomes the focal point for monitoring and managing. However, the tools, mechanisms or metrics that can be universally/simultaneously/equally used to measure system's each componential elements and to monitor their complex interaction remains unclear.

3.1. STRUCTURAL CHARACTERISTICS OF CONSTRUCTION AND CIVIL ENGINEERING

Unlike other industrial work environments, componential elements (i.e. WMS) of the construction and civil engineering industry (herein termed the 'construction industry' for brevity) are dynamic, transient and complexly interconnected (Borys, 2011; Albert *et al*., 2014;

Arslan *et al.,* 2019). Facilities, plant, machinery and equipment vary in size and type at different stages of construction work (Edwards *et al.,* 2003; Elbeltagi *et al.,* 2004; Neitzel *et al*., 2010). Site layout is bespoke and unpredictable due to climatic conditions and proximity of high-speed traffic; while working at height and/or with underground services shifts the working environment into different levels of hazard and risk exposure (Guo *et al*., 2015; Sadeghpour and Andayesh, 2015). Moreover, the workforce is highly transient and subject to frequent work team rotation, which makes the relationship of people and organisations engaged in construction projects a short-term and project-based interaction (Alsamadani *et al*., 2013; Okorie and Musonda, 2018; Swallow and Zulu, 2019).

Therefore, the unacceptably high accident occurrence statistics recorded in the construction industry is mostly attributed to: its transient structural characteristics (Choudhry, 2015; Boadu *et al*., 2020); short-term relationship of stakeholders in construction projects (Jones *et al.,*2006; Atkinson and Westall, 2010; Hallowell *et al*., 2013); and prevalence of goals conflict (Oswald *et al*., 2020). As the Health and Safety Executive (HSE) reports, the UK construction industry's fatal injury rate in 2023 (data up to March 2023) accounts for 45 workers, which is an increase of 16 from the previous years' total fatal injuries (i.e. n = 29) (cf. HSE, 2023). 11 out of these 45 fatal injuries are from civil engineering (HSE, 2023a).

Nevertheless, according to numerous academics (Atkinson and Westall, 2010; Alsamadani *et al.,* 2013; Albert *et al.,* 2014; Manu *et al*., 2014; Liu *et al.,* 2018) these compelling statistics (except for the fatal accident records) are unreliable due to the: inherent challenges such as under-recordings; misrepresentation in classification of injury severity; and exclusion of certain accidents as unreportable or unrecordable by legislation. For instance, in the UK, recordable serious accidents (defined by The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013) are those with more than three days absence from work (Health and Safety Executive, 2013). Furthermore, financial circumstances, reputational concerns and cultural expectations of workers and supervisors might obscure the true safety records of companies in the construction industry (Atkinson and Westall, 2010). To delineate on industry-specific factors impacting safety management innovation, Rawlinson and Farrell (2010) study the impact of three driving forces *viz.* academia, government and industry. This content analysis-based research (*ibid*) concludes that existing direction of construction safety management has been impacted by a shift of focus from 'how to achieve the goals' towards merely 'setting goals'. In congruence, Sherratt (2014) describes goals such as 'Zero Harm', ‘Mission Zero’ or ‘Target Zero’ and accident-free day counts as unattainable goals for high-risk industries (e.g. construction industry) which diminish the ambition of goal-achievers and occasionally lead them to falsify the actual safety occurrences. However, with the similar objective, more recent research by Boadu *et al*. (2020) reviews the influence of the construction industry’s characteristics on its safety management approaches. The study (*ibid*) identifies nine distinct characteristics of the construction industry and establishes that particularly ‘the lack of skilled and educated workforce’, ‘reliance on labour intensive methods’ and ‘lack of single regulatory authority’ characteristics present huge challenges to safety management.

3.2. SOCIOTECHNICAL SYSTEMS

Paramount ideology of ‘New View’ or Safety-II concepts (cf. Hollnagel *et al*., 2015; Dekker, 2019; Sujan *et al.,* 2019; Wang *et al*., 2020) are that the contemporary approach to safety management (referred as Safety-I approach) is anachronistic in the current era where systems have become intractable and unpredictable, while the interaction of their components are complex and emergent (Woolley *et al.,* 2019). Therefore, such complex systems require a holistic view which is emanating from systems or STS thinking. Originally coined by Emery and Trist (1960), the term STS denotes a system entailing a complex interaction of human, machinery and environmental or context aspects of the work arrangement (Baxter and Sommerville, 2011; Davis *et al.,* 2014; Woolley *et al.,*2019). Therefore, the systems thinking approach, which views construction project as a complex STS, focuses on the study of interrelations of WMS elements rather than concentrating on each element in individual silos (Woolley *et al.,*2019). Systems thinking or systems theory dates back to 1940s and 1950s and the emergence of concept, theory or new approach occurred in order to manage increasingly complex systems that were being built after World War II (Leveson, 2020a). This systems theory focuses on complex systems as a whole by rejecting reductionism or decomposition and by including concepts of feedback and feedforward control, adaptability and nonlinear interaction to understand systems behaviour (Davis *et al*., 2014).

Leveson (2020) emphasises the difference between systems theory and complexity theory (theories that are erroneously used interchangeably), where the former: is associated with natural/biological as well as man-made systems; and considers that all systems display emergent behaviour. Whereas the latter complexity theory is differentiated in terms of: being exclusively associated with natural or biological systems that are not designed by humans; and classification of systems as simple, complicated, complex and chaotic, of which only complex and chaotic systems are described to bear emergent behaviour (*ibid*). Badham *et al.* (2000) identifies STS by their five key features, namely: 1) containing interdependent parts; 2) pursuing a goal in an external environment; 3) achieving a goal(s) by more than one way; 4) containing separate but interdependent social and technical subsystems within an internal environment; and 5) achieving success premised upon solely joint optimisation of social and technical subsystems. The fundamental principle of the STS approach is to equally integrate social and technical factors in systems design (Baxter and Somerville, 2011); an approach that emerged in response to inundating failures of systems that were designed based on techno-centric concepts. Researchers studying STS (cf. Badham *et al.,* 2000; Baxter and Somerville, 2011; Davis *et al*., 2014) claim that adopting STS thinking for systems design and analysis creates systems with greater acceptance by end users and delivers better value to stakeholders. Earlier research, which led to the development of STS theory, were in the areas of organisational change, implementation of new technology and business change programme (Davies *et al.,* 2017). Implementation and adoption of the National Programme for information technology (NPfIT) in the National Health Service (NHS), UK (Waterson, 2014) and building-integrated photovoltaic (BIPV) uptake in Australia's renewable energy sector (Weerasinghe *et al.,*2021) are exemplars of success stories of applying STS theory principles. However, Davis *et al*. (2014) advocate expanding the core ideas and principles of STS beyond the traditional application on new technology adoption; since availing the STS approach for different disciplines and domains renders opportunities to prevent systemic failures in (for example) the construction industry.

3.2.1. Accidents within sociotechnical systems

Safety critical industries or organisations are entities in which safety is closely entangled with their core business activities and the work environment or product/outcome of such entities involves high risk (Woolley *et al*., 2019). Several headline-making major accidents have occurred in those safety critical organisations in recent years. For example, such catastrophic events include: Flixborough and Ladbroke Grove rail crash in the UK (Walker and Strathie, 2015; Qi *et al*., 2012); British Petroleum (BP) Texas city refinery explosion and Three Mile Island catastrophes in the USA (Grabowski *et al*., 2010; Raben *et al*., 2018; Swuste *et al*., 2019; Behie *et al*., 2020); failures at Challenger and Columbia space shuttle programmes (Grabowski *et al*., 2007; Lofquist, 2010; Givehchi *et al*., 2017); accidental release of methyl isocyanate (MIC) from the Union Carbide plant in Bhopal, India (Qi *et al*., 2012; Leveson, 2015); the Pike River mine explosion in New Zealand (Salmon *et al*., 2022); and the Esso

Longford gas plant explosion in Australia (Hopkins, 2009; Johnsen *et al*., 2012). However apart from these examples of headline making catastrophic accidents, there are greater number of incidents with not as severe consequences (but still major events) that go unnoticed but reoccurrence of which could be prevented, if early warning signs are used (Loosemore and Cheung, 2015). These early signals are referred as LIs – a measurement informing about eminent threat, upcoming event or current status. An investigation to these major catastrophic accidents later revealed that early signs and signals (i.e. LIs) had been present prior to occurrence of those severe impact occurrences, however entities failed to address or react to those LIs (Johnsen *et al*., 2012; Leveson, 2014; Sultana *et al.,* 2019). Such conclusions from catastrophic events' investigations compelled extrapolation of LIs use amongst safety critical entities. For example, Leveson (2014) states that the acceleration of LIs development took place after the Grangemouth incident investigation report, which concluded that use and development of LIs is recommendable for major hazards prevention. In the same way, Raben *et al*. (2018) state that the proactive approaches involving anticipation and early warnings has rapidly evolved in the aftermath of major accidents such as Piper Alpha blowouts and the Texas city Refinery and Deepwater Horizon explosions.

3.3. MEASURING SAFETY AND PREDICTING UNSAFETY

Measuring, achieving, managing and maintaining safety is complicated process, since safety is an elusive phenomenon, which is tangibly perceived when it is absent. That is because safety is dynamic over time (Leveson, 2015), not easily discernible or sampleable (Hudson, 2009), the impact of steps taken to improve safety takes long time to measure (Ale, 2009) and safety occurs or fails to occur as a result of multilevel, multifarious and multigranular elements (Mousavi *et al*., 2018). Hudson (2009) highlights some of the intrinsic impediments of measuring safety, such as: lack of a theoretically coherent framework of how and why accidents happen; and the inherent difficulty associated with the timescale of outcomes, where workers find incomprehensible that their actions or inactions have an impact on the safety outcome. Furthermore, Mengolini and Debarberis (2008) cite the paradox associated with safety which states that the success or return from efforts put to maintain safety is not visible or measurable, since the outcome from enhancing safety is indiscernible. Authors (*ibid*) highlight that due to this reason, organisations tend to opt for more solid measurement of safety, i.e. lagging indicators (which reflect the outcome or past performance of safety). Lagging indicator is the measurement of safety performance based on the consequences or outcomes which are predominantly unfavourably and negative events (such as accidents and failures). Such approach (i.e. using only lagging indicators) denotes: the measurement of safety or success by association (Grabowski *et al.*, 2007; Oswald, 2020); monitoring and tracking unsafety (Khan *et al*., 2009; Raben *et al*., 2018); and being guided by outcomes only (Almost *et al*., 2019; Xu *et al*., 2023). Whereas a metric known as LI focuses on early, weak signals that signify of upcoming event (whether the event favourable or not). However, safety is not just state of its presence and absence, but there is a 'grey area' or period between those two, where the condition might not be safe but accident has not been manifested yet (Guo and Yiu, 2015). This 'grey area' is referred as '*drifting to danger or disaster*' (Zwetsloot *et al*., 2014) or '*slow deterioration of the process*' (Mengolini and Debarberis, 2008). Rasmussen's model of migration is prominent example describing this blurred boundary between safety and unsafety, where systems may become prone to degenerate over time (Read *et al*., 2021). Therefore, use and application of LIs in the process of decision making around safety management, measurement and maintenance becomes indispensable.

3.3.1. Safety indicators: leading or lagging

In endeavouring to define LIs, many studies (cf. Hopkins, 2009; Podgórski, 2015; Sheehan *et al*., 2016; Alruqi and Hallowell, 2019) suggest contrasting the nature, function and focus of LIs with lagging indicators. Some studies on these indicators describe the relationship of leading and lagging indicators as a continuum (Reiman and Pietikäinen, 2012); whereas other studies describe it as relative (Dyreborg, 2009), negative (Haas and Yorio, 2016), bidirectional (Kongsvik *et al*., 2010) or time dependent (Yorio *et al*., 2020). Conversely, other scholars (cf. Saqib and Siddiqi, 2008; Mearns, 2009; Øien *et al*., 2011; Murray, 2015; Swuste *et al*., 2016; Neamat, 2019) view the relationship of these indicators as undistinguishable, overlapping and blurred and hence, both indicators are collectively referred to as process safety indicators (Swuste *et al*., 2016; Bayramova *et al*., 2023), safety performance indicators (Saqib and Siddiqi, 2008; Grecco *et al*., 2013) or key performance indicators (Murray, 2015; Yorio *et al*., 2020). For example, Haas and Yorio (2016) develop 22 performance measurements which combine leading and lagging indicators, and categorise them as worker performance, organisational performance and interventions indicators. Furthermore, other studies on the interrelationship between these indicators have developed models and frameworks that explicate the indicators' relationship based on severity and predictability of occurrence (Swuste *et al*., 2016; Swuste *et al*., 2019). The Bowtie diagram represents a prominent visual metaphor that describes the sequential relationship of leading and lagging indicators in relation to accident occurrences (Swuste *et al*., 2016). The Bowtie's centre is depicted as an accident or other unfavourable event, the left side demonstrates barriers targeted to prevent hazards, whereas the right side represents consequences (Swuste *et al*., 2019). In this metaphor, LIs reveal any gaps or faults of preventative measures and barriers adopted, whereas lagging indicators describe the consequences of that undesirable event or accident (Schmitz *et al*., 2021). Based on this explanation, Swuste *et al*. (2016) describe LIs as proxies for barriers, hazards and management factors that inform the cases of process deviations or the stability of a safe system of working. In contrast, lagging indicators are proxies for the event at the centre and consequences (*ibid*). Similarly, the Safety Pyramid (developed in process safety management studies) represents another schematic representation of two indicators' relationship and delineates four levels of event occurrences, each increasing in severity from the pyramid's bottom to top (Murray, 2015; Swuste *et al*., 2016; Stauffer and Chastain-Knight, 2021). The pyramid's lower level is tier 4 type LIs representing minor severity level events, known as challenges to safety management systems, which are followed by tier 3 LIs that are near miss occurrences (Stauffer and Chastain-Knight, 2021). The top two levels are described as lagging indicators with the last tier 1 level event representing the most severe consequences (*ibid*).

Both alluded models of safety performance indicators (i.e. Bowtie and Safety Pyramid) highlight the complementary and inseparable relationship of both leading and lagging indicators and their pivotal role in providing critical information on the safety levels within an organisation (and/or satellite sites managed) – importantly, they also reveal the efficiency/inefficiency of adopted safety management systems (Øien *et al*., 2011). However, the relationship between leading and lagging indicators becomes blurred when elements of indicators (such as near misses, safety climate or frequency of toolbox meetings) are studied. Complexity increases with some scholars stating that lagging indicators can elucidate upon the efficiency of LIs, in which case the relationship of indicators appears bidirectional or reverse causational and their function is interchangeable (cf. Kongsvik *et al*., 2010; Haas and Yorio, 2016; Yorio *et al*., 2020). According to Haas and Yorio (2016) and Oswald *et al*. (2020) some elements can be considered leading or lagging indicators depending on the focus and purpose of measurement, e.g. a near miss can serve as a LI if it predicts a severe future event (Sheehan *et al*., 2016). Yet focusing on the event (near miss) as a minor severity level incident that has already occurred, will render the event as a lagging indicator (Murray, 2015).

3.4. SUMMARY OF CHAPTER 3

Increasingly, safety experts are: acknowledging the importance of shifting away from reductionistic notion of regarding complex system (such as construction projects) as the sum of its componential parts; and highlighting to approach safety management with holistic view and STS thinking which allows studying intrinsically interconnected relationship of componential parts and phenomena occurring from it (Hollnagel *et al*., 2015; Dekker, 2019). Therefore, the current chapter outlined the inherent characteristics of projects in construction and civil engineering and explicated intricacies of achieving and maintaining safety in such complex systems.

However, managing an elusive phenomenon such as safety is becoming ever more challenging with dynamic and unpredictable nature of those componential elements of systems. At present, widespread use of lagging indicators in safety management allows gleaning of some insights about interaction of system elements but only retrospectively. Indeed, analysing past occurrences through a STS lens yields invaluable insights about complex systems and their elements' interrelationships, the knowledge which set fundamentals for designing and generating preventative countermeasures for future projects and undertakings. However, such knowledge obtainment occurs too late in the stage where unfavourable occurrences have already taken place. Furthermore, such knowledge or information collection is replete with noises associated with the accuracy of data reported and recorded, unconscious bias such as retrospective view, confirmation bias or unknown unknown. Also, systems are extremely complex, dynamic and unpredictable that the task to accurately predict upcoming events becomes challenging since systems will not behave in a meticulous and identical way that was observed in the past. That is because systems' status is constantly changing and observations about these changes are emergent in real time. Therefore, to proactively manage and maintain safety, decision making and preventative measurements must be based on those emergent signals or early signs generated by LIs. LIs enable pre-emptive intervention by reacting with corrective countermeasures to a timely observed changes in the system and allow continuous monitoring of the systems' status of safety. All these particulars of using LIs for real time safety status monitoring, the proactivity of LIs for accident prevention and barriers of adopting LIs are delineated in this current chapter. Cumulatively, the chapter demonstrates insights emanating from the literature of safety management that requires holism (via the use of STS thinking) and proactivity (via the adoption of LIs) in understanding, planning for, achieving and maintaining safety. Therefore, to address this fragmented nature of safety management in construction (as identified gap in the existing literature), this study will review the literature of construction safety management in order to generate a theoretical basis in the form of conceptual model that promote integration of: concepts within safety management; work mode; information source and type used; design and construction stages; and system elements (WMS).

CHAPTER FOUR – PROACTIVE SAFETY MANAGEMENT THROUGH LEADING INDICATORS

4.0. INTRODUCTION

Despite the widespread acknowledgement amongst scholars and practitioners within safety critical industries about the advantages of proactive safety management, numerous challenges (such as unpredictability of events due to the dynamic nature of complex systems and inaccuracy of data used for prediction due to the subjectivity involved in recording systems) hinder the implementation and adoption of such an approach in practice. A tool used to propagate a proactive safety management approach is the adoption of LIs. LIs are described as events, measures or conditions that precede unfavourable events (such as accidents, unsafe conditions or incidents) and have a predictive value about those unfavourable events (Leveson, 2015; Haji *et al*., 2022). This common description of LIs elucidates upon its function to provide an early warning signal to avoid those negative events (Shea *et al*., 2016). However, because of the incipiency of using and adopting LIs in safety management, the propagation of such an approach progresses poorly, if at all. Such retardation is due to lack of clarity about what are LIs as a concept and absence of comprehensive and unanimous guidance as to how LIs can be developed, used and benefitted. Moreover, the distinctiveness of every organisation's safety management system(s), safety culture maturity level as well as different capacity and resources allocated to develop, measure and record the LIs make the elements and application of LIs non-generalisable and unique to every organisation and individual project (Xu *et al*., 2021). This and many other nebulous details of LIs (such as development method, identification or selection of LIs) hinder their widespread adoption in safety management (Hudson, 2009; Guo and Yiu, 2015). Hence, the main constructs of LIs, which enable elucidation of such concept and facilitate their wider adoption for proactive safety management, must be reviewed (Bayramova *et al*., 2024a).

4.1. BACKGROUND TO LEADING INDICATORS

The use of LIs is widespread, from food and drug safety (cf. Lauková *et al*., 2020; Assiri *et al*., 2022), economics (cf. Vašíček *et al*., 2017) to environmental changes (cf. Carr *et al*., 2012) and education (cf. Thomson *et al*., 2020). The object or target being measured through LIs in these fields (whether with the purpose of avoiding or achieving a certain outcome) represent impalpable, nonphysical phenomena (i.e. imminent threats such as economic recession, disease outbreaks, natural disasters or risk of accident or unsafety) that are difficult to discern and measure directly, promptly or conclusively (Hudson, 2009). These phenomena occur in a closed system (i.e. systems like a black box, for example, human health or mechanical device) or in an open dynamic system (i.e. complex systems that has no definitive boundaries such as construction projects) (Grenn *et al*., 2014; Read *et al.,* 2021). These objects are being measured through LIs for various reasons: 1) the length of time between the action or influence taken and their consequences is long and difficult to correlate (Mengolini and Debarberis, 2008); 2) the object being measured occurs by the impact of multigranular, multilevel and multifarious elements (Leveson, 2015); 3) manifestation (or otherwise) of those measured objects are not easily controlled/influenced or tracked (Arnold, 2015); and 4) the object being measured requires continuous monitoring, since the measurement (or the state of the object) is dynamic over time (Haas and Yorio, 2016). Measurement of safety falls under all these four categories because safety is dynamic over time (Leveson, 2015), not easily discernible or sampleable (Hudson, 2009), the impact of steps taken to improve safety takes a long time to measure (Ale, 2009) and safety occurs or fails to occur as a result of multilevel, multifarious and multigranular elements (Mousavi *et al*., 2018).

As numerous scholars state (cf. Haas and Yorio, 2015; Walker and Strathie, 2016; Patriarca *et al*., 2019; Oswald, 2020) the concept of LIs derives from the field of economics and was later adopted for use in safety management. Falahati *et al*. (2020) cite that LIs usage in safety management was pioneered by the nuclear industry and followed by the chemical process and petroleum industry. For example, guidance notes (about how to adopt and use LIs) published in the nuclear industry by institutions such as the Organisation for Economic Co-operation and Development (OECD), International Atomic Energy Agency (IAEA) and World Association of Nuclear Operators (WANO) showcase early adoption of LIs by the nuclear and chemical industries (Mengolini and Debarberis, 2008). Patriarca *et al*. (2019) mention that the induction of LIs in safety management practices expanded after the publication of Baker report on the BP Texas City explosion event (cf. Baker *et al*., 2007). Similarly, Swuste *et al*. (2016) contrast eminent historical major accidents occurring during the 1970s-1980s with major accidents occurring during the period 2000-2010 and highlight the ubiquitous mentioning of LIs in their retrospective safety analysis. Akroush and El-adaway (2017) allude to the use of LIs in the safety management of construction projects by referring to the work of: Hinze and Hallowell (2013) which identifies 50 active LIs; the Construction Industry Institute (CII, 2012) research which registers 100 passive LIs; and Rajendran and Gambatese (2009) which finds around 300 different LIs.

4.2. LEADING INDICATORS IN SAFETY MANAGEMENT

Unlike lagging indicators, the definition, nature, identification process and utility of LIs in safety management have failed to reach a consensus in theoretical and practical terms (Haas and Yorio, 2015; Guo and Yiu, 2015; Jazayeri and Dadi, 2017; Xu *et al*., 2021). Alruqi and Hallowell (2019) ascribe scant LI studies to the lack of resources and the difficulty in accessing and objectively analysing the large volume of sensitive organisational data. Similarly, Mearns (2009) highlights that despite the abundance of data (i.e. records of safety performance) being collected in organisations, exiguous knowledge of how to effectively use the data for safety improvement impedes the application LIs. However, Oswald (2020) states that the major source of confusion regards these concepts (i.e. leading and lagging indicators) is their importation from the economics discipline to safety management without due rigorous consideration to this unique setting.

4.2.1. Sources of data and methods to develop leading indicators

Methods for identification or development of LIs for safety management vary immensely from root cause analysis to hazard analysis and probabilistic risk analysis (Alexander *et al*., 2017; Oswald, 2020; Haji *et al*., 2022). Guo and Yiu (2015) emphasise that a lack of guidance on the development, application and validation of LIs constitutes a major challenge to their adoption. However, akin to the multifariousness of LIs development methods, the sources to develop or identify LIs are manifold (Santos *et al*., 2019). Oswald *et al*. (2020) emphasise using information that are more apposite to safety and safety activities such as safety audits, near miss reports, safety walk reports and recorded safety observations to develop efficient LIs. Many other scholars (cf. Hallowell *et al.,* 2013; Kenan and Kadri, 2014; Costantino *et al*., 2020; Falahati *et al*., 2020) use sources gathered directly from operators, experts and safety managers to develop, classify and validate LIs. Examples of common data sources used can be thematically grouped into three categories (refer to Table 4.1) *viz.*: 1) *primary data*; 2) *secondary published data*; and 3) *secondary unpublished data*.

Table 4.1 – Examples of data sources to develop leading indicators with their pros and cons.

Group of data source	Examples of data source	Advantages	Disadvantages	Citations
Primary data.	Opinions of experts and other relevant operators (collected through questionnaires, interviews and focus group).	-Data is collected in accordance to aim and objectives of study. -LIs developed from such source of data increases acceptance of users when LIs are implemented.	-Difficulty to discern reality from opinions. -Interviewer effect and group effect. -Researcher bias. -Questionnaire fatigue. -Low generalisability.	Mengolini and Debarberis, 2008; Hallowell *et al.,* 2013; Kenan and Kadri, 2014; Erkal *et al*., 2021.
	Data from ongoing project(s) and safe behaviour observations.	-Real time data. -Data is specifically relevant to study.	-Observer effect. -Halo effect. -Impact of self-fulfilling prophecy.	Pettinger, 2013; Costantino *et al*., 2020; Falahati *et al*., 2020; Toellner, 2014.
Secondary published data (relevant to LIs and safety activities).	Pertinent literature and publications of best practices.	-Peer reviewed publications convey high reliability and robustness	- Data might not duly be fitting for research purpose	Podgórski, 2015; Guo and Yiu, 2015; Neamat, 2019; Xu *et al*., 2021; Hallowell *et al*., 2013; Haji *et al*., 2022.
	Normative documents such as, industry standards (e.g., OSH MS ILO-OSH 2001, OHSAS 18001).	-Content of normative document are useful to: 1) develop LIs that measure positive activities; and 2) learn about shortcomings in organisation's safety management.	- Organisation's approach to safety management could be different to industry standard papers.	Podgórski, 2015; Robson *et al*., 2017; Falahati *et al*., 2020.
Secondary unpublished data (recorded by organisations e.g., administrative documents).	Documents from accident investigation or near miss reports.	Data source provides closest to reality information that is most relevant to organisation.	The data recorded is subject to judgement, interpretation and intention of the person recording it.	Akroush and El-adaway, 2017; Santos *et al*., 2019; Oswald, 2020; Shrestha *et al*., 2020.
	Safety performance records of an organisation in the certain time periods (e.g., safety audit and safety observation records or safety walks' reports).	Data is useful to monitor safety performance of organisation and detect drift/deviations to safety or unsafety, if tracked in a timely manner.	Data refers to past and might not be relevant to current activities of organisation.	Pettinger, 2013; Poh *et al*., 2018; Jafari *et al*., 2019; Oswald, 2020; Yorio *et al*., 2020; Ebrahimi *et al*., 2021.

Primary data include opinions of experts and other relevant operators (i.e. people who are performing the work) collected through questionnaires, interviews, focus groups, data from ongoing project(s) and safe behaviour observations. *Secondary published data* represent publications that are focused to augment LIs adoption, safety improvement or propagation of proactive safety management; whereas *secondary unpublished data* are documents and recordings captured by organisations such as accident investigation reports (Gale *et al.,* 2013; Akroush and El-adaway, 2017; Santos *et al*., 2019; Shretha *et al*., 2020) and safety performance records of an organisation (Poh *et al*., 2018; Jafari *et al*., 2019; Yorio *et al*., 2020; Ebrahimi *et al*., 2021). *Secondary unpublished data* are gathered for administrative purposes (e.g. as part of routine work, post-accident or regular inspection) and might be in different formats as follows *viz.*: 1) written records of pre-work meeting, documentation of safety policy implementation, audio records of witness statement; 2) photographic evidence (e.g. from the site of accident investigation); and 3) video recordings (e.g. of activities prior to an incident). Each group has their inherent advantages and drawbacks or limitations to be considered that are respectively exemplified in the 'advantages' and 'disadvantages' column in Table 4.1. For example, basing the development of LIs on solely *primary data* will bear the advantage of being most relevant to the specific safety element that company is interested, while simultaneously having the disadvantage of being limited to workers opinion, bias and perspective - and representing only the snapshot of activities, events or conditions. Most examples of the three data sources to develop LIs represent qualitative type data which contradicts a plethora of researchers who state that literature is predominated with quantitative type LIs (cf. Haas and Yorio, 2016; Oswald, 2020; Floyd, 2021; Xu *et al*., 2021). One plausible interpretation of this contradiction might be associated with how these qualitative type data sources are used to develop LIs, *viz*., by quantification, by measuring/counting certain activities, events or tasks, rather than focusing on content or semantics.

4.3. CONSTRUCTS OF LEADING INDICATORS

Many scholars accentuate, question and/or criticise that: LIs are limited to being general (Xu *et al*., 2021; Salmon *et al*., 2022); methods to develop LIs are confined to being based on traditional hazard analysis techniques (Leveson, 2015; Bayramova *et al*., 2024); and techniques to identify LIs are solely grounded on a quantitative approach (e.g. that are founded on probabilistic risk assessment method) (Oswald, 2020; Xu *et al*., 2021). For example, Leveson (2015), Xu *et al*. (2021) and Salmon *et al*. (2022) argue that developing solely general LIs (intended for widespread industrial applications) is inefficient and fails to incorporate the inherent uniqueness of a company, project or system. However, Sinelnikov *et al.* (2015) state that studying LIs' common features and characteristics and discerning insights about their generic attributes will enable generation of knowledge that are generalisable and applicable for widespread use of LIs.

4.3.1. Features/characteristics/attributes of leading indicators

The most commonly agreed characteristics of LIs are that they must be specific, measurable, achievable, relevant and time bound (SMART) (Toellner, 2014; Tang *et al*., 2018; Falahati *et al.,* 2020). Alternatively, Grabowski *et al*. (2007a) and Toellner (2014) describe eight core features of LIs, *viz.* : 1) worth measuring and represent salient aspects of the organisation's safety management system; 2) simple to understand; 3) measured for diverse populations; 4) understandable by people who need to act (during the operational stage of works undertaken); 5) useful to galvanise action (i.e. to maintain safety) at various levels; 6) associated with actions that can lead to improvement in safety; 7) measurable over time, with the measurement reflecting tangible results of the actions taken; and 8) cost efficient in terms of their maintenance (i.e. the hours and technology required to gather information and to review LIs). Similarly, Akroush and El-Adaway (2017) cite four main characteristics of LIs, namely: 1) *time frame* – the capacity of LIs to precede the accident, incident or injury; 2) *predictive value* – the ability of LIs to predict the occurrence of a negative event; 3) *proactivity* – the capability of LIs to proactively prevent and intervene with corrective action; and 4) *measurability* – the facility of LIs to evaluate safety performance. Omidi *et al*. (2023) highlight that key characteristics of LIs are: *simplicity*, readily *interpretability*, objectively and reliably *measurability*, easily and accurately *communicated* and broadly *applicability*. Such characteristics convey the need for LIs that are useful for practitioners throughout industry. Table 4.2 provides some existing examples of LIs which are aggregated according to their description.

Table 4.2 – Leading indicator descriptions in the literature.

Leading indicator described as…	Examples of leading indicator elements	Citations
Safety management system element	Alcohol/ drug testing; attitudes and safety climate; housekeeping; safety behaviour of safety; fall protection; training and job safety talk; near misses; safety correction; safety inspection; and subcontractor safety.	Neamat, 2019.
	Worker observation process; near miss reporting; project management team safety process involvement; job site audits; stop work authority; housekeeping programme; and safety orientation and training.	Elsebaei *et al.,* 2020.
	Safety training; ergonomic opportunities identified and corrected; reduction of musculoskeletal disorder (MSD) risk factors; employee perception surveys; and safety audits.	Hughes and Ferrett, 2020.
	Zero injury techniques; demonstrated management commitment; staffing for safety; pre-project and pre-task planning; safety education and training; employee involvement; safety recognition and rewards; incident investigations; substance abuse programs; and subcontractor management.	Hallowell *et al.*, 2013.
	Near misses; safety audits; safety culture; and safety climate measures.	Eaton *et al.,* 2013.
	Upper management involvement; training/orientation; pre-task safety meeting; safety inspections/observations; hazard and accident analysis; owner involvement; safety record; worker involvement; safety resource; staffing for safety; written safety plan; personal protective equipment (PPE); substance abuse; and incentives.	Alruqi and Hallowell, 2019.
	Safety climate.	Zohar, 2010; Schwatka *et al.*, 2016.
Safety hazard and risk perception surveys	Questionnaire-assessed safety hazards and management practices.	Moore *et al.,* 2022.
	Survey of workers, regarding the human factor issues.	O'Connor *et al.,* 2010.
Safety culture	Accountability; consultation and communication; management commitment and leadership; audits and workplace OSH inspections; empowerment and employee involvement in decision making about OSH; positive feedback and recognition for OSH; prioritisation of OSH; risk management and systems for OSH; and the provision of OSH training, information, tools and resources.	Sheehan *et al.,* 2016.
	Top-level commitment to safety; organisational learning; organisational flexibility; awareness; just culture; and emergency preparedness.	Grecco *et al.*, 2014.
Safety status monitoring, recording and reporting practices	Information from a safety audit that can lead to systematic changes for safety, such as a change in equipment or procedure. A near miss report that explains a 'difficult to observe' unsafe action, such as fluid and momentary human error, that has readily been shared without fear of punishment. A safety walk report explaining a solved dynamic safety problem that unexpectedly arose on site; and A recorded safety observation that identifies and explains potential problems for upcoming high-risk activities, such as work at height.	Oswald, 2020.
Organisation's occupational health and safety (OHS) performance.	OHS leadership; OHS culture and climate; employee participation in OHS; OHS policies, procedures and practices; and OHS risk control.	Yanar *et al.,* 2020.
Assessment of adopted safety management system	Direct measures of safety management systems such as frequency or timeliness of audits.	Hopkins, 2009.
Preventative measures	Activities, practices, and programs for preventing injuries and minimizing duration and severity of injuries when they do occur.	Moore *et al.,* 2022.

The table illustrates those other known proactive measurements of safety (e.g. safety climate, safety culture, near miss occurrences) appear as safety LI examples (Alruqi and Hallowell, 2019; Golzad *et al*., 2023), since they all indirectly measure the status or the strength of safety (Erkal *et al.,*2021; Xu *et al*., 2021). Most examples in the table represent elements of safety management systems and hence, highlight the function of LIs to measure the efficiency of policies, rules and preventative steps. However, LIs illustrated by every study in the 'safety management systems element' group are multifarious and distinctive from every other example, since a safety management system of each individual organisation is unique and contextual (Xu *et al.*, 2021).

4.3.2. Classification of leading indicators

These LI examples (exemplified in Table 4.2) can be broadly divided into two common dichotomous classifications *viz*.: 1) based on their stage of adoption, *active* and *passive* LIs (cf. Hinze *et al.,* 2013; Jazayeri and Dadi, 2017); and 2) based on their function, *structural* and *operational* LIs (Falahati *et al.,* 2020). According to Hinze *et al.,* (2013), *passive* LIs (PLIs) take a long time to measure while *active* LIs (ALIs) can be measured within a shorter time period. In other words, PLIs are a manifestation of actions or events that have taken place long before the operation or project has been initiated (i.e. design stage), whereas ALIs are a manifestation of actions or events that has since taken place during the operation or project and hence, can be timely corrected once observed (*ibid*). Examples of PLIs include: a steel-toed boots policy (Alruqi and Hallowell, 2019); the percent of management personnel with 10-hour or 30-hour OSHA certification (Jazayeri and Dadi, 2017); contract provisions that require subcontractor compliance with a site-specific safety policy or programme (Hinze *et al*., 2013); and other safety management activities that are adopted prior to the project initiation stage.

To a degree, PLIs are almost indistinguishable to *structural* LIs which encapsulate all health and safety management efforts made by a company such as policies, objectives and plans, procedures and guidelines (Cambon *et al.,* 2006; Falahati *et al.,* 2020). Similarly, there is an overlapping construct in the definition and examples of ALIs and *operational* LIs; where ALIs are described as a measurement of safety in real time and operational LIs are described as a measurement of the effectiveness of safety and health management systems in an operation stage (Podgórski, 2015; Falahati *et al.,* 2020). Examples of ALIs include: quality of pre-job safety meetings (Alruqi and Hallowell, 2019); physical stress caused by overexertion (Costin *et al*., 2019); percent of adherence to safety based on audits (Jazayeri and Dadi, 2017); and rate of involvement of upper management in safety walk-throughs (Hinze *et al*., 2013).

These examples show that ALIs are monitored and measured both quantitatively and qualitatively. Quantification of ALIs is the most prevalent and conventional approach where safety management activities such as subcontractor safety audits, safety observations, toolbox talks are measured in terms of frequency of occurrence (Swuste *et al.,* 2016; Bayramova *et al*., 2024). However, many scholars (cf. Hopkins, 2009; Costin *et al.,* 2019; Xu *et al*., 2021; Schmitz *et al.,* 2021) argue that sole quantification of ALIs is insufficient and therefore, qualitative description and measurement of such indicators must be combined to establish a complete more in-depth picture of safety status. For example, mere measurement of the frequency of toolbox talks fails to elucidate upon the effectiveness, content and quality of those toolbox talks, which can inadvertently promulgate the notorious 'box-ticking' approach in safety status measurement (Xu *et al.,* 2021). Another drawback of only quantitatively measuring safety is that any positive or negative event(s) with low frequency and minor severity will remain statistically insignificant, in which case those records will not be recognised and the opportunity to learn from those occurrences will be lost (Floyd, 2021). Therefore, for holistic indication of safety performance, and comprehensive monitoring of safety, quantification of safety activities must be accompanied with supplementary qualitative information (*ibid*).

4.3.3. Functions of leading indicators

Apart from definition, characteristics or typology of LIs, their functions are a key construct or important feature to expound such concept, especially for their adoption stage (Rhodes *et al*., 2009; Sheehan *et al*., 2016; Bayramova *et al*., 2023). Functions of LIs described in the literature are multifarious. The study by Alexander *et al*. (2017) focus on LIs' function to measure and predict positives (such as success in maintaining safety, resilient capacity and continuous learning) rather than solely concentrating on negatives (incidents, accidents and errors). Quigley *et al*. (2012) emphasise the characteristic of LIs that provides a measurable indicator: first, as feedback about the process compliance to a specified performance standard; second, as a predictor of future process problems. Laitinen *et al*. (2013), similarly, emphasise the feedback function of LIs, calling for development of real-time *outcome* LIs instead of *activity* LIs such as the number of safety audits conducted, number of workers trained or number of risk assessments completed. Whereas Guo and Yiu (2015) accentuate two, informative and decision aiding functions of LIs, i.e. LIs ability *viz.*: 1) to provide information about the state of safety; and 2) to help decision makers take remedial actions. The authors (*ibid*) state that these two functions are an important feature of LIs for promotion of double loop learning which involves, first reflecting any existing safety model and second, enabling the construction of a new model and explanation through continuous validation. Furthermore, functions of LIs are also reflected in the studies focusing on their definition and characteristics. Table 4.3 exemplifies some of the definitions and descriptions of LIs which implicitly reflect their functions.

Table 4.3 – Examples of leading indicators descriptions that denote their functions.

Description or definition of leading indicators that reflect their functions	**Authors**
The goal of leading indicators for safety is to identify the potential for an accident before it occurs.	Leveson, 2015.
The purpose of leading indicators is to understand and manage the organisational circumstances thought to precede undesired occupational health and safety outcomes.	Haas and Yorio, 2015.
The information gathered can not only identify holes in your safety systems but can also be used as a positive safety metric to be shared with employees.	Pettinger, 2013.
A measure or combination of measures that provides insight into an issue or concept.	Rhodes *et al*., 2009.
There are four main characteristics of leading indicators, namely: 1) time frame, the capacity of leading indicators to precede the accident, incident or injury; 2) predictive value, the ability of leading indicators to predict the occurrence of negative event; 3) proactivity, the capability of leading indicators to proactively prevent and intervene with corrective action; and 4) measurability, the facility of leading indicators to evaluate safety performance.	Akroush and El-Adaway, 2017.
The condition, the event or the measure that has some value in predicting the occurrence of the undesirable event.	Grabowski *et al*., 2007.
Something that provides information about undertaken activities on the antecedents of safety performance.	Mousavi *et al*., 2018.
Leading indicators are intended to provide insight into the probable future state, allowing projects to improve the management and performance of complex programs before problems arise.	Rhodes *et al*., 2009.
Leading indicators are proactive measures of performance before any unwanted outcomes have taken place.	Dyreborg, 2009.
Leading indicators of safety performance consist of a set of selected measures that describe the level of effectiveness of the safety process.	Hinze *et al*., 2013.
Leading indicators are those on which the organisation can act to leverage achievement of the organisational goals monitored by the lagging indicators.	Mengolini and Debarberis, 2008.
An indicator is leading if it forewarns the analyst about potentially different actions to be undertaken in order to grasp an opportunity or to evade a threat.	Patriarca *et al*., 2019.
Leading indicators not only predict negatives (incidents, accidents and errors) but also success.	Alexander *et al*., 2017.

Areas of the text that are shaded with blue in the first column of the table highlight some of the functions of LIs. Most commonly, LIs are described to have a predictive, interventional and corrective functions. Xu *et al.* (2021) perform similar exploration of definition, characteristics and functions of LIs but reversing the approach; i.e. the study develops a working definition of LIs by studying some of the characteristics and functions of LIs.

Many scholars (Zheng *et al*., 2019; Xu *et al*., 2021; Salmon *et al*., 2022; Haji *et al*., 2022) agree that LIs are unique to every company based on their safety management systems, on their safety culture maturity level and their allocated resources for safety management (to develop LIs) and cannot be generalised. Therefore, to adopt LIs as a gauge of safety, two points becomes fundamental requirements for successful LIs implementation and adoption, *viz*.: 1) to understand the meaning and purpose of LIs rather than collecting what they are in other companies; and 2) to consider capabilities and weaknesses of the organisations (i.e. safety maturity level of organisations) that are planning to adopt LIs.

4.4. SUMMARY OF CHAPTER 4

LIs' usage in safety management practices has been 'borrowed' from the field of economics to proactively mitigate risks and accident occurrences (Oswald, 2020). However, the context that LIs are being applied in (i.e. safety management) entails some inherent hurdles (Mengolini and Debarberis, 2008). Specifically, using LIs in their original provenance (i.e. in economics where a measured object is of quantitative and explicit nature) is different from using LIs to measure an incorporeal object such as safety (Guo and Yiu, 2015; Oswald, 2020). Therefore, this current chapter reviewed existing knowledge on LIs use in the management of safety, methods and sources of data used to develop LIs.

The fundamental importance of LIs' implementation in safety management was escalated in the aftermath of numerous catastrophic events that have engendered major changes in safety management practices (Swuste *et al*., 2016; Zhen *et al.,* 2022). Previous studies in the literature of LIs use in safety management: researched LIs' definition (cf. Guo and Yiu, 2015; Xu *et al*., 2021); contrasted LIs with lagging indicators (cf. Sheehan *et al*., 2016; Quaigrain and Issa, 2021); and studied taxonomy of LIs (Alruqi and Hallowell, 2019; Bayramova *et al*., 2023). Similarly, a plethora of researchers explain the nebulousness existing between lagging and LIs by referring to: their use and application context (Hinze and Hallowell, 2013; Oswald, 2020); the way they are measured (e.g. when LIs can statistically both lead and lag) (Hinze and Hallowell, 2013; Lingard *et al*., 2017); and their function (e.g. when lagging indicators predict another outcome) (Sheehan *et al*., 2016; Yorio *et al*., 2020). All these particulars are summarised in the chapter by alluding to LIs features and characteristics. Consequently, the existing knowledge presented in the literature on LIs in safety management demonstrate the necessity for: an in-depth LIs study in order to identify their main constructs for much-needed clarity; and a guidance for LIs development and implementation in order to foster the propagation of proactive safety management. This represents the gap in the existing knowledge domain, which the current study will address by reviewing the literature of LIs in order to identify main constructs of LIs that foster understanding the LIs as a concept and enable development, implementation and efficient adoption of LIs in safety management.

CHAPTER FIVE – METHODOLOGY

5.0. INTRODUCTION

Research is a systematic way of extending our knowledge and understanding of the world, using socially approved methods (Robson and McCartan, 2016; Collis and Hussey, 2021; Fellows and Liu, 2022). Whereas social research is research with people at both ends, i.e. a researcher is studying people, not physical matters or objects as in natural science research (Gillham, 2000; Robson and McCartan, 2016). Examples of disciplines in social science incorporate education, politics, social politics, anthropology, human geography, criminology and many other wide varieties that involve studying human interactions and their outcomes (Gillham, 2000; Clark *et al.,* 2021). Therefore, the balance of objectivity and subjectivity and the researcher's capacity for reflexivity become extremely important in social research practices to: formulate a research question (Clark *et al*., 2021; Fellows and Liu, 2022); select the most apposite data analysis and data collection tool (Saunders *et al*., 2019); and present impartially-generated explanation of the studied phenomena (Denscombe, 2021).

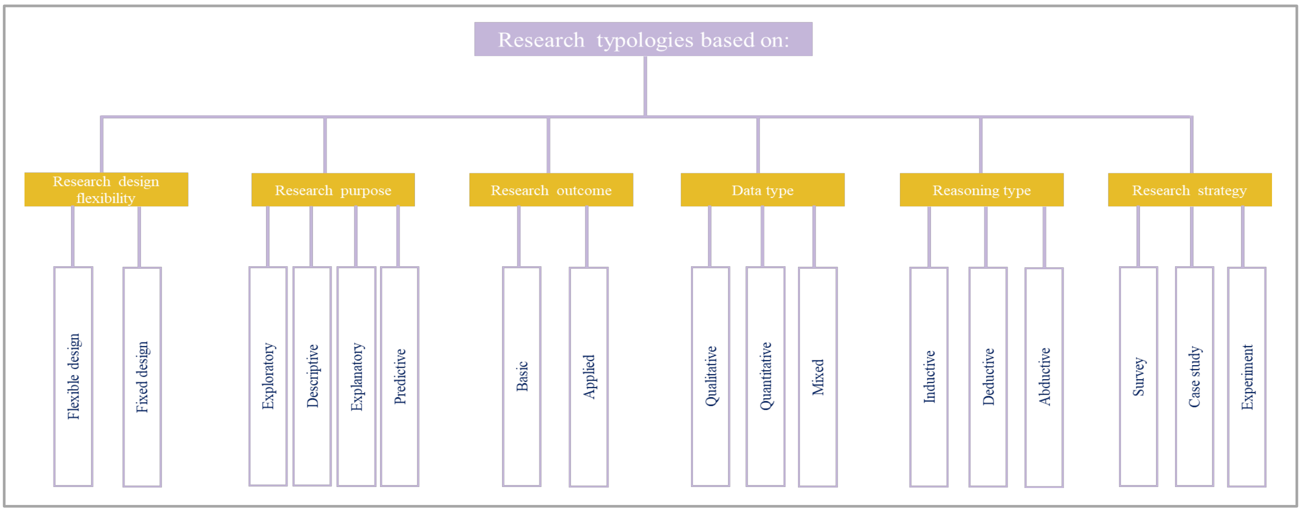
The tools selected for data analysis and data collection in such studies are collectively referred as research methods (Saunders *et al.,* 2019). However, research method is erroneously considered to be synonymous with the concept of research methodology (Collis and Hussey, 2021; Fellows and Liu, 2022). The significant difference between the research method and research methodology is that the former is only one subset of the latter (Clark *et al.,* 2021; Denscombe, 2021). Research methodology denotes broad and overall approach to study and describes the elements of research design such as research paradigm/philosophy, research strategy and research logic or reasoning (including research tools and techniques i.e. research method) and justification of their selection (Robson and McCartan, 2016; Collis and Hussey, 2021; Fellows and Liu, 2022). One of the most prominent and frequently referred work to explain research methodology is Saunders' research onion – a model explaining the selection of different tiers of research methodology elements. The model is a metaphor in the shape of onion layers, starting from the outer layer denoting research philosophies, followed by approach, strategy, time horizon and data gathering methods in the inner layers (Saunders *et al.,* 2019).

These are the pivotal elements of every research that a researcher will face to make appropriate decisions (from variety of options) after formulating their research question. The selection of certain approach towards conducting research can be impacted by: the research question and dataset type available to explain the researched phenomena (Clark *et al.,* 2021); the common research methods used in the field of research (Saunders *et al*., 2019); or simply by the preference of researcher's specific adept approach (Robson and McCartan, 2016). Therefore, identifying the processes, studying advantages and disadvantages of research methodology elements and determining the most apposite research design prior to research commencement becomes a pivotal step for a successful completion of research.

5.1. RESEARCH TYPOLOGIES

Selection of different elements of research methodology leads to different research designs with different characteristics and outcomes (Collis and Hussey, 2021). Therefore, studies are differentiated by their purpose, process, outcome and logic they constitute and grouped accordingly (Saunders *et al.,* 2019; Collis and Hussey, 2021). Robson and McCartan (2016) describe the classification of research based on the flexibility of research design, namely *fixed design* and *flexible design* research types. *Fixed design* research is a theory-driven approach to study where the variables to be included, exact procedures to be followed are specified in advance, whereas in *flexible design* research, the study's design is work-in-progress at the outset (Robson and McCartan, 2016; Collis and Hussey, 2021). Studies can also be categorised based on the research reasoning adopted in the study such as inductive, deductive or abductive studies (Collis and Hussey, 2021). Similarly, research works are classified on the ground of implemented research strategy, e.g. survey, case study or experimental studies. All three of these typologies (i.e. classification of studies based on research design, research reasoning and research strategy) along with other examples of typologies identified in research methodology literature are presented in Figure 5.1.

Figure 5.1 - Classification of studies based on their different characteristics.



Other typologies of research study are based on research purpose, research outcome and data type (or data analysis method type). These typologies are not mutually exclusive and hence, a single study can be identified to belong to different group of typologies that are described in Figure 5.1. For example, a single study using quantitative data analysis method in a long-term project of case study that commences exploratively and applies the outcome of research in organisational setting can simultaneously described as quantitative, exploratory, case study, applied and abductive study.

5.1.1. Classification of research based on its purpose

Based on the study's purpose, research is broadly classified into *exploratory*, *descriptive* and *explanatory* research types (Saunders *et al.*, 2019; Collis and Hussey, 2021). *Exploratory* research is focused on providing a general understanding about the phenomena being investigated (usually when there is not any or few studies conducted on the phenomena) to discover the need or feasibility of future studies (Saunders *et al.*, 2019; Fellows and Liu, 2022). Therefore, this type of research rarely provides conclusive answers to the problem but assesses whether current available theories and concepts are applicable for the investigated topic, or a new theory is required (Fellows and Liu, 2022). Similarly, *descriptive* research is concerned with identifying the main characteristics of the phenomena but based on empirical evidence and an in-depth examination, so to generate a basis for arguments (Collis and Hussey, 2021). A *descriptive* study can be an extension of *exploratory* research but also a precursor or forerunner of *explanatory* research which attempts to provide a clear picture of the phenomenon to be studied (Fellows and Liu, 2022). However, *explanatory* studies go beyond mere description or exploration of the topic by: testing hypothesis (Clark *et al.*, 2021); studying causal relationship between variables (Saunders *et al*., 2019); and providing an explanation of the cause and effect of studied topic (Robson and McCartan, 2016).

Alongside these three types of research alluded, Collis and Hussey (2021) mention *predictive* research which aims to make prediction based on a hypothesised general relationship (that is previously established by *explanatory* research). The outcome of *predictive* studies can be applied to other similar issues, given that predictive research provides a valid and robust solution (*ibid*). Additionally, Saunders *et al.* (2019) introduce *evaluative* studies (also called *instrumental* by Fellows and Liu, 2022) (alongside the *exploratory*, *descriptive* and *explanatory* type studies) that have the purpose of assessing the effectiveness of newly adopted policy, technology, training programmes or work process. The authors (*ibid*) also state that a single study can incorporate different combination of four types of research purposes rather than being based on single purpose. Similarly, Fellows and Liu (2022) add another classification of studies based on research purpose, namely *interpretive* studies that are focused to fit findings or observed experience to a theoretical model or framework (which can be heuristic or ontological model).

5.1.2. Classification of research based on research outcome

Another way of differentiating studies is based on the research outcome, namely *applied* and *basic* types of research (Collis and Hussey, 2021; Fellows and Liu, 2022). *Basic* research type (also referred as *fundamental* or *pure* research) is concerned with generating a knowledge and explanation about a researched area which will enable solving the issues and challenges associated with studied phenomena (Saunders *et al*., 2019; Fellows and Liu, 2022). Similar to *exploratory* research, the aim of *basic* research is to make a contribution to the knowledge by studying the relationships between variables (rather than resolving an immediate challenge identified and applying the obtained knowledge) (Collis and Hussey, 2021). The outcomes of *basic* research tend to be a research publication at academic conferences or in academic journals and the key impact of *basic* research remains within the academic community (Saunders *et al*., 2019). Therefore, academic rigour and strong research design is at the core of *basic* research.

In contrast, *applied* research aims to solve the identified problem area by applying the research findings (Saunders *et al*., 2019; Collis and Hussey, 2021). *Applied* research is used to improve management policies and processes in organisations rather than generating a new explanation to the problem area (Fellows and Liu, 2022). The outcome of *applied* research might be a research report with recommendations, new layout plan, instructional software or textbook (Collis and Hussey, 2021).

5.1.3. Classification of research based on data types

Along with other factors contributing to selection of certain research design (such as research question, research purpose, previous studies conducted in the research field), the type of data collected and analysed in research and their availability determine the selection of data collection and analysis tool (Fellows and Liu, 2022). Premised upon this, research is broadly classified as *quantitative* and *qualitative* research types (Robson and McCartan, 2016; Clark *et al*., 2021; Collis and Hussey, 2021). As the naming suggests, *quantitative* research focuses on generating knowledge based on the collection and analysis of numerical or quantitative type of data (Saunders *et al*., 2019; Collis and Hussey, 2021). *Quantitative* research measures the range, frequency or scale of phenomena in a shorter time period or in a time series manner (Clark *et al.,* 2021; Collis and Hussey, 2021). Generally, this type of research is highly detailed and structured, which is hard to design initially but easy to collate and present the results (Collis and Hussey, 2021; Denscombe, 2021). The input and output of *quantitative* type research is known as 'hard facts' that bear no chance to be modified (Denscombe, 2021). However, the findings of *qualitative* research are generally based on the researcher's interpretation which can be easy to start but hard to finalise, since the subjective interpretation of the researcher can easily be challenged (Collis and Hussey, 2021; Denscombe, 2021).

The attempt to highlight the strength of each research type has led to long-lasting disagreement amongst researchers as to which (*quantitative* or *qualitative*) research type is superior or trustworthy than the other (Robson and McCartan, 2016; Collis and Hussey, 2021). However, there is a growing acknowledgement (Bryman, 2012; Clark *et al.*, 2021; Collis and Hussey, 2021) about the potential use of both *quantitative* and *qualitative* type research by combining their values in one research, the approach known as *mixed method* research. *Mixed method* research type integrates the use of quantitative and qualitative data types, data collection techniques and data analytical procedures in single research project (Robson and McCartan, 2016; Fellows and Liu, 2022).

Another essential point is that the distinction between *quantitative* and *qualitative* research is not without its nebulousness (Clark *et al*., 2021). Techniques such as *quantitising* (which is the practice of quantifying qualitative data for frequency) and *qualitising* (which is the way of turning frequencies into texts – although, extremely rare in practice) are methods that alter the type of data as an outcome of the research (Saunders *et al*., 2019; Fellows and Liu, 2022). Therefore, for a research design to be classified as qualitative or quantitative, not only the data type used as an input into research must be considered, but also the output of the research must be taken into account.

5.2. REASONING IN RESEARCH METHODOLOGY

One of the examples of choice to make, in the process of knowledge generation, is the selection of *research reasoning*, also called *research logic*. *Research reasoning* is an approach to theory development which entails the process of constructing explanations, making predictions or drawing conclusions based on existing knowledge in the interested field (Saunders *et al.*, 2019; Denscombe, 2021). Therefore, a stage to select the reasoning of a study occurs in the step of defining the relationship of selected study with theories and concepts used in the field of study. *Theory* denotes an explanation generated for particular events or patterns that bears observed regularities (Clark *et al.*, 2021). However, *theories* in natural and social science differ from each other in terms of abstractness (Saunders *et al.,* 2019; Fellows and Liu, 2022). For example, Clark *et al.* (2021) refer to Merton's (1967) differentiation of theory as *grand* and *middle range* theories, that are respectively associated with theories in natural science and social science. *Grand theories* possess a high level of abstractness that does not bear any links to apply to real world (i.e. social science) or to draw an inference (Saunders *et al*., 2019; Clark *et al.*, 2021). Saunders *et al.* (2019) exemplify Newton's theory of gravity, Darwin's theory of evolution or Einstein's theory of relativity as *grand theories*. Whereas *middle range theories* which attempt to explain a particular aspect of the social world, are much more likely to be the focus of empirical enquiry. *Middle range* theories are not concerned to change the way of thinking about the world but are focused on explaining social interactions and phenomena occurring from those interactions (Clark *et al*., 2019). Examples of *middle range theories* are labelling theory or differential association theory such as Maslow's hierarchy of needs, Herzberg's two factor theory of motivation (Saunders *et al*., 2019).

In natural science the expected outcome from the research is the closest identification of absolute truth about the studied phenomenon, whereas phenomena being studied in social science are complex and linked to multiple bodies of knowledge, i.e. explaining the phenomena solely through one perspective or one approach is impossible (Robson and McCartan, 2016).

Therefore, different studies in social science will find different explanations of the same phenomenon – explanations that are referred to as *theories* (Collis and Hussey, 2021). Examples of theories in social science are structural functionalism, symbolic interactionism, critical theory, poststructuralism and structuration theory (Robson and McCartan, 2016; Clark *et al.*, 2021).

Bryman (2012) explains the concept of *theory* by contrasting it with *hypothesis*. *Hypothesis* is the researcher's assumption adopted to explain the studied phenomenon at the outset of study that must be tested through study; whereas the outcome of such study when any *hypothesis* is tested and proved to be right is referred as *theory* (*ibid*). Collis and Hussey (2021) describe *theory* as a group of interrelated variables, definitions and propositions that specifies the relationships between those variables, while a *hypothesis* is depicted as an idea or proposition developed from the *theory* that requires testing (mainly using statistics). Similar to Merton's (1967) classification of *theories*, Bryman (2012) differentiate two types of theory namely, *substantive* and *formal theory*. *Substantive theory* is a theory that applies to a certain empirical instance or substantive area, whereas *formal theory* is more abstract (akin to *grand theories*) and has wider applicability to several substantive areas.

Another explanation of theory is based on contrasting *theory* with *description* (Fellows and Liu, 2022). According to Jabareen (2009) *theory* constitutes group of concepts and statements that explain the relationship of those concepts, whereas *description* consists of themes that are conceptualisation of the data. There is a little, if any, interpretation involved in constructing themes, since *themes* tend to be a precise summary of the data (Jabareen, 2009; Clark *et al.*, 2021). Therefore, *description* in contrast to *theory* does not involve interpretation (Fellows and Liu, 2022). In contrast, *concepts* (which are constituent part of *theories*) are interpretation of the data or labels assigned to the certain aspects of social world that are defined by its components (Bryman, 2012).

5.2.1. Inductive, deductive and abductive reasoning

When the focus of research is to generate a new explanation or *theory* based on the observation of empirical reality, the research is inductive (Clark *et al.*, 2021). *Inductive reasoning* type research induces statements of general patterns from specific empirical occurrence, namely *inductive reasoning* represents a movement from the specific individual observation to general inferences (Collis and Hussey, 2021; Denscombe, 2021). Ergo, *inductive research* is known to be theory-building approach to a study (Saunders *et al*., 2019). Studies based on *inductive reasoning* are generally known to involve qualitative type data (*ibid*).

However, in *deductive reasoning* research, the study commences with a *theory* as a basis for the research to deduce a *hypothesis*, an approach otherwise known as theory-testing practice (Saunders *et al.,* 2019; Collis and Hussey, 2021). In this type of research, specific instances (e.g. a conceptual and theoretical structure) are deduced from general inferences to be tested in an empirical observation (Clark *et al*., 2021). Therefore, *deductive* research represents the movement from general to specific, namely, the study commences with a *theory* and applies it into research (Collis and Hussey, 2021; Denscombe, 2021). In a way, *deductive* type research resonates with the features of *applied research*, since there is an element of application of *theory* in practice for a testing (Collis and Hussey, 2021).

Similar to other dichotomous groups of research classification (e.g. quantitative and qualitative research types described in Figure 5.1) both *inductive* and *deductive* research type have their own merits and inherent limitations that different groups of researchers are appraising and criticising. For example, *inductive reasoning* is questioned for the fact that not all empirical observations can be developed into a theory (Saunders *et al*., 2019). Whereas *deductive reasoning* type research is critiqued for vagueness or lack of description as to how to select a particular theory for a study in the first place (Denscombe, 2021). Similarly, proponents of *inductive* reasoning criticise *deductive* approach for its tendency of using rigid methodology and highly structured research design that has no space for alternative explanation (Saunders *et al*., 2019).

However, there is third type of reasoning called *abductive* reasoning that addresses these drawbacks of both *inductive* and *deductive* research type (Clark *et al*., 2021). *Abductive* reasoning is a mixture of both *inductive* and *deductive* reasoning, that commences with observation and attempts to interpret the phenomena with the most plausible explanation by switching back and forth between research data and *theory* (Fellows and Liu, 2022). This process of iteration between the observation and possible explanations is referred as *dialectical shuttling* (Atkinson *et al.,* 2003; Clark *et al*., 2021). *Abductive* research type, is similar to *mixed methods* research or *flexible design* research type, attempts to identify the closest to reality explanation for the studied phenomena without any constraints of predefined steps or prespecified variables (Saunders *et al.,* 2019). Therefore, *abductive* type research acknowledges that initial conclusion arising from the observation is although plausible, not complete explanation and hence, enables identification of the most apposite explanation through iterative application (Denscombe, 2021).

5.3. RESEARCH STRATEGY

Research strategy is described as a plan set to achieve the goal of answering the research question (Saunders *et al.*, 2019; Denscombe, 2021). For example, Figure 5.1 alludes to classification of three types of *research strategies* namely, *survey*, *case study* and *experiment*. Saunders *et al.* (2019) highlight that different research tradition leads to different strategies being associated with different data types (such as *quantitative*, *qualitative* or *mixed*) and research reasoning (such as *inductive*, *deductive* or *abductive*). For instance, *experiment research strategy* is prevalently associated with *quantitative* data types and *deductive* reasoning (Fellows and Liu, 2022).

Occasionally, the term *research strategy* is used interchangeably with the terms such as research methods (Saunders *et al*., 2019), research design (Clark *et al*., 2021), main research methods (Denscombe, 2021) and research styles (Fellows and Liu, 2022). However, Denscombe (2021) disagrees on the interchangeability of the concepts *research methods* and *research strategy* and emphasises that *research methods* exclusively refer to methods of data collection not the data analysis. The author (*ibid*) describes *research strategy* as a research design incorporating distinct research logic and paradigm that are set to achieve the goal of addressing the clearly identified research problem. Examples of *research strategy* provided by Denscombe (2021) are *surveys*, *case studies*, *experiments*, *ethnography*, *phenomenology*, *life course perspective*, *grounded theory*, *action research*, *systematic reviews* and *mixed methods*. However, the semantics of these terminologies (*research methods* and *research strategy*) become even further equivocal, in the case when Clark *et al*. (2021) define *research strategy* as a general approach to conducting social research and exemplify *quantitative* and *qualitative* studies as two main *research strategies*. The authors (*ibid*) refer to research strategy as a research design and cite the following types as its examples: *experimental* (including quasi-experimental); *cross-sectional* (or survey); *longitudinal*; *case study* and *comparative* research designs, i.e. research strategies.

5.3.1. Main characteristics of research strategies

Different authors suggest different numbers and varieties of research strategies. The earlier work by Bell (1993) mentions *surveys*, *case study*, *experiment*, *action research* and *ethnography* and Yin (1994) cites *surveys*, *experiment*, *archival analysis*, *histories* and *case studies* to be the main research methods or research strategies. More recent work by Saunders *et al.* (2019) cite *experiment*, *survey*, *archival* and *documentary research*, *case study*, *ethnography*, *action research*, *grounded theory* and *narrative query*. Table 5.1 presents some examples of research strategies that are widely used in small scale studies of social science with the description of their strengths and weaknesses. However, the list of research strategies described in the table is only indicative and by no means represent a comprehensive list.

Table 5.1 – Main characteristics of some common research strategies.

Research strategy	Definition and main characteristics	Application example (time required and place it takes)	Strengths	Weaknesses
Ethnography	Study of lives, cultures, lifestyles and beliefs of certain group of people (usually the group that are considered to be exotic, alien or unorthodox) (Saunders *et al.,* 2019).	Long period (overt or covert) observation and data collection in its natural environment (Robson and McCartan, 2016; Fellows and Liu, 2022).	-Direct observation in natural environment provides empirically grounded, rich and detailed study (Collis and Hussey, 2021). -Long observation period sharing circumstances, events and experiences of members of the group (i.e. observees) enables revelation of observees' perspective (thorough witnessing their behaviour rather than accepting their opinion-based responses as data) (Saunders *et al.,* 2019).	-In overt observation, the impact of observer effect, halo effect on observants might change their genuine behaviour and distort the conclusion of the study (Saunders *et al*., 2019; Fellows and Liu, 2022). -In covert observation, obtaining informed consent from observants becomes impossible which raises main ethical concerns (Robson and McCartan, 2016). -Heavy reliance on researchers' interpretation makes the study irreplicable and weakens the validity of research findings (Collis and Hussey, 2021).
Phenomenology	Study of people's everyday experiences that are routine and ordinary and faithful description of subtleties and complexities of that authentic experience (Robson and McCartan, 2016).	Small scale study with particular group whose experiences are being investigated, through an in-depth long interview in the natural setting (Clark *et al*., 2021).	- Had the researchers' interpretation and editing of the data collected successfully kept to minimum, the study can reveal a unique, undiscovered (previously considered to be trivial) details of complex issues of social lives (Denscombe, 2021).	-Suspending researchers' preconceptions and common-sense beliefs is challenging practice to achieve (Robson and McCartan, 2016; Clark *et al*., 2021). -Small number of members included in the study might not be representative sample and hence the study can hardly be considered as generalisable (Denscombe, 2021).
The life course perspective	Study of age and trajectories of individuals' lives in terms of: 1) their stages of life; 2) significant personal or historical events; 3) experiences and decision made in journey through life; 4) biological aging process (Denscombe, 2021).	Large scale or small-scale longitudinal study of individuals (more specifically their age and life journey) through regular series of survey point in extended period of time—combining with other sources of relevant documents (e.g. archival data, official statistics, reports) (Robson and McCartan, 2016).	-The life course perspective is a multidisciplinary, multi-causal approach which encourages to study items/event with holistic point of view including personal and contextual factors (Denscombe, 2021). -Studying age is alternative research to other analyses that focus on the impact of gender, social class and ethnicity in the studies of society (Bengtson *et al*., 2012).	-Large scale longitudinal the life course perspective studies are expensive and time-consuming (Bengtson *et al*., 2012). -Using chronological aging stages (i.e. childhood, adolescence, adulthood and old age) as regular survey points for sequential data gathering can be misleading, since chronological aging stages are not definitive markers of transition between stages (*viz*., stages change in different ages for different people) (Denscombe, 2021).
Grounded theory	An approach dedicated to developing a theory grounded in empirical data of real-world situation that are iteratively collected and analysed until theoretical saturation is achieved (Saunders *et al.,* 2019; Denscombe, 2021).	Small scale, exploratory research that uses qualitative data to study human interaction in particular settings (Denscombe, 2021).	-Flexible design of grounded theory in terms of sampling size, sample selection and data analysis create adaptable approach to discover new theory and explanation of complex interaction-based topics (Robson and McCartan, 2016). -Concepts and theories developed in grounded theory are grounded on empirical data (i.e. real-world phenomenon with sound foundation of evidence) rather than abstract speculation (Saunders *et al*., 2019). -Grounded theory requires a researcher to base their theory building process exclusively on the data (i.e. let the data speak for themselves) rather than relying on the	-Although Strauss's (one of two authors from whose work the grounded theory originated) version of approach to grounded theory is attempting to systematise the data analysis process, ambiguity around reaching theoretical saturation and selection of samples that are purely left on researcher's judgement can prove problematic (for novice user) (Saunders *et al*., 2019; Denscombe, 2021). -The length of time that grounded theory strategy-based study can take becomes unpredictable since it is determined by achievement of theoretical saturation (Denscombe, 2021). -There is the possibility that study based on grounded theory might not generate a viable conclusion or indeed a theory, if the data for

Research strategy	Definition and main characteristics	Application example (time required and place it takes)	Strengths	Weaknesses
			interpretation of the influenced by other known theories. This practice of suspending the role of the researcher and prior known theories enables objective presentation of insights that are gleaned from the data only (Collis and Hussey, 2021; Denscombe, 2021).	sampling is not adequate to reach theoretical saturation (Robson and McCartan, 2016). -Testing the adequacy of data to reach theoretical saturation prior to data analysis is not possible since data collection and data analysis commences almost simultaneously with iteration between two steps (Saunders *et al*., 2019; Denscombe, 2021).
Action research	A strategy that studies practical issues (usually of workplaces) through insider knowledge of participants/practitioners with the purpose of instigating change towards professional (and organisational) improvement (Robson and McCartan, 2016; Denscombe, 2021).	Applied research in the context of workplace and organisational settings (Robson and McCartan, 2016; Collis and Hussey, 2021; Fellows and Liu, 2022).	-Research strategy that is purely focused on producing actionable insights (rather than abstract, theoretical explanations) that drive positive changes by application (Saunders *et al*., 2019; Denscombe, 2021). -The data used in analysis which is based on insider knowledge enables collecting data that are close to reality, while the conclusion and insights drawn from those data are likely to be most relevant and applicable in practice (Robson and McCartan, 2016; Denscombe, 2021).	-The specificity of the findings that are most apposite to the studied setting reduces the generalisability of the research to other instances (Denscombe, 2021; Fellows and Liu, 2022). -Democratisation of research towards practitioners/participants might create ambiguity (or conflicts between a researcher and practitioner/participant) around the selection of data, data collection methods, data analysis techniques, data inclusion criteria where ownership of the research process might become contestable (Robson and McCartan, 2016; Saunders *et al*., 2019).
Systematic review	An approach of generating objective overview of the evidence that is currently available on a specific topic (Saunders *et al*., 2019).	Small scale study on a topic that have considerable body of evidence, i.e. previously conducted studies that share similar premises (research methods, reasoning or themes) (Robson and McCartan, 2016; Saunders *et al*., 2019; Denscombe, 2021).	-The outcome of the study based on systematic review strategy generate practical value for policy makers and practitioners by informing about current state of knowledge (e.g. effectiveness and success rate of innovations or new policy, dissemination of new practice) (Robson and McCartan, 2016). -Adopting Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) checklist in systematic reviews ensures the replicability of qualitative type research by clearly representing the steps taken and selection criteria used (Saunders *et al.*, 2019).	-The dependence on the amount of pre-existing research constrains the applicability of systematic review strategy on the areas that lack adequate numbers of studies (Denscombe, 2021). -Absence of predefined steps as to how to conduct systematic literature review requires researchers to go through long and steep learning curve which may prove/appear complicated and restrictive for novice researchers (Robson and McCartan, 2016).
Experiment	An approach to empirically study the relationship between specific factors under controlled environment by isolating individual variables and observing their effects at length (Robson and McCartan, 2016; Saunders *et al*., 2019; Collis and Hussey, 2021).	Small scale explanatory research with fixed design which focuses on studying associations and relationships of variables in controlled or natural environment (Saunders *et al*., 2019; Denscombe, 2021).	-Control over environment and certain independent variables in experiment strategy allows a high level of precision and consistency (Collis and Hussey, 2021; Denscombe, 2021). -Systematised and precise procedures in laboratory experiments, randomised controlled trials and retrospective experiments makes the research replicable and testable in another study (Robson and McCartan, 2016; Fellows and Liu, 2022).	-Contrived environment created for conducting laboratory experiments can hardly replicate natural occurrence of real-life conditions (Saunders *et al*., 2019; Denscombe, 2021). -Observer effect and halo effect on participants in field experiments might distort the findings (Collis and Hussey, 2021; Fellows and Liu, 2022) -Experiments are limited in application to study underlying causes of many social phenomena, since this strategy focuses on observable effects of relatively straightforward matters (Robson and McCartan, 2016).

Research strategy	Definition and main characteristics	Application example (time required and place it takes)	Strengths	Weaknesses
Case study	An in-depth study of one or small number of events that intends to illuminate general by focusing at the particular case (Yin, 2018; Collis and Hussey, 2021).	Small-scale and intensive study with flexible research design which aims to investigate and generate an account of naturally occurring events (Yin, 2018; Denscombe, 2021).	-Flexible research design in case study strategy allows the use of different variety or number of data analysis and data collection methods that are most suitable for that specific case (Denscombe, 2021). -Increased focus on one instance of case or event enables holistic approach to study and in-depth and detailed analysis which reveal finer subtleties of complex social phenomena (Robson and McCartan, 2016; Fellows and Liu, 2022).	-Gaining access to case-specific documents, settings and people in data collection stage is a demanding part of case study strategy (Saunders *et al.,* 2019; Collis and Hussey, 2021). -Determining the criteria for data inclusion in case study strategy can be a challenging task, since the boundaries of the case are not neatly predefined (Collis and Hussey, 2021). -Findings of case study cannot be easily generalisable to other studies due to their case specific nature (Robson and McCartan, 2016; Denscombe, 2021).
Survey	A broad and extensive study of phenomenon through seeking information from close to source, relevant people and sites (Collis and Hussey, 2021; Denscombe, 2021).	Large or small-scale research with wide and inclusive coverage that aims to provide a snapshot of empirical evidence at a current state of affairs (Robson and McCartan, 2016; Fellows and Liu, 2022).	-Data collected from direct source of information (i.e. relevant people and sites) makes the outcome of such strategy empirically sound that reflects close-to-reality insights (Robson and McCartan, 2016). -Survey strategy is equally suitable for collection of both qualitative and quantitative type data by using interviews and self-completion questionnaires respectively (Denscombe, 2021; Fellows and Liu, 2022).	-Data collection stage in survey is the most laborious and challenging part which involves multiple steps (e.g. locating research population or sampling frame, selecting participants through sampling, recruiting participants, constructing questionnaires or interview questions, setting arrangements for data collection) (Collis and Hussey, 2021; Denscombe, 2021). -The requirement to use sampling for data collection in survey strategy creates another level of quandary (in terms of samples size or samples selection techniques) and credibility concerns (such as sampling error, sample bias) (Denscombe, 2021; Fellows and Liu, 2022).
Mixed methods	A strategy that allows selecting and combining different types of strategies, data analysis methods or data types that are complementary to each other (Denscombe, 2021; Fellows and Liu, 2022).	Small scale study with flexible research design which aims to generate problem-driven and practical knowledge through the combination of research tools that are the most apposite to research problem (Robson and McCartan, 2016).	-Mixed method approach enables triangulation of methods and/or types of different data which respectively increases validity of findings and creates more comprehensive account of phenomenon being investigated (Robson and McCartan, 2016; Clark *et al.,* 2021). -Combining different research strategy or methods in single study allows harnessing the strengths of those combined research strategy or methods while each of them cancelling out other's weaknesses reciprocally (Clark *et al*., 2021; Denscombe, 2021).	-The process in mixed methods strategy can be time-consuming for following reasons: combining different source and types of data in single study will increase the workload of data collection; the same data will be analysed through different data analysis methods on different phases; and in case the findings of different data analysis methods do not corroborate one another, the research will involve the need to be extended (Robson and McCartan, 2016) - The combination of different methods and strategies can become arduous process since it requires to have knowledge about: suitability of the methods and strategies to the research problems; the strengths and weaknesses of each method and strategy to be adopted; and the compatibility of selected methods and strategies with each other (Robson and McCartan, 2016; Denscombe, 2021).

As Table 5.1 indicates, every strategy bears some inherent strengths and weaknesses which prompts that no one strategy is superior or inferior to other (Denscombe, 2021). Instead, strategy selection must be guided by the fitness of a particular strategy for a specific research question(s) and problem(s) which results in coherent research design (Saunders *et al*., 2019; Collis and Hussey, 2021).

For example, *ethnography* (as a research strategy) aims to study the lives of groups of people and their culture which requires considerable time spent amongst the group in extended fieldwork (Saunders *et al*., 2019; Denscombe, 2021). This long time period spent within the community being investigated enables: generation of thick description of the topic investigated (Fellows and Liu, 2022); and revelation of closest to reality perspectives of people being observed (Robson and McCartan, 2016). Saunders *et al.* (2019) differentiates three types of ethnography based on the role of researchers and their relationship with ethnographic group they are studying. The first type is the *realist ethnography* – the strategy where a researcher strives to maintain objectivity through factual reporting of customs, practices, routines and norms within studied group that is described as subjects (Saunders *et al.,* 2019). Whereas the *interpretive ethnography* strategy is concerned about interpretation and multiple meanings of observed structures in the studied group of people whom a researcher treats as participants rather than subjects (Robson and McCartan, 2016; Fellows and Liu, 2022). *Critical ethnography* is the third type of *ethnography* strategy that adopts an advocacy role by studying the power dynamics within the group and strives to instigate a change for betterment of marginalised minorities in that group (Saunders *et al*., 2019; Denscombe, 2021).

In contrast to *ethnography* which focuses on exotic or alien features of people's lives, *phenomenology* is concerned with routine and ordinary sides of social life (Denscombe, 2021). Examples of subjects that can be studied through *phenomenology* strategy are experiences of homelessness, being bullied, dealing with a divorce, adoption of child, management of work-life balance or coping with physical disabilities (*ibid*). *Phenomenology* is a study of human experience which attempts to gain insights based on participants' perspective with as little interpretation of the researcher as possible (Robson and McCartan, 2016). Therefore, researchers need to suspend their: preconceptions about the nature of thing being studied (Denscombe, 2021); presuppositions drawn from existing theories (Clark *et al*., 2021); or any predispositions towards their own experience or common-sense beliefs to describe the essence of authentic experiences (Robson and McCartan, 2016). This practice of bracketing off the ‘self’ of the researcher, referred as *epoche* (which means suspension of judgement), is the strength of *phenomenology* strategy (Clark *et al*., 2021; Denscombe, 2021). Achieving *epoche* can be a challenging practice where a researcher should strive to deliver the obtained data in an impartial manner (*ibid*).

The life course perspective is a research strategy that studies people’s journey through life from birth to death with particular focus on the age of people in terms of four strands or factors impacting the life course (Robson and McCartan, 2016; Denscombe, 2021). The first strand to *the life course perspective* is *stages of life* that attempts to study the structure of life, social norms in terms of different biological stages of life (such as childhood, adolescence, adulthood and old age) (Denscombe, 2021). The second strand is *life events* which focuses on the impact of a particular era they were born in and historical life events (such as political upheaval, economic recession, predominant illness or war) in the shaping of individuals’ lives (*ibid*). The last two strands of studying the life-course of individuals are based on a *journey through life* which studies the influence of past experience and decisions taken and *aging process* that concerns with effects of mental and physical changes that comes with aging on lives of people (Bengtson *et al*., 2012). All three alluded strategies (cf. *ethnography*, *phenomenology* and *the life course perspective*) have already predefined objects (group of people, experiences and age respectively) for study. However, not all research strategies are constrained to study one particular object but can be applied to many areas based on the suitability of research strategy with the research question and study’s aim. Examples of such strategies are *grounded theory*, *action research*, *systematic reviews*, *experiment*, *case study* and *surveys*.

Grounded theory, as the name indicates, is a strategy that attempts to construct a new theory and concept based on the data that are grounded in real-world empirical data (Robson and McCartan, 2016). However, the phrase grounded theory is also used to refer to a data analysis method, *viz.*, the processes of grounded theory can be used as a separate data analysis method in any qualitative research strategies or as a standalone research strategy (Robson and McCartan, 2016; Saunders *et al*., 2019). Similar to this, another research strategy known as *narrative inquiry* also denotes a data analysis method which is the process of enquiring phenomena as a complete story with the purpose of preserving the chronological connections and sequencing of events as told by a narrator (Saunders *et al*., 2019).

The range of topics or study objects to be researched using *grounded theory* is multifarious, but this strategy is most suitable to the area of study that involves complex human interactions (Saunders *et al*., 2019; Denscombe, 2021). The purpose of *grounded theory* strategy is to generate a theory which is grounded in the data collected through an iterative process of coding, categorising and merging concepts (Robson and McCartan, 2016; Collis and Hussey, 2021). As an outcome, these concepts engender a theory which enables explanation of complex social phenomenon (Robson and McCartan, 2016; Fellows and Liu, 2022). However, the significant difference of *grounded theory* strategy from other research strategies is that data collection and data analysis stages take place simultaneously rather than sequentially (Collis and Hussey, 2021). The data collection process is stopped only when data being collected ceases to produce any new knowledge or concept, the stage known as *theoretical saturation* (Saunders *et al.,* 2019; Fellows and Liu, 2022).

Similarly, *action research* is an approach or strategy used to study the complexity of human interaction but with the specific purpose of instigating a change within the studied setting (which is commonly in workplace and other organisational settings) (Saunders *et al*., 2019; Denscombe, 2021). There is another version of *action research*, called *participatory action research* which reflects the importance of practitioner participation in the study, that is people who are actually engaged with the work that are subject to change due to this strategy (Robson and McCartan, 2016; Collis and Hussey, 2021). However, Denscombe (2021) differentiates the *action research* and *participatory action research* in a way that former focuses on practical issues in the workplace whereas latter is concerned with policy issues (such as problems with public health, minority rights and literacy) in community which requires the participation of the people who are adversely affected by those issues. The *action research strategy* attempts to achieve the change by cyclical process of referring to initial findings, generating possibilities for change, implementing the change and evaluating the impact of the change and based on the feedback received at the first implementation adopt the second cycle of same steps (Saunders *et al*., 2019; Fellows and Liu, 2022). Therefore, research process in *action research* strategy is emergent and iterative, where with every iteration the focus of research question can change in accordance with findings of previous cycle (Robson and McCartan, 2016).

A *systematic review* strategy is a study of a specific topic in order to reveal its state of current knowledge through: a search of relevant literature using systematic and explicit methods (Clark *et al.,* 2021); a review of the findings of those selected literature with explicit criteria (Robson and McCartan, 2016); and a conclusion based on objective analysis of existing data in those literature (Denscombe, 2021). This strategy adopts such a research design that is systematised and replicable where the outcomes of such data analysis become testable (Clark *et al.,* 2021). A *systematic review* strategy is most applicable for the research topics that have been researched extensively and the literature on that topic has adequate amount of already conducted studies that share similar topic, research methods or research reasoning (Robson and McCartan, 2016). This strategy is comparable with another strategy that Saunders *et al*. (2019) refer as *archival and documentary research* strategy. *Archival and documentary research* strategy generically denotes the study of wide range of secondary type data which might include: media documents, administrative records (i.e. meetings, contracts, memos and strategy statements) of organisation; individual records (i.e. diaries, notes); records of group communication (i.e. emails, media or blog posting); government documents such as publications, reports and data on statistics; and visual and audio documents (in the form of audio-visual communication, advertising posters, photographs and other artefacts) (Robson and McCartan, 2016; Clark *et al.,* 2021). Although these documents represent a rich source of data, Saunders *et al*. (2019) warn about the suitability of such sources for research purposes by questioning the rigorousness, structure, completeness and quality of such data, since these secondary data are not originally created for research purposes. However, a *systematic review* specifically focuses on publications such as articles and research papers, conference papers and reviews that, although considered to be a secondary data source, are generally produced for research and knowledge generation purposes (rather than mere record-keeping) and commonly undergo the practice of peer-review prior to publication (Robson and McCartan, 2016). Therefore, *archival and documentary research* strategy is more likely to be related to *case study* research strategy that studies a specific case when a study includes the documents that are generated for recording-keeping purpose, whereas using documents of publication that are contributed towards specific research area and literature is more likely to be resonated with *systematic review* strategy (Fellows and Liu, 2022).

A *mixed method* is a research strategy where different research designs, research strategies, data types or data analysis techniques are combined and used within a single study (Clark *et al.,* 2021). The notable strength of *mixed methods* strategy is its flexibility around selection and combination of different research methods, data types and sources (Robson and McCartan, 2016; Fellows and Liu, 2022). This feature of *mixed methods* enables: generation of more complete account of investigated topic by combining different data types and sources (Clark *et al.,* 2021); and validation of research findings and improvement of accuracy by analysing the same subject through different data analysis methods (Saunders *et al.,* 2019). Therefore, this strategy is known as a problem-driven approach which aims to select the most apposite research methods for research problem (Clark *et al.,* 2021; Collis and Hussey, 2021). Studies based on a *mixed method* strategy commonly entail more than one phase of data collection or data analysis, where one phase subsequently informs and directs the next phase (Saunders *et al*., 2019; Fellows and Liu, 2022). However, Denscombe (2021) cites other varieties of research design based on *mixed method* strategy, namely research designs constructed according to their: 1) sequence, *viz*., sequential and simultaneous mixed method design; 2) relative importance, *viz*., equivalent, dominant and less dominant status mixed method design. Similarly, Saunders *et al*. (2019) classify mixed method studies into: 1) single phase or concurrent research design; and 2) double phase research design, *viz.,* sequential exploratory, sequential explanatory; and sequential multi-phase research design.

5.3.1.1. Experiment as research strategy

Experiment is an investigation of relationship of specific factors by isolating individual variables and meticulously observing their effect under controlled conditions (Gillham, 2000; Collis and Hussey, 2021). This way of generating knowledge has its roots in natural sciences where studies are conducted in laboratories (i.e. controlled environment) by manipulating independent variable to observe its impact on dependent variable (Robson and McCartan, 2016; Saunders *et al*., 2019). *Independent variable* is a variable that a researcher changes to measure its impact on observed outcome, which is known as *dependent variable* (Collis and Hussey, 2021; Denscombe, 2021). An *experiment* uses hypothetical explanations or assumptions (otherwise known as *hypothesis*) rather than research question, to identify causal relationships between two or more factors (Saunders *et al*., 2019; Denscombe, 2021). Therefore, studies based on *experiment* research strategy are well suited for *explanatory* type research where the research aim is to test hypothesised explanation or predicted outcome and to identify exact cause of observed outcome by introducing or excluding certain variables (Robson and McCartan, 2016; Denscombe, 2021). To select the *experiment* as the main research method of a study, existing knowledge in the field of investigated phenomenon must be well established, so as to allow the formulation of hypothesis and deliberate selection of factors that are known to be relevant and significant (Saunders *et al.,* 2019; Denscombe, 2021). For this reason, *experiments* are not appropriate for *descriptive* or *exploratory* studies (Fellows and Liu, 2022). Another prominent feature of *experiments* is their association with quantitative type data rather than qualitative data (Robson and McCartan, 2016). Since *experiments'* main process is to control variable and intricately measure occurring changes through statistical analyses, *experiment* research strategy uses quantification of data and generates an outcome that is numerical (Robson and McCartan, 2016; Collis and Hussey, 2021). Therefore, *experimental* research design is known as a signpost of trustworthiness and robustness due to its: tight control over independent variables that are causing the outcome being observed; and ability to measure the outcome (*dependent variable*) objectively, precisely and consistently (Robson and McCartan, 2016; Fellows and Liu, 2022).

5.3.1.1.1. Types of experiment

Despite the features of *experiments* that are seemingly over-restrictive in terms of design and process of analysis, the application of *experiments* in psychological and social science is feasible and regarded as the most scientific and credible approach to research (Clark *et al*., 2021; Denscombe, 2021). However, all mentioned features of *experiments* may vary in different types of experiment. The *experiment* that is conducted in controlled environment where the variables can be manipulated is referred to as a *laboratory experiment* type (Collis and Hussey, 2021). *Laboratory experiments* by their nature are conducted on site (rather than in field or real-world setting) and people or items being observed come to the laboratory (Robson and McCartan, 2016; Denscombe, 2021). Contrived settings created in laboratories enable precision and consistency of the observation and close control of variables by eliminating other causal factors (Robson and McCartan, 2016; Collis and Hussey, 2021). However, there is a significant drawback to *laboratory experiment;* the natural occurrence of 'real' life conditions can be hard to replicate in laboratories (Robson and McCartan, 2016). Therefore, *laboratory experiments* must be checked against ecological validity (Robson and McCartan, 2016; Denscombe, 2021). *Ecological validity* here denotes how well the artificial conditions in laboratory replicate the real context (Clark *et al.,* 2021; Fellows and Liu, 2022).

In contrast to *laboratory experiment*, *field experiment* takes place in real settings such as offices, schools, factories, hospitals or construction sites (Robson and McCartan, 2016). Therefore, this 'out of the laboratory' experiments, otherwise known as *quasi-experiments,* are more common in social sciences and related subject fields (Robson and McCartan, 2016; Fellows and Liu, 2022). *Quasi-experiments* or *field experiments* possess some (but not all) experimental characteristics. Although, the ability to control variables and environment is limited in *field experiments*, a researcher can manipulate (to a limited extent) certain key variables by introducing them to or excluding them from the observed field and measure their impact (Robson and McCartan, 2016). These variables introduced into the field can be a new process, new technique, rule or new technology, whereas excluded variable from the field observed can be any adversary conditions such as eliminating noise, shortening long working hours (Saunders *et al*., 2019). *Field experiment* is the opposite of *laboratory experiment* in a way that in *field experiment* the environment is the real condition that was not created for research's sake and therefore, studies within *field experiment* design do not raise *ecological validity* concerns (Robson and McCartan, 2016; Clark *et al.,* 2021).

Two other types of experiments namely *natural experiment* and *retrospective experiment* are similar to the *field experiment*, conducted in their real settings (Denscombe, 2021). The *natural experiment* takes place in naturally occurring events and circumstances (e.g. economic recession, poverty or smoking habit) which provide a researcher with the opportunity to observe and measure the effect of isolated variables through circumstances as they happen and explain the causes of that phenomena (Clark *et al.,* 2021; Denscombe, 2021). Whereas the *retrospective experiment* commences with the effect or the outcome of certain event and attempts to identify the possible cause of that outcome by tracing back to the origin (Denscombe, 2021). Another type of experiment, known as *randomised controlled trials* (RCTs) is an experiment that entails measuring the effects of specific 'treatment' in accordance with experimental and control groups (Robson and McCartan, 2016; Clark *et al.,* 2021). Random allocation of participant to two groups ensures there is no difference between the groups. This type of experiment is also known as *classical experiment* (Saunders *et al*., 2019; Clark *et al.,* 2021).

5.3.1.2. Case study as research strategy

A *case study* strategy is an in-depth account of events, experiences, relationships or processes occurring in that specific event which aims to illuminate the general from particular (Gillham, 2000; Yin, 2018; Saunders *et al*., 2019; Clark *et al.,* 2021; Denscombe, 2021). The case here denotes a naturally occurring phenomenon that exists before the research and continues to exist after the research project finalised (Robson and McCartan, 2016; Yin, 2018; Denscombe, 2021). The case is the basis of *case study* strategy and hence, for any event to become a valid case, it has to be a self-contained entity that has fairly distinctive boundaries (Saunders *et al*., 2019; Denscombe, 2021). In other words, a valid case being studied must be representative of a broader category of other cases and must have a common feature with other instances in that category (Gillham, 2000; Robson and McCartan, 2016; Collis and Hussey, 2021). For example, a study of events (such as riots, strikes or ceremonies), organisation (such as hospital, school), location (such as accident hotspot, traffic congestion on road), process (such as recruitment procedure, contractor selection steps) or policy (such as change to safety prevention measures, new health intervention) are instances suitable to be used in *case study* research strategy (Robson and McCartan, 2016; Clark *et al.,* 2021; Denscombe, 2021; Fellows and Liu, 2022). Therefore, a case for *case study* strategy is not selected based on a randomisation principle, but rather deliberately chosen on the basis of its known distinctive feature (Yin, 2018; Denscombe, 2021).

Unlike the *experiment* research strategy which focuses on the isolated factors causing the outcome, *case study* research strategy adopts a holistic view to provide an in-depth study of one particular event in one setting by using multiple sources of data that can be quantitative, qualitative or a mixture of both (Saunders *et al*., 2019; Denscombe, 2021; Fellows and Liu, 2022). These features of case study research strategy enable the use of *case studies* for both *inductive* and *deductive reasoning* type studies which can be of *exploratory*, *descriptive*, *explanatory, predictive* or indeed *evaluative* purpose type (Yin, 2018; Saunders *et al*., 2019). *Inductive* reasoning-based case studies allow the identification of new intricate details of certain phenomenon and provide description, comparison and explanation of that particular event (Collis and Hussey, 2021; Denscombe, 2021). This discovery-led application is the most predominant use and purpose of *case studies* which generates *exploratory* and *descriptive* research types (Collis and Hussey, 2021; Fellows and Liu, 2022). Although less common, case studies are used to test a theory in *deductive reasoning* type studies (Yin, 2018; Saunders *et al*., 2019). In this theory-led application of case study strategy, the purpose of study is to test whether a particular theory can be applied in real settings and to demonstrate its value for application (Clark *et al*., 2021; Fellows and Liu, 2022). However, case study is not restricted to only one of the applications, but rather case study might have more than one purpose (e.g., for *descriptive*, *exploratory* or *explanatory* research) and can adopt any research reasoning (*inductive*, *deductive* or *abductive*) to generate a new knowledge (Yin, 2018; Fellows and Liu, 2022).

All these alluded features of case study strategy (e.g. flexible research design, leeway to use multiple methods and multiple data types, holistic explanation of the phenomenon) highlight the advantages of adopting case study as the main research strategy (Clark *et al.,* 2021; Fellows and Liu, 2022). However, when adopting a case study as the research strategy, there are some considerations to include that might impede the success of such an approach (Gillham, 2000;

Yin, 2018). Examples of the difficulties in using case study approach on its different stages are: 1) defining the boundaries to the case at case selection step (Denscombe, 2021); 2) gaining access to documents, people or location at data collection step (Collis and Hussey, 2021); or 3) producing generalisable findings at the final stage of the research (Saunders *et al.,* 2019).

5.3.1.3. Survey as research strategy

A *survey* is a form of enquiry that aims to comprehensively study a phenomenon by seeking information from relevant people and sites (Robson and McCartan, 2016; Denscombe, 2021). Compared to the *case study* strategy which is an intensive and in-depth study of a phenomenon, *survey* research design focuses on extensiveness and breadth of coverage and provides a snapshot of the observed event rather than tracing the event over time (Denscombe, 2021; Fellows and Liu, 2022). Examples of using a *survey* as research strategy are to study: voting behaviour; consumer preferences; product evaluation; service rating or customer satisfaction (Robson and McCartan, 2016). Surveys as a research strategy is most appropriate for *exploratory* and *descriptive* studies and permits collection of quantitative data that can be analysed through descriptive and inferential statistics (Saunders *et al*., 2019).

Types of *survey* research strategy are classified based on the techniques used to communicate with participants and collect data. Postal survey, face-to-face survey, phone survey, group-administered survey, email survey, web-based questionnaire, social media survey are examples of survey types (Robson and McCartan, 2016; Collis and Hussey, 2021). A *postal survey* is used in a large-scale survey covering a wide geographical area when the research population (identified by respondents' names and addresses) are accessed through mail (Robson and McCartan, 2016). However, there are number of considerations that must be taken into account when *postal survey* is selected *viz.*: 1) time delay involved in turn-round time due to time-consuming posting and returning process (Denscombe, 2021); 2) costs associated with printing, packaging, posting and providing stamped addressed envelope for the return (Saunders *et al*., 2019); 3) low response rate due to absence of person-to-person interaction (Robson and McCartan, 2016). Response rate is the level of success that data collection method achieves in obtaining replies from initially contacted potential respondents (Collis and Hussey, 2021).

Similarly, *email surveys*, *internet* or *web-based surveys* and *social media surveys* are based on the distant interaction of a researcher and respondents via emails, online survey software (such as SurveyMonkey, Microsoft Forms, Survey Planet, Zoho Survey and Google Forms) and social media platforms (such as Twitter and Facebook) respectively (Denscombe, 2021). All these three types of surveys are advantageous in terms of providing cost-effective access (e.g. mostly no cost or with little fee for software usage) and instant contact to respondents (Saunders *et al*., 2019; Fellows and Liu, 2022). However, due to the distant interaction of researcher and respondents in all three alluded survey types, the collection of responses does not happen instantaneously (*ibid*). Nevertheless, as Denscombe (2021) states taking following steps can significantly help to speed the turn-around time and improve the response rate: making the topic interesting and conspicuous; gathering respondents' agreement to participate with prior invitation; selecting respondents who are potentially interested in the topic of research; highlighting the importance of respondents' contribution; instilling trust by detailing the legitimacy of the research; and re-contacting and sending reminders for non-responses.

On the other hand, *face-to-face survey* and *group-administered survey* have the benefit of conducting the survey in person which enables a higher response rate, but the expenditures related to travel and researcher time to personally meet respondents make these survey types costly (Robson and McCartan, 2016). However, a *phone survey* is a well-established alternative to *face-to-face* and *group administered survey*, which allows convenient and timely access to participants without the need of travelling and permits to collect instantaneous responses (Denscombe, 2021). Moreover, emergence of smart phones (instead of landlines) has extended the range of possibilities for the *phone survey* (Fellows and Liu, 2022). Interaction in *phone surveys* can be enhanced through video calls (using apps such as WhatsApp, Duo or Facetime) which is equivalent to face-to-face interaction, whereas multimedia features that enable to exchange images and videos make respondents experience more interesting and immersive. All alluded survey types enable collection of standardised (mostly quantitative data) responses that are collected through questionnaires (Saunders *et al*., 2019). However, surveys can also be conducted through interviews, in which case the data collected will be of qualitative type and not as standardised as in questionnaires (Collis and Hussey, 2021).

5.4. RESEARCH METHODS FOR DATA COLLECTION

Data collection methods are tools for gathering facts and evidence about the topic being investigated. Types of data collection methods are multifarious, each with their own strengths and weaknesses that can be used to meet the requirements of specific research design and research question (Saunders *et al.,* 2019). Therefore, one data collection method is not superior to other but rather, the selection of data collection tools must be made based on their suitability with the selected research strategy, adopted research design and research question. Similarly, the selection of data collection tools is not mutually exclusive and hence, more than one tools for data collection can be combined in one study using mixed methods or triangulation approach (Robson and McCartan, 2016; Clark *et al.,* 2021).

Another important point to highlight is that definitively classifying data collection methods as quantitative and qualitative types is misleading, since it stems from erroneous association of certain data collection tools with sole quantitative or qualitative data type collection (Denscombe, 2021). Therefore, this classification is actually related to the data types that are being collected not the data collection tools *per se* (*ibid*). Moreover, despite the fact that certain data collection tools are better suited for quantitative or qualitative types of data, all data collection methods are feasible for collection of both data types (with only few exceptions) (Robson and McCartan, 2016). As an example, a questionnaire data collection method is equally effective to collect quantitative and qualitative type data through variation of close-ended and open-ended questions respectively.

5.4.1. Characteristics of data collection methods

Data collection methods are broadly classified into *reactive* and *non-reactive* methods based on respective overt and covert approach to collecting data (Robson and McCartan, 2016; Denscombe, 2021). Questionnaires, interviews and (overt) observations are *reactive* data collection methods that directly collect data from participants (Denscombe, 2021). In *reactive methods* of data collection, since researchers are openly collecting data from participants by listening, watching or recording, ethical issues on interaction of a researcher and participants is relatively minimal (given that prior informed consent are obtained from participants) (Saunders *et al.,* 2019; Denscombe, 2021). However, the flipside of this advantage is that in the *reactive* data collection approach, participants become more prone to what is called an *observer effect* (*ibid*). *Observer effect* is an impact of a researcher on participants, when people (participants) knowing that they are being observed are not acting as genuinely or accurately (usually becoming more self-conscious and anxious) as they would be on normal occasions (Robson and McCartan, 2016; Denscombe, 2021). This is similar to *interviewer effect* which occurs in interview data collection method. Another drawback of open data collection is known as the *halo effect*, when participants enjoy being the subject of special attention, that they act with enthusiasm and motivation that are atypical from normal conditions/occasions (Denscombe, 2021).

Then there is the impact of *self-fulfilling prophecies* on overt data collection; an occasion when participants are aware (or they believe they are aware) of the true purpose of the study, that with the intention of helping the researcher, they alter their behaviour taking directly that purpose of the study into account (Saunders *et al.,* 2019). Participants verbalise or act indifferently only to demonstrate what they think is expected of them (Denscombe, 2021). Therefore, all these effects impacting participants behaviour in *reactive* data collection methods must be considered and minimalised as far as practically possible.

Non-reactive data collection methods, on the other hand, are indirect or unobtrusive manner of collecting data that helps to avoid the effects the researcher might exert on participants' behaviour as in open data collection methods (Robson and McCartan, 2016). *Non-reactive* data collection methods are broadly categorised into three ways of data collection, *viz.*, 1) following traces; 2) studying documents, images and artefacts; 3) covert observation (Saunders *et al.,* 2019). Following traces are performed through studying the digital footprints of the people the researcher wants to include as participants. 'Following traces' refers to using online sources about the participants' activities (such as history of purchase or log in time in social media account) as and evidence to deduce the information that a researcher wants to collect from participants. Similarly, 'studying documents, images and artefacts' provides direct evidence of people's activity, their belief, culture and behaviour. These artefacts can be in the form of texts, documents, forms or visual images. Third way of non-reactive data collection, 'covert observation', enables real time observation of events and people in indirect covert manner (Robson and McCartan, 2016). This can be performed through *remote observation* and *participant observation*. *Remote observations* are conducted at a distance to study people and their behaviour in public which can involve secret observation (e.g. through one way mirror) to prevent the observer to be noticed by participants. Whereas, in *participant observations* researchers actively participate in pertinent settings, but hide their true purpose, observing and recording their interested data in clandestine manner (Saunders *et al.,* 2019).

However, despite the benefits of *non-reactive* data collection methods in eliminating the factors influencing participants' behaviour, the major issue of ethical considerations arises when a study is conducted without prior explicit consent of participants (Robson and McCartan, 2016). First, in a covert manner of collecting data, obtaining informed consent from participants becomes impossible. Second, the principle of participants' privacy becomes infringed. Whether participants are secretly observed, their digital footprints are traced or the documents, artifacts and other records with personal details are studied, the privacy of participants are invaded even if the data are anonymised (Saunders *et al*., 2019). Therefore, the trade-offs between benefits and issues of both *reactive* and *non-reactive* data collection methods need to be thoroughly weighted when selecting data collection methods.

5.4.2. Observation as data collection method

Observations are data collection method that relies on eye-witnessing of direct evidence and recording of people's behaviour in given setting (rather than recording what respondents say what they do) by a researcher (Saunders *et al*., 2019). However, a significant drawback associated with *observation* data collection method is the reliability of data, namely the potential difference in data collected by different researchers (Denscombe, 2021). Therefore, the possibility of different researchers' perception, their prior knowledge and world view to influence the data collection must be incorporated into research planning to be mitigated (Clark *et al.,* 2021).

5.4.2.1. Types of observations

Systematic (or structured) observation is one way of mitigating this impact (i.e. bias that a researcher subconsciously might render on data collection) by applying certain structures to observational data collection (Robson and McCartan, 2016; Clark *et al.,* 2021). *Systematic observation*, as the name suggest, is a data collection method that introduces a system which aims to make the data collected consistent between observers by eliminating psychological and personal factors of each observer (Saunders *et al*., 2019; Denscombe, 2021). To eliminate the factors emanating from individual researcher, systematic observation adopts an approach known as *observation schedules* (also called *coding schedules* (Saunders *et al.,*2019) or *coding schemes* (Robson and McCartan, 2016)) (Denscombe, 2021). *Observation schedules* are a predefined list of: 1) the same and exact observation time for every researcher (to ensure that every researcher is recording the same event at the same time) (Clark *et al.,* 2021); 2) exact item/ event to be observed (to enable consistency of format and details of data recorded) (Denscombe, 2021); and 3) how those items/events to be measured (Robson and McCartan, 2016). *Observation schedules* ensure that all the observers are following the same activity and looking out for the same item which enables them to measure and record in a systematic and standardised way (Saunders *et al*., 2019). As a result, with the help of *observation schedules*, *systematic observation* minimises the impact of individual researcher's memory and perception, whilst maximising inter-observer reliability (also called inter-rater reliability)

(Robson and McCartan, 2016). Following these pre-set instructions (e.g. tables of features to look for, frequency of events occurrences to count) *systematic observation* generates data that are of quantitative nature (i.e. counts, amounts, frequency or duration of events), the data that are consistently and objectively recorded (Saunders *et al.,* 2019). However, it is a good practice to combine these quantitative records with individual supplementary field notes that are of qualitative nature (e.g. description of context or individual researcher's impression about the circumstances).

Another type of *observation* data collection method is *participant observation*. The significant differences of *participant observation* from *systematic observation* are that the former: 1) enables qualitative data collection that are about the lifestyles, cultures and beliefs of people being observed (Clark *et al.,* 2021); and 2) requires for the researcher to participate in the observed setting, rather than passively observing from the touchline (Collis and Hussey, 2021; Denscombe, 2021). These features of participant observation demand devotion of considerable amount of time and commitment, since the longer the researcher participates and stays as part of the setting, the richer and more in-depth insights will be gained from the data collection (Robson and McCartan, 2016). The focus of *participation observation* on gaining insider perspective (to study cultures, beliefs and lifestyles) makes this data collection method better suited for *phenomenology* research strategy (Saunders *et al*., 2019); whereas the capacity to study the meaning behind observed people's actions for a reasonable time period in natural setting makes *participant observation* appropriate data collection method for *ethnography* research strategy (Denscombe, 2021; Fellows and Liu, 2022).

Saunders *et al.* (2019) classify the *observation* data collection method into three groups, adding *internet-mediated observation* to the previous two types of observation. *Internet-mediated observation* is an observation taking place in virtual setting, when researcher observes activities, behaviour or social interactions of groups in social networks, internet forums and virtual world by becoming a member or a guest of that online community (*ibid*). The internet as the data source in *internet-mediated observation* allows access to a large quantity of archived data from past social interaction of people in a group which is known as asynchronous or delayed time collection of data (Clark *et al.,* 2021). In the same way, the researcher is able to interact and collect data in real time using synchronous text or live video. The authors (Saunders *et al.*, 2019) also mention that *internet mediated observation* can be applied as *participant observation* (cf. *internet mediated participant observation*) and *structured* *observation* (cf. *internet mediated structured observation*) which allows using advantages of both observation types but in online setting.

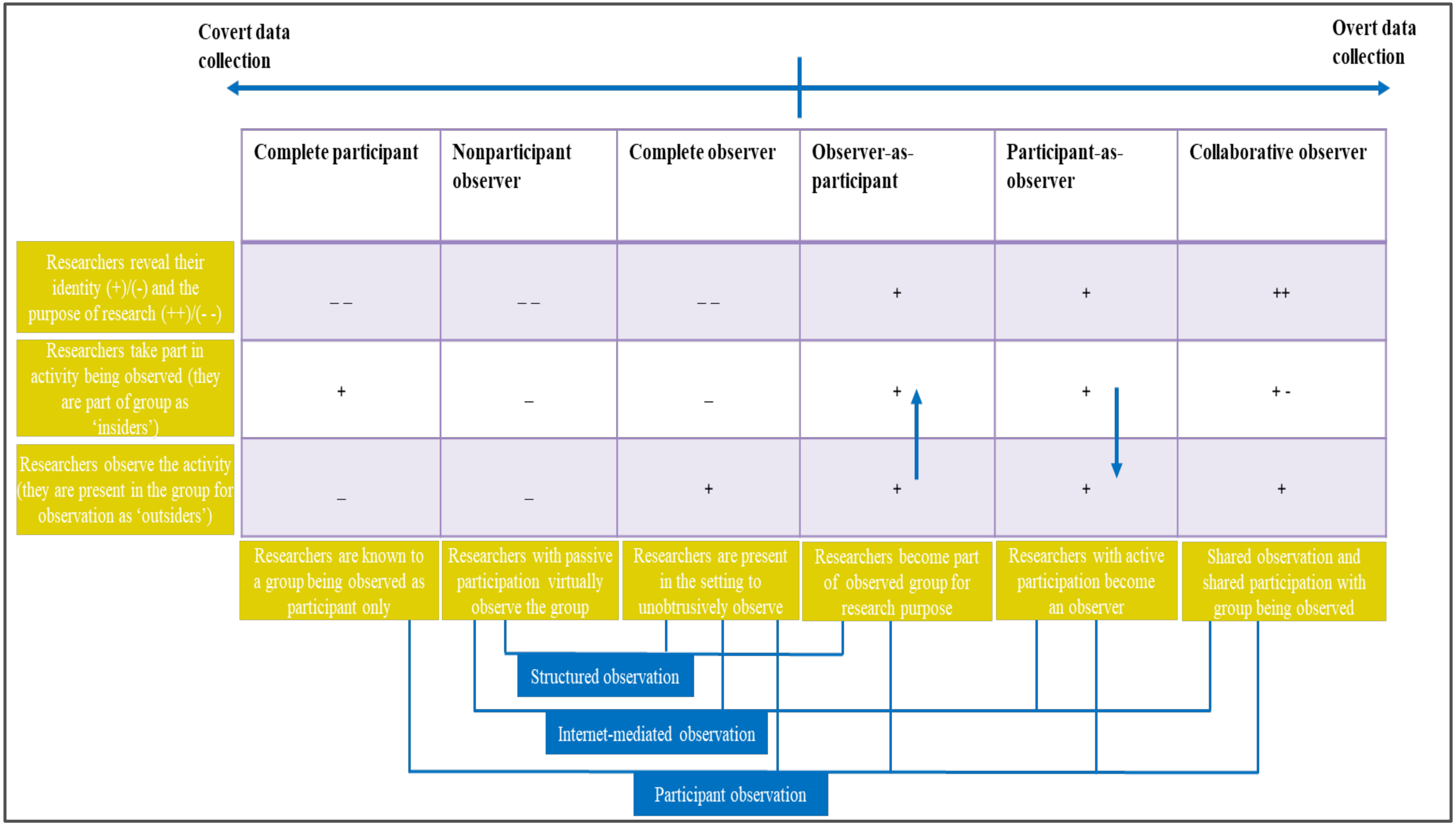
5.4.2.2. Participation and role of researcher in observation

Participation of the observer in this data collection method can vary based on the extent of information revealed (to the people being observed) about the presence and role of the researcher (Saunders *et al*., 2019; Clark *et al.,* 2021; Denscombe, 2021). The evidence or event being recorded is taking place in natural settings, 'in the field' (as well as in virtual environment as described in *internet-mediated observation*) that can be observed in an open or overt manner as well as secret or covert way (Clark *et al.,* 2021; Collis and Hussey, 2021). All the issues and characteristics of overt and covert data collection methods (i.e. advantages and disadvantages stated previously) similarly apply to observations and hence, must be taken into consideration in the research process.

There are four main varieties of participation/role of researcher in data collection such as, *total* (or *complete*) *participant*, *participant-as-observer*, *observer-as-participant* and *total* (or *complete*) *observer* (Robson and McCartan, 2016; Saunders *et al.,* 2019). Figure 5.2 outlines some key characteristics of those four main participation types along with other less known two types such as, *collaborative observer* and *nonparticipant observer*. The infographic in Figure 5.2 also describes these six types of participation on the spectrum from covert to overt data collection, whilst highlighting the level of participation and observation in each type.

In *total participant*, the researcher's role is kept completely secret, where a researcher assumes the role of a certain person who are normally part of that setting (or already is fully participating in given social setting) and observes behaviour, interaction or event in covert manner (Robson and McCartan, 2016). *Total participant* eliminates the *observer effect* (along with other impacts such as *halo effect* and *self-fulfilling prophecy*) while conserving the naturalness of the setting, since informants are not aware of them being observed (Saunders *et al*., 2019). On the downside of this advantage, obtaining the informed consent from the people being observed becomes impossible, which raises ethical concerns (Robson and McCartan, 2016). Similar to this covert approach, in data collection as a *nonparticipant observer* and *complete observer,* a true identity of researchers (and their purpose of observing) will be concealed from the people being observed.

Figure 5.2 – Key characteristics of different roles of a researcher in observation data collection method.



However, *observer-as-participant*, *participant-as-observer* and *collaborative observer* are complete opposite of covert data collection. In overt data collection methods, a researcher's role is openly introduced to the people in the setting, which enables gaining informed consent from the people observed (Robson and McCartan, 2016). Therefore, in all three types of researchers' role on overt side of data collection, ethical issues will be eliminated but at the cost of introducing the issues of data reliability and validity due to factors such as *observer effect*, *halo effect*, *self-fulfilling prophecy* (Robson and McCartan, 2016; Saunders *et al*., 2019). However, these drawbacks associated with data validity and reliability in overt data collection methods can be offset with measures and strategies such as: ensuring the disruption is short-lived and 'fading into background' (Denscombe, 2021); building a rapport with the participants (Clark *et al*., 2021); or enabling 'habituation' with people being observed (Robson and McCartan, 2016) to preserve the naturalness of the setting and to form an environment that causes people being observed to drop their cloaking behaviour.

Denscombe (2021) describes another type of researchers' role, *viz.*, *participation in the normal setting*, as a middle ground between *total participation* (covert participation) and *participation as observer* (overt participation). The author (*ibid*) describes that when participation of the researcher is known only to certain 'gatekeepers' or authorities and hidden from most of the people in the setting, the researchers' participation known as *participation in normal setting*. This is similar to *complete participant* when researchers keep their observation process and note-taking secret from the group being observed but in *participation in the normal setting* only number of people (people who are not part of the group being observed) are aware of the process since researchers get those gatekeepers permission (Robson and McCartan, 2016; Denscombe, 2021). This role is adopted either when a researcher is reluctant to take complete participant position or because the researcher lacks the personal/ necessary credentials to take on the role amongst people observed or on the grounds of propriety (Denscombe, 2021). This role permits conducting observation in an undisturbed, natural setting and commonly in distance.

Additionally, all six types have been allocated to the groups of three that are representing three classification/mode of observation, namely *participant observation*, *structured observation* and *internet-mediated observation*. *Non-participant*, *complete observer* and *observer-as-participant* roles are mostly applicable to *structured observation*, since this type of observation cannot be conducted by an active participant and requires passive or detached observational position (Saunders *et al*., 2019). Whereas researchers in *participant observation* may adopt any roles apart *from non-participant observer* role. Lastly, in *internet-mediated observation*, researchers' role will be based on either *non-participant* and *complete observer* roles (when researchers disguise their true identity from members of online community) or *participant-as-observer* or *collaborative observer* roles (when researchers reveal their identity in order to gain a richer understanding of the data being collected by checking and verifying their interpretation with members of online group being observed).

5.4.3. Questionnaires as data collection method

As a data collection tool, *questionnaires* consist of a written list of questions (exact same questions for every participant taking part in questionnaires) that are directly asked with the purpose of subsequently using those answers for data analysis (Saunders *et al*., 2019; Denscombe, 2021). For data (that had been collected through questionnaires) to be counted as valid, the formulation of questions, the process of asking questions and obtaining responses require some considerations to be included in design stage (Robson and McCartan, 2016). Initially research questions must be uniform for each participant and must provide answers that produce standardised data (Collis and Hussey, 2021). Every effort should be made to design questions in a way that requires brief, succinct and straightforward answers to reduce the effect of '*response burden*' (Robson and McCartan, 2016; Fellows and Liu, 2022). '*Response burden*' is the amount of time and effort required from participants to answer the question and participate in a study (Denscombe, 2021). Excessive and undue '*response burden*' (e.g. lengthy questionnaires or complex questions requiring recollection of intricate detail) on respondents can become deterrent to obtaining responses and drop the *response rate* (i.e. the number of responses returned) and *completion rate* (i.e. the number of returned responses that are fully completed) of a study (Robson and McCartan, 2016; Denscombe, 2021). Another point to augment *response* and *completion rate* of the study is to design the *questionnaire* considering the factors such as language, age (e.g. vulnerability of different age groups), intellect (literacy), health condition (e.g. eyesight or hearing impairment) so that respondents can clearly read and understand the questions (Robson and McCartan, 2016). Additionally, informing the participants about: the timeframe it might take to complete the *questionnaire*; and the exact number of questions that are needed to be answered will help to prevent *questionnaire fatigue* (Robson and McCartan, 2016; Denscombe, 2021). A *questionnaire fatigue* is when participants feel exhausted or lose interest in continuing the questionnaire that they start exerting a minimal effort to provide a genuine or thought-through answers by merely ticking the boxes (which reduces the validity of the data collected) (Clark *et al.,* 2021; Collis and Hussey, 2021). Another example of good practice to mitigate aforementioned drawbacks and to enhance the success of data collection is to conduct a pilot study of data collection prior to actual data collection. Performing a pilot study will enable: testing the data collection environment (Denscombe, 2021); assessing the questionnaire (e.g. lengthy questionnaire or complicated questions) (Robson and McCartan, 2016); and calculating the time that a *questionnaire* might take to be completed (Saunders *et al.,* 2019).

These are considerations that can be addressed during the design stage of *questionnaires*. However, in the process of obtaining the responses, care should be given to create open social climate (by providing assurances of anonymity and confidentiality and showing sensitivity to personal feelings of respondents or avoiding questions that are embarrassing, intrusive or irrelevant to respondent) to enable respondents to answer honestly, fully and accurately (Robson and McCartan, 2016; Collis and Hussey, 2021; Denscombe, 2021). This step at the data gathering stage will augment the validity of responses that will ultimately impact the study's research findings.

5.4.3.1. Types of questionnaires

Questionnaires are categorised based on the means of communication used to collect data (Robson and McCartan, 2016). As described in *survey strategy*, data collection through *questionnaires* can be based on the modes such as face to-face, telephone, postal (mail), short message service (SMS), internet or delivery and collection (Clark *et al.,* 2021; Collis and Hussey, 2021). Saunders *et al*. (2019) broadly classify these modes of conducting questionnaire into two groups of *self-completed* and *researcher completed*. *Self-completed questionnaires* are respondent read and answered questionnaires (Clark *et al.,* 2021), whereas in *researcher completed questionnaire*, as the name suggests, the questions are read or introduced, and answers are recorded by a researcher (Saunders *et al*., 2019). Due to different levels of closeness in communication required in two types of questionnaires, only certain modes of communication can be used in each questionnaire type. A *researcher completed questionnaire* can be conducted on face-to-face mode and through telephone (along with other mode of synchronous communication that smart mobile phones enable, i.e. video chats) (Robson and McCartan, 2016; Collis and Hussey, 2021). For a *self-completed questionnaire*, on the other hand, postal (mail), SMS, internet as well as delivery and collection modes of contacting and communicating can be adopted (Robson and McCartan, 2016; Clark *et al.,* 2021).

5.4.4. Interviews as data collection method

Interviews, are a method of data collection that similar to *questionnaires*, use participants' responses to researcher's question as data for analysis (Denscombe, 2021). *Interviews* are generally prearranged and scheduled for a convenient time and location (Collis and Hussey, 2021). Responses to *interviews* are self-reports of participants about what they perceive, say, do and believe (as opposed to predefined potential options to select from like in questionnaires) (Robson and McCartan, 2016). However, using interviewees' responses (that are not factual but based on their opinion and perception) as the research data requires some validity and reliability checks (Saunders *et al*., 2019; Denscombe, 2021). As previously stated, *interviews* are a *reactive* method of data collection that involves interaction of respondents and a researcher (Denscombe, 2021; Fellows and Liu, 2022). This might cause the *interviewer effect* on respondents; a situation when respondents based on their perception and impression of the researcher might alter the true nature of their responses (either to fit to what they perceive to be expected of them or to conceal true answer, feeling threatened or embarrassed) (Saunders *et al.,* 2019; Denscombe, 2021). *The interviewer effect* is particularly common in face-to face interviewing but can be mitigated by switching to online interviewing mode (*ibid*).

Interviews are best suited for the studies that focuses on: an in-depth exploration of opinions, feeling and experiences (Robson and McCartan, 2016); detailed understanding of factors and their interrelationship in complex issues (Denscombe, 2021); gaining a valuable insights from the experience or position of key informants in researched settings (such as organisation, schools or factories) (Collis and Hussey, 2021). Alongside these features, also the synchronous nature of collecting data through *interviews* allows: checking the interviewees' responses to ascertain their meaning; prompting to clarify the questions that respondents might find ambiguous; and detailing a thorough probing of a subject, issue or line of investigation that may arise during the data collection (Robson and McCartan, 2016; Saunders *et al*., 2019; Clark *et al.,* 2021; Denscombe, 2021).

5.4.4.1. Types of interviews

Interviews can be conducted in three ways, *viz*., *structured*, *semi-structured* and *unstructured* based on the flexibility in sequencing the interview questions and leeway in adding unplanned and emergent questions in the process of interviewing (Robson and McCartan, 2016; Saunders *et al*., 2019; Denscombe, 2021). *Structured interviews* (also called *standardised interviews*) rigidly follow the agenda of interviews and involve tight control over the structure of questions and answers (similar to researcher completed questionnaires) (Robson and McCartan, 2016; Clark *et al.,* 2021). In this type of interviews, the process of data collection is standardised by strictly following the list of predefined question and inviting the respondents to offer limited-option responses which generates standardised and quantitative type data (Saunders *et al.,* 2019). Therefore, as data collection method *structured interviews* are most appropriate to be used in *surveys* research strategy and in studies that are *descriptive* and *explanatory* (Saunders *et al*., 2019; Denscombe, 2021).

However, data collected from other two types of interviews (specifically in *semi-structured* and *unstructured interviews*) will not be standard and the content of each answer will be different from others, since interviews are used developmentally in both interview types. Variability of responses attained from interviewers (in *semi-structured* and *unstructured interviews*) is ascribable to inconsistency in the number and the content of questions being asked from one respondent to another; because as participants are interviewed consecutively more information and knowledge about the studied phenomenon are accumulated from every interview, which consequently changes number and content of questions for the consecutive interview (Denscombe, 2021). This feature of *interviews* (cf. data collected being different from one participant to another) generates large volume of qualitative data and makes the data collected through *semi-structured* and *unstructured interviews* best suitable, for instance, to be used in *grounded theory* research strategy (Saunders *et al*., 2019).

In contrast to *structured interviews*, *semi-structured interviews* introduce some flexibility to be applied in the process of asking interview questions (Robson and McCartan, 2016). This approach to interview still uses clear list of predetermined questions and topic areas to be covered, but the order of questions being asked are allowed to develop according to the flow of information coming from the interviewee (Clark *et al.,* 2021; Denscombe, 2021). Therefore, *semi-structured interviews* are most commonly used in *explanatory* and *evaluative* type research that aim to identify cause and effect of the phenomena based on combination of predefined questions and emerging-in-the-process questions (Saunders *et al*., 2019).

Unstructured interviews, as the name suggests, are a method of data collection where a researcher only introduces the topic and stays as non-directive as possible throughout the interview (Saunders *et al*., 2019; Denscombe, 2021). The focus of such approach is to understand the thoughts and beliefs of interviewee by letting them develop their ideas and thoughts about studied topic (*ibid*). Hence, *unstructured interviews* also referred as *in-depth interviews* (Saunders *et al*., 2019) or *non-directive interviews* (Robson and McCartan, 2016). *Unstructured interviews* can be classified based on: the purpose of research, *viz*., *narrative* and *biographical interviews*; and the role of interviewee and interviewer in the data collection process, *viz*., *dialogic* and *convergent interviews*. *Unstructured interviews* that are dominated/led by the interviewee while the interviewer occasionally asks very few questions are referred to as *convergent interviews*; whereas equal engagement of interviewer and interviewee in the data collection step is described as *dialogic interview* (Robson and McCartan, 2016; Saunders *et al*., 2019).

5.4.4.2. Different modes and participant numbers in interviews

Interviews can be performed in one-to-one form or in groups using various means of communication with respondents (Clark *et al.,* 2021; Collis and Hussey, 2021). Therefore, apart from the level of structure and process of data collection, interviews are classified based on: 1) number of participants involved in the process, such as *one-to-one*, *one-to-many* (or *group*) interviews; and 2) the mode of interviews, such as *face-to-face*, *telephone* or *internet mediated* interviews (Robson and McCartan, 2016; Saunders *et al.,* 2019; Collis and Hussey, 2021). All the characteristics of different modes of contacting participant alluded to in survey strategy similarly apply to the modes of interviews (i.e. face-to-face, telephone or internet mediated interviews).

Due to its convenience of arranging the interview, recording, sorting and analysing data, *one-to-one interviews* are deemed to be the most common option (Collis and Hussey, 2021). Arranging *one-to-one interview* is relatively easy, since the researcher needs to make time for one participant at a time (Denscombe, 2021). Locating specific ideas with specific participant also becomes convenient in *one-to-one interviews*, since a researcher channels interview questions and responses to and from one source only (Collis and Hussey, 2021). This feature also simplifies the process of grasping and interrogating the responses for a deeper understanding. Similarly, in the last stage of *one-to-one interviews*, when the data is prepared for analysis, transcribing the recordings of one participant at a time is much simpler as opposed to group interviews that require to differentiate different participants' responses and voices (Saunders *et al*., 2019). However, if the researcher is successful in arranging and gathering the number of participants at the same time, then *group interviews* are great method to dramatically: increase the number of responses in a short amount of time; enhance the richness of responses (since variety of experiences and opinions from participants generate more intense data) (Robson and McCartan, 2016); and decrease time spent on arranging interviews for each participant, on separately asking questions and on obtaining responses one by one (Denscombe, 2021). Other types of interviews that are conducted in groups are *focus groups* and *Delphi technique*.

Focus groups interviews are small group interviews (ideally six to nine people) conducted to study shared views of participants about specific topic (Robson and McCartan, 2016; Denscombe, 2021). Securing the right number of participants is crucial in *focus groups*, since a group that is not large enough will not generate a prerequisite range of opinions and views required for heterogeneity (Saunders *et al.,* 2019; Denscombe, 2021; Collis and Hussey, 2021). Whereas a group with too many participants will be difficult to manage and communicate (Clark *et al.,* 2021). Elicitation of information in *focus groups interviews* is achieved through group dynamics, encouraging interaction and discussion of the topic as the focus of a study rather than the researcher leading the interview and conversation (like in other *interviews* data collection methods) (Robson and McCartan, 2016; Collis and Hussey, 2021). Therefore, apart from selecting and deciding the number of participants, the researcher performs the role of a moderator by facilitating the group interaction and fostering the climate of trust amongst participants (Robson and McCartan, 2016; Denscombe, 2021).

The *Delphi technique* is a systematic way of gathering views and opinions of experts to find a common ground through a series of interviews (i.e. number of question iterations) (Collis and Hussey, 2021). Experts here denote people with specialist knowledge or experience in the subject area that is being studied (Denscombe, 2021). Interviews based on the *Delphi technique* commence with contacting each participant separately to keep the anonymity of their responses (Saunders *et al.,* 2019; Collis and Hussey, 2021). Anonymisation of participants' views and responses helps to avoid the undue influence of *group effect* that might otherwise encourage conformity with the views of other participants (Robson and McCartan, 2016; Collis and Hussey, 2021). After the first round of questions, anonymised responses are collected, analysed and fed back to the same expert group with the aim of achieving a consensus among them (Denscombe, 2021). Analysing responses involves collating and summarising: instances where opinions are shared; the reasoning used by each expert to reply; key factors and their significance noted by experts; and additional information that each expert asking for (*ibid*). This process of collecting responses and feeding back is iterated a number of times (commonly three to four times) unless experts' opinions coincide to an acceptable degree (Robson and McCartan, 2016). Each consecutive round of questioning enables to narrow the focus of questions and eliminate the areas emerging as less important. As a final result, when the experts' opinions reach a consensus, outcome of such data collection method helps to develop a new policy, forecast a future situation or make a decision on an important topic (Robson and McCartan, 2016).

5.4.5. Research sampling

The data collection process requires significant devotion of time and resources, regardless of whether the research is small scale or large scale (Clark *et al.*, 2021). To mitigate this resource and time expenditure without compromising the accuracy of the findings, a sampling technique is used (Robson and McCartan, 2016; Collis and Hussey, 2021). *Sampling* is a strategic way of collecting data from some, rather than all, members of a research population (Robson and McCartan, 2016; Fellows and Liu, 2022). Based on the purpose of sampling, two types of samples, namely, *exploratory* and *representative samples* are differentiated. An *exploratory sample* is used to probe a relatively unexplored topic to discover a new idea or theory (Denscombe, 2021). Small scale, qualitative data-based studies commonly adopt *exploratory sample* as means of generating insights and knowledge. Conversely, if the aim of the research sampling is to match the proportion of overall population by including all relevant factors, variables or events, *representative sample* is used (Saunders *et al.*, 2019; Collis and Hussey, 2021). In contrast to an *exploratory sample*, a *representative sample* is associated with larger scale research involving quantitative data collection that focuses on drawing a valid conclusion representing the overall research population (Robson and McCartan, 2016; Collis and Hussey, 2021).

5.4.5.1. Sample selection techniques

Based on the sample selection methods, two broad categories of sampling, *viz*, ***probability*** and ***non-probability sampling*** types are classified (Fellows and Liu, 2022). ***Probability sampling*** is a random selection of samples from sampling frame through various systemised methods with as little involvement of the researcher as possible (Saunders *et al.*, 2019; Denscombe, 2021; Clark *et al.,* 2021). *Sampling frame* here means encapsulating information about the targeted research population in the form of a list of names, postal or email addresses or employee records from which samples (or potential participants) are selected (Collis and Hussey, 2021; Denscombe, 2021). Random selection of samples is conducted using sampling frame without which ***probability sampling*** cannot be performed (*ibid*). Selection based on ***probability sampling*** is grounded on basis of the statistical theory known as 'normal distribution' which attempt to achieve *representative sample* by minimising researchers' impact and maximising objectivity in the selection process (Saunders *et al*., 2019; Fellows and Liu, 2022). Random sampling, *systematic sampling*, *cluster sampling*, *multi-stage sampling*, *stratified sampling* are sampling techniques that refer to ***probability sampling*** category (Robson and McCartan, 2016; Saunders *et al*., 2019; Clark *et al.,* 2021).

As the name suggests, *random sampling* is based on randomness which (from statistical perspective) means giving each unit within a sample equal chance for inclusion (Collis and Hussey, 2021; Denscombe, 2021). *Random sampling* is considered as an ideal selection technique for *representative sample*, since the items are selected entirely based on chance without the researcher's impact (Robson and McCartan, 2016; Collis and Hussey, 2021). However, to use random sampling, a researcher have to: 1) know the make-up (e.g., total number, age range or categories of the data) of the overall population (Collis and Hussey, 2021; Denscombe, 2021); 2) have a sampling frame with unique identifier such as employee number or birth date (Saunders *et al*., 2019; Denscombe, 2021); 3) have a process or tool for random selection (e.g., using random number generator that is available as a feature of computer software packages) (Robson and McCartan, 2016; Saunders *et al*., 2019).

Systematic sampling shares the same principles with *random sampling* (cf. 1 and 2 steps alluded to above); however, the process of random selection is based on a systematic approach rather than random number generating (Clark *et al.,* 2021; Collis and Hussey, 2021). The items are selected based on every n^{th} basis, i.e. at regular intervals (Robson and McCartan, 2016; Saunders *et al*., 2019). In this systematic way of picking every n^{th} item, n is decided based on the proportion needed to be selected from sampling frame (Robson and McCartan, 2016). Both *random sampling* and *systematic sampling* select one item at a time from sampling frame or list of research population, whereas *cluster sampling*, *multi-stage sampling* and *stratified sampling* involve selecting clusters or selecting from clusters (Denscombe, 2021).

Cluster sampling is the process of randomly selecting a cluster (or number of clusters) from the number of naturally occurring clusters within sampling frame and include all the items from that certain cluster (or number of clusters) for the research (Collis and Hussey, 2021). However, clusters must be pre-existing and naturally occurring (i.e. without the influence of a researcher in the formation of clusters) in the research population, and the items within the cluster must reflect the heterogeneity of the overall research population (Denscombe, 2021).

In case the items in clusters do not provide a cross-section of overall research population, the *multi-stage sampling* will be more suitable sample selection technique (Collis and Hussey, 2021; Denscombe, 2021). *Multi-stage sampling* involves randomly selecting items in a sequence of stages, i.e. randomly selecting items from each naturally occurring group/cluster, as opposed to including all the items from the cluster as in *cluster sampling* (Robson and McCartan, 2016). However, description of *multi-stage sampling* technique by Saunders *et al.* (2019) differs in a way that this sampling technique refers to any sampling design constituting two or more successive stages of either ***probability***, ***non-probability*** or combination of both sampling techniques.

Stratified sampling is broadly similar to *multi-stage sampling,* except the clusters in *stratified sampling* is not naturally occurring but rather generated by a researcher (Robson and McCartan, 2016; Collis and Hussey, 2021). Both *multi-stage sampling* and *stratified sampling* focus to ensure that crucial parts of the population are uniformly presented in sample selection (e.g. balancing representation of gender, age or geographical groups) (Robson and McCartan, 2016; Denscombe, 2021).

Generally, all examples of ***probability sampling*** are considered to be well-suited for studies that are large scale and quantitative data-based and for *representative sampling* purposes, where the scope of a researcher to influence the selection process is absent or minimal (Clark *et al.,* 2021; Denscombe, 2021). Whereas sampling techniques in ***non-probability sampling*** category entail some intervention by a researcher in selection process (Robson and McCartan, 2016). ***Non-probability sampling*** category includes: *quota sampling*; *convenience sampling*; *purposive sampling*; *theoretical sampling*; and *snowball sampling* (Saunders *et al.,* 2019; Denscombe, 2021).

Quota sampling is a popular selection technique used in market research which shares very similar principle to *stratified sampling* (Clark *et al.,* 2021; Denscombe, 2021). *Quota sampling* commences with establishing certain categories and setting the quotas for each category in advance and seeks to fill these categories in proportion to their existence in overall research population (Saunders *et al*., 2019; Collis and Hussey, 2021). However, unlike *stratified* *sampling*, selection of the people or events in *quota sampling* is not based on randomisation, but rather it is performed on 'first to hand' basis by ensuring that the number of items selected for each category fulfils the previously set quotas (Denscombe, 2021). Therefore, *quota sampling* is considered as cost-effective sample selection technique, since it includes items without waste and no item that might be 'surplus to requirements' is included in the research (*ibid*). Robson and McCartan, (2016) cite another sampling technique called *dimensional sampling* as an extension of *quota sampling*, which is roughly equivalent to *quota sampling*. *Dimensional sampling* categorises the population based on significant factors or dimensions (e.g. ethnic group or length of stay in different country) which is more granular compared to generic representative elements of overall population (e.g. gender or age group) that *quota sampling* categorises research population by focusing on representativeness of sample of overall population (Robson and McCartan, 2016).

Another *non-probability sampling* technique that is concerned about cost-effectiveness and 'first to hand' approach is *convenience sampling* selection technique. *Convenience sampling* is utilised when two or more equally valid and appropriate items are available for selection (Clark *et al.,* 2021; Collis and Hussey, 2021). The most convenient item (e.g. geographically close location or publication with open access) is selected since that option is the easiest, cheapest and quickest compared to other equally valid possibilities (Robson and McCartan, 2016; Denscombe, 2021). Saunders *et al.* (2019) emphasise that findings generated based on *convenience sampling* technique will bear very little credibility due to poor representativeness, especially when the target population of study is more varied and heterogenous. Therefore, convenience sampling is more appropriate for studies with homogenous target population or cases of extreme or unusual event (*ibid*).

Purposive sampling is the process of deliberately selecting the people or event for their known attributes (rather than through random selection) such as: relevance to the topic, theory or issue being investigated; or knowledge and expertise of the participant (Collis and Hussey, 2021; Denscombe, 2021). Therefore, a researcher is expected to know the particulars of overall research population in order to be able to deliberately select the most apposite people or events (Robson and McCartan, 2016; Denscombe, 2021). Having that knowledge, a researcher can aim to generate a *representative sample* by ensuring a wide cross-section of events and people selected (Denscombe, 2021). Similarly, an *exploratory sample* can be generated with the help of *purposive sampling* technique by focusing on solely events and people that are most likely to provide valuable insights about investigated phenomenon (Robson and McCartan, 2016; Clark *et al.,* 2021).

Theoretical sampling, as the name indicates, focuses on selecting items that augment the discovery or development of a specific theory (Robson and McCartan, 2016). Unlike *quota sampling technique*, there is no quota or predefined sample size in *theoretical sampling*, since sample or number of selected items evolves and continues to grow unless the researcher achieves a sufficient *theoretical saturation* (Robson and McCartan, 2016; Clark *et al.,* 2021). *Theoretical saturation* here denotes an instance in the item selection process when the items already included in the sample meet the requirement (i.e. sufficient to build a theory) and new item is no longer helpful or becomes repetitious to include in sample (*ibid*). Robson and McCartan (2016) and Saunders *et al.* (2019) describe *theoretical sampling* as one of the techniques of *purposive sampling* along with other sampling techniques such as: *extreme case* (or *deviant sampling*), *heterogenous* (*maximum variation sampling*), *homogenous*, *typical case*, *critical case*, *politically important* and *opportunistic*.

The last sample selection technique in ***non-probability sampling*** category is *snowball sampling*. This selection technique is based on the selection of items through process of reference from initial number of items (Collis and Hussey, 2021). In *snowball sampling* the initially selected items (e.g. people or publications) guide towards or nominate more similar items for potential selection, which snowballs the number of items for inclusion in research (Clark *et al.,* 2021). Therefore, *snowball sampling* is particularly useful in the absence of sampling frame and can provide the quickest way of accumulating a large number of relevant items with multiplier effect (Denscombe, 2021). This feature of receiving more apposite items from initial items makes the *snowball sampling* technique compatible with *purposive* and *theoretical sampling* where initial items propose more items that meet certain criteria or attributes such as gender, age, qualification, geographical location or state of health (Robson and McCartan, 2016). Saunders *et al*. (2019) designate the *snowball sampling* as a technique within *volunteering sampling* group alongside another technique called *self-selection sampling* technique. The authors (*ibid*) characterise both techniques as practice that is driven by respondents.

5.4.5.2. Size of the sample

There are three ways of calculating the sample size, *viz*., *statistical*, *pragmatic* and *cumulative approach* that are suitable for different scale research and compatible with different sampling techniques.

The *statistical approach* of selecting sample size is best suited for a large-scale survey that uses ***probability sampling*** to generate a *representative sample* (Collis and Hussey, 2021; Denscombe, 2021). The approach is based on statistical theory and the normal curve (parametric) distribution of events. The calculation of sample size based on the *statistical approach* depends on the: size of the research population; accuracy of the estimates; level of confidence; and variation in the population (Saunders *et al*., 2019). *Statistical calculation* of sample size is relevant to use in government surveys or opinion polls that are very costly and involve very large population (Clark *et al*., 2021).

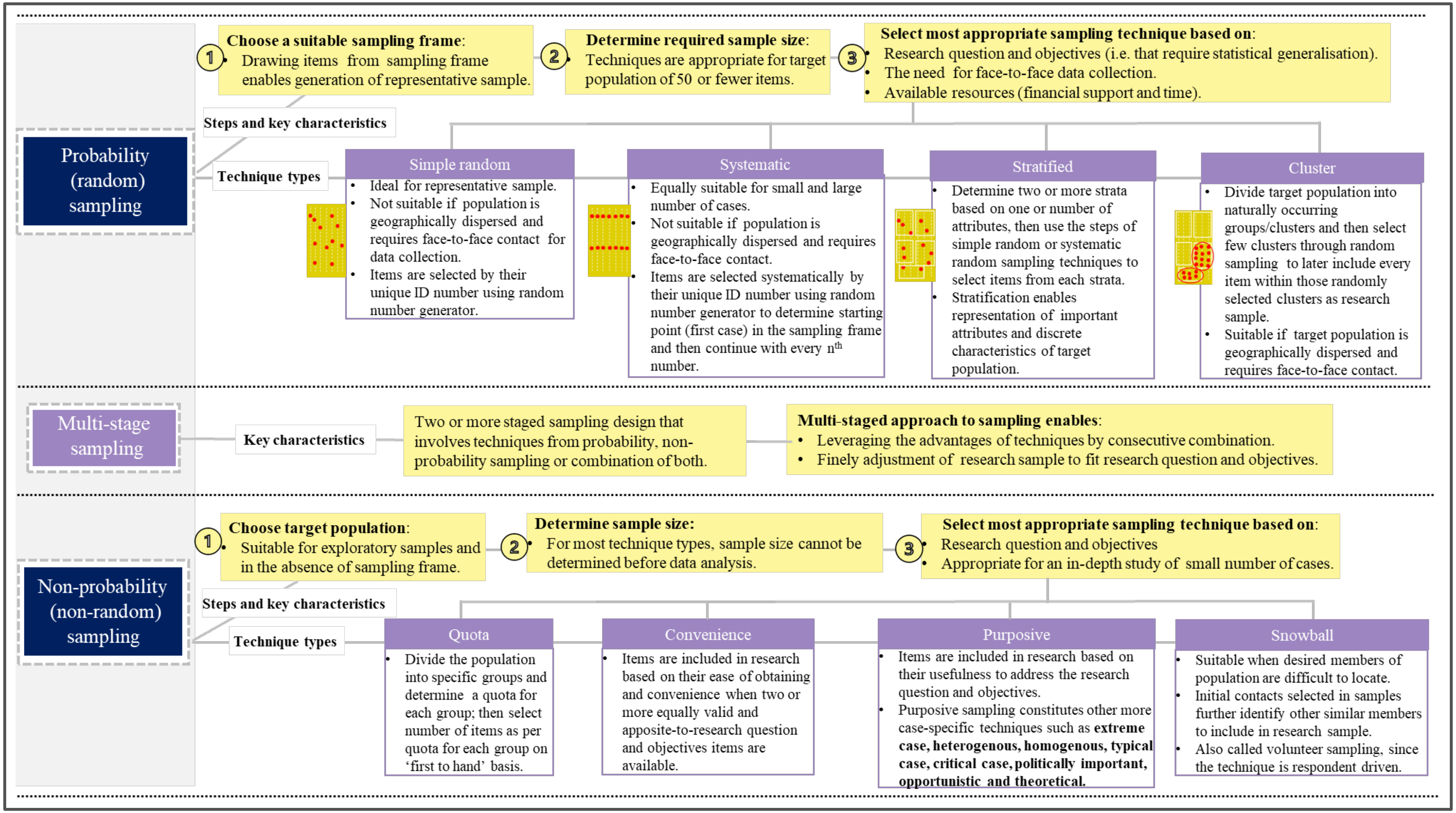
Whereas for smaller scale research with ***non-probability sampling*** technique generating a *representative sample*, a *pragmatic approach* is used. This sample calculation approach is commonly used in market research by estimating the sample size based on: accumulated practical experience; and acknowledgement of resource constraints (i.e. time and money) (Denscombe, 2021). Compared to a *statistical approach* of sample calculation, a *pragmatic approach* does not provide an exact figure, since *pragmatic sample calculation* depends on good judgement that relies on four factors (*ibid*). The first factor is the practice of comparing with other similar studies, *viz.* literature review of similar research provides helpful guidance for establishing the number of items required for a sample (Fellows and Liu, 2022). The second and third factors are respectively ensuring adherence to the minimum of 30 sample items (Bryman, 2012; Denscombe, 2021) and ensuring that every subdivision has a balanced number of items (Denscombe, 2021). Even the seemingly large sample size can prove problematic if subdivision (i.e. categories and attributes) within that sample has unbalanced the number of items. This factor ensures that a sample is evenly distributed and generalisable and the items selected in the sample are representative (Collis and Hussey, 2021). The last factor is acknowledging the limitations *viz.,* recognising the limited extent to which research findings can be generalised (Clark *et al*., 2021).

A *cumulative approach* to sample size calculation is most appropriate for small scale research that uses ***non-probability sampling*** for an *exploratory sample* (Denscombe, 2021). In some studies of social research, to estimate sample size is impossible, since the study's research population cannot be identified in advance (Clark *et al*., 2021). Instead, the sample size increases during the course of the study and continues to grow until sufficient information required for the research is obtained (Saunders *et al*., 2019; Collis and Hussey, 2021). Therefore, the *cumulative approach* to sample size calculation is common in studies at the core which strive to focus on quality of information obtained from each item rather than quantifying items for inclusion (Clark *et al*., 2021). Examples of applying *cumulative sample calculation* are: studies conducted through *purposive*, *snowball* and *theoretical sampling techniques*; and small-scale studies that require *exploratory sample* and use qualitative data.

5.4.5.3. Characteristics of sampling techniques

All alluded types of sampling techniques have various level of: autonomy for a researcher; suitability for small- or large-scale study; appropriateness for quantitative or qualitative data selection; capacity to produce small or large sample size; and requirement for resources (time and money). All these features of sampling types are outlined Figure 5.3. These features are the inherent characteristics of each sampling techniques that enable a researcher to select from, depending on: appropriate data type for answering the research question (i.e. choice of quantitative data or qualitative data); the purpose of the sample (selecting *representative* or *exploratory sample*); sample selection approach suitability (benefit from random or deliberate selection); availability of sampling frame and its accessibility; and resource available for the research. This variety of options, which cover most requirements of conducting a rigorous study is the main advantage of using a sampling technique instead of a resource-intensive way of including all people or items within a larger research population (Saunders *et al*., 2019; Clark *et al.,* 2021).

Figure 5.3 - Main characteristics of probability and non-probability sampling.



However, as convenient as it may be, sampling has some constraints that must be acknowledged and if possible avoided. A major risk is the possibility of *sampling error* in the form of random error and systematic error (Clark *et al.,* 2021; Collis and Hussey, 2021). *Random error* is an inbuilt feature of sampling that inevitably occurs when drawing some items from an overall research population (Denscombe, 2021). Inescapably, items included in the sample will not be an exact match of the total research population (Fellows and Liu, 2022). This condition is particularly problematic when the purpose of the research is to generate a *representative sample* and to generalise the findings to the research population (Robson and McCartan, 2016). However, the consequence of *random error* can be downplayed by using a ***probability sampling technique***, since statistical analysis using this method recognises the *random error* and enables the researcher to predict the chances of its occurrence and the amount of error (Fellows and Liu, 2022). Additionally, sufficiently increasing the sample size enables the researcher to cancel the effect of *random error* to certain extent.

As a second kind of sampling error, *systematic error* occurs when the disparity between sample and research population are based on the systematic mistakes that can be avoided (Denscombe, 2021; Fellows and Liu, 2022). The main cause of *systematic error* is using incomplete or not-updated *sampling frame* to select the items from, which is known as *sampling bias* (Clark *et al*., 2021). *Sampling bias* distorts the outcome of the research by: overlooking particular characteristics of item/people; omitting some representative items; or including items that are not part of the *sampling frame* any more (since the data has not been updated), which lead to a biased sample (Saunders *et al*., 2019; Denscombe, 2021). Compared to *random error*, *systematic error* or *sampling bias* can be avoided with due diligence towards ensuring the *sampling frame* is comprehensive and updated (Collis and Hussey, 2021).

5.5. RESEARCH METHODS FOR DATA ANALYSIS

Having collected the required data to address the study's research question, the following step is to analyse the data collected. Data analysis is a systematic interrogation of the raw data to: create a comprehensive and clear picture of the information by summarising the key point from a mass of data (Fellows and Liu, 2022); and/or generate explanation of the data by investigating variables and their interrelationship (Saunders *et al*., 2019; Denscombe, 2021). These two ways of generating knowledge whether it is interpretation or studying correlations (and causal factors) represent qualitative and quantitative analysis techniques respectively. Selection of methods for data analysis is heavily determined by factors such as the: study's aim, objective and research question (e.g. interpretation or correlations and frequencies) (Collis and Hussey, 2021); format, type and details of the data collected (e.g. numbers or texts, quantifiable or interpretable) (Fellows and Liu, 2022); focus of the research (e.g. extensive or intensive study) (Denscombe, 2021); and scale of research (e.g. large or small scale) (Robson and McCartan, 2016).

5.5.1. Quantitative analysis techniques

Because data is in numerical form, quantitative analysis techniques generally focus on association between variables, evidence of correlations, causes of the factors and frequency of occurrence (Robson and McCartan, 2016; Collis and Hussey, 2021). Examples of data collection methods and strategies that might generate data that are quantitatively analysed are: closed-ended questions from *questionnaires*; measurements from *experiments*; observation (or coding) schedule, used for event frequencies in *observations*; and content analysis of text and transcripts (frequency of occurrence) in *interviews* (Saunders *et al*., 2019; Denscombe, 2021). Therefore, data to be analysed in quantitative analysis techniques must be either already quantified (e.g. number of events observed in observation data collection method) or be in the form that can be transformed into quantitative data (e.g. qualitative/non numerical data transformed into quantitative data through coding and quantification in content analysis) (Denscombe, 2021; Fellows and Liu, 2022).

Although all these data (cf. gathered from data collection methods mentioned above) are collectively known as quantitative data, differentiating variations of quantitative data becomes important in the data analysis stage (Collis and Hussey, 2021; Denscombe, 2021). *Categorical data* (also called *nominal data*) is a type of data that merely represent the name or label attached to the item, but do not bear any value or measurement of that item (Saunders *et al*., 2019; Fellows and Liu, 2022). Therefore, *categorical* or *nominal data* are not suitable to calculate the averages of the variable or item but can indicate the frequency with which that item occurs in the dataset (Clark *et al.,* 2021). Whereas *ordinal data* measures the rank order of things and events in relation to others in data (Collis and Hussey, 2021). *Ordinal data* are used to represent and measure magnitude, quality, order, preference and level of things from the highest to lowest ranking (Denscombe, 2021). Compared to *categorical data*, numbers attached to items in *ordinal data* bear some relative value and hence, the frequency of *ordinal data* can be analysed in terms of some relevant numerical order (Robson and McCartan, 2016; Fellows and Liu, 2022). Two other types of data, *interval* and *ratio* data, are collectively known as scale data;

both of which correspond to naturally occurring properties of the items that they measure (Clark *et al.,* 2021; Denscombe, 2021). *Interval data*, similar to ordinal data indicate some measure of order or sequence but unlike *ordinal data* the difference between things (in orders and sequences) in *interval data* is a precisely known amount (e.g. years with certain intervals) (Robson and McCartan, 2016; Collis and Hussey, 2021). *Ratio data*, on the other hand, measures the true value and physical property of things such as length, height, weight as well as productivity, income, population of items in social science (Collis and Hussey, 2021; Denscombe, 2021). *Scale data* (i.e. ratio and interval data) have the most potential in terms of mathematical and statistical manipulations in a way that they can be multiplied, divided and averaged (Robson and McCartan, 2016; Saunders *et al*., 2019).

Quantitative analysis techniques can be broadly categorised as univariate, bivariate or multivariate analyses representing analyses that entail respectively one, two, three or more variables in the analysis (Clark *et al.,* 2021; Collis and Hussey, 2021). *Univariate* analysis focuses on the patterns of variation that a single quantitative variable might display (*ibid*). Frequencies, mid-points or measures of central tendency (i.e. mean, median, mode) and measures of dispersion (such as range, fractiles and standard deviation) of data are examples of analysing a single variable for its patterns (Saunders *et al*., 2019; Clark *et al.,* 2021; Denscombe, 2021). *Bivariate analysis*, on the other hand, is a method of investigating any apparent correlation and patterns of association between two variables (Saunders *et al.,* 2019; Collis and Hussey, 2021). Examples of *bivariate analysis* are: correlation statistics that are concerned with closeness of relationship between two numerical variables with interval or ratio data (Robson and McCartan, 2016); a chi-square test which focuses on determining whether association between two variables with either categorical or ordinal data are statistically significant (Clark *et al.,* 2021); a t-test is for comparing two variables one of which are of categorical data and other variable with interval or ratio data (Saunders *et al*., 2019; Denscombe, 2021). Similarly, in multivariate analysis three or more variables are analysed to search for complex relationships (Clark *et al.,* 2021). The prominent example of multivariate analysis is multiple regression analysis (*ibid*).

Quantitative analysis techniques are substantiated, objective and a scientific approach to data analysis, since techniques rely on consistent, repeatable and verifiable tools and tests (such as statistical data analysis, the use of statistical test of significance) (Saunders *et al.,* 2019); and the quantitative data represent hard facts that are not linked to researchers' interpretation (Collis and Hussey, 2021; Denscombe, 2021). However, these benefits can be shadowed by data overload, since quantitative data analysis techniques rely on extensiveness of coverage and large number of items. Similarly, the advantages of using quick, powerful and user-friendly tools offered by computer-aided analysis software might become challenging to interpret and hard to justify the selection of metrics and tools (Robson and McCartan, 2016; Saunders *et al.,* 2019).

5.5.2. Qualitative analysis techniques

In contrast to quantitative analysis, qualitative analysis techniques are directed at making sense of the data through interpretation, since the data are in text or image format (Bayramova *et al*., 2021; Clark *et al.,* 2021; Denscombe, 2021). The sources of qualitative data can range from: open-ended questions in *questionnaires*; images and artefacts in *observations*; transcripts from *interviews* and *focus groups*; and video-recordings of events in *observations*. The types of analysis involving text format include thematic analysis, content analysis, grounded theory analysis, narrative analysis, discourse analysis and conversation analysis (Saunders *et al*., 2019; Collis and Hussey, 2021; Denscombe, 2021). All qualitative analysis techniques are based on analysing the content of text but with different granularity; some of the techniques focus on the level of words, while others use a whole sentence or paragraphs as a unit of analysis (Clark *et al*., 2021; Denscombe, 2021; Fellows and Liu, 2022).

Thematic analysis is a method of grouping data into emerging themes by reading, re-reading and inductively generating themes within significant amount of dataset and coding the data into identified themes (Saunders *et al.,* 2019; Denscombe, 2021). Coding here denotes the act of linking parts of the text to relevant codes (i.e. emerging idea or theme), where codes provide a shorthand way of representing the nuanced and complex set of ideas and concepts in the text (Clark *et al*., 2021). Codes in thematic analysis are not pre-existing but rather occur through reading the text and determining shared views, ideas and themes. *Thematic analysis* can be used as a stand-alone approach or as a starting point to be used with other qualitative analysis techniques (Saunders *et al.,* 2019). The unit of analysis (i.e. elements being coded) in *thematic analysis* can be a word, phrase, symbol, sentence or paragraph in the text (Clark *et al.,* 2021).
Grounded theory, is performed through similar to *thematic analysis* processes of reading and re-reading the sentences and paragraphs, coding the data and merging codes through constant comparison (Fellows and Liu, 2022). However, in the instance of *grounded theory*, analysis is looking for concepts within the text (rather than themes as in *thematic analysis*) with the final

aim of generating a theory (Saunders *et al.,* 2019; Denscombe, 2021). Another distinctive feature of *grounded theory* analysis (from other techniques) is that processes of data collection and data analysis are performed concurrently with iteration between two processes (Collis and Hussey, 2021). As the data collection process commences, so does the data analysis process until collected data reaches the data saturation (Clark *et al.,* 2021).

Content analysis is a method of analysing text to identify hidden messages by quantification of words or phrases (Clark *et al.,* 2021). *Content analysis* can reveal deep-rooted and possibly unintentional messages or hidden clues in the text such as: portrayed priorities, conveyed values and related ideas (Collis and Hussey, 2021). The process of identifying the clues in the text commences with preestablishing the relevant indicators (i.e. code names) and looking for instances in the text to code them into those indicators (Robson and McCartan, 2016; Clark *et al.,* 2021). This coding process is followed by the analysis of the frequency of coded units and their relationship with other units and codes (*ibid*). As a result, the more frequent the writer or speaker uses certain words or phrases, the more emphasis and weight is given to those words or phrases to represent that speaker or writer holds and conveys those values and beliefs (Robson and McCartan, 2016; Denscombe, 2021). The main advantage of using *content analysis* is that it uses clear and repeatable (by other researchers) method of identifying the significance of the words and phrases based on quantification (Clark *et al.,* 2021). However, drawing the significance of words and phrases based on their frequency of occurrence has a limitation; *viz*., this approach fails to convey the contextual meaning of those words and phrases. For example, the reason why certain words or phrases occur more frequently than others might be because they are associated with negative semantics (when examining the context); in which case a speaker or writer might condemn but not value those frequently occurring words and phrases (Denscombe, 2021). Therefore, if the study's purpose is to analyse the content in the context, then other types of text analysis must be used, since *content analysis* only focuses on surface content of texts (Fellows and Liu, 2022).

Indifferent from *content analysis* that focuses on words and phrases as a unit of analysis, *discourse analysis*, *conversation analysis* and *narrative analysis* treat a whole document, blocks of text and a whole story respectively as one integral unit of analysis (Robson and McCartan, 2016; Collis and Hussey, 2021). *Discourse analysis* attaches significance to implied meaning and content in context (i.e. in paragraphs or whole documents) to indicate how power is exercised through language (Saunders *et al.,* 2019; Denscombe, 2021). To analyse a text through a *discourse analysis*, the researcher is expected to be familiar with the topic being discussed in the text (Clark *et al.,* 2021; Denscombe, 2021). *Discourse analysis* goes beyond the evidence identified in the text and includes outside factors that are not contained within the text to enhance interpretation and reveal cultural assumptions and shared background meanings that words are attempting to represent (*ibid*).

Similar to *discourse analysis*, *conversation analysis* focuses on the role and the power of words (in the episodes of conversation that are recorded and transcribed) to influence the situation under investigation (Robson and McCartan, 2016). In *conversation analysis*, a researcher attempts to reveal underlying rules and structures of naturally occurring interaction by: looking at the structure of content (Denscombe, 2021); identifying recurring patterns of interaction (such as 'turn-taking', 'cooperative or interruptive overlap', 'adjacency pairs' or 'asymmetry' in conversations) (Fellows and Liu, 2022); and emphasising the data with displayed meaning(s) that may be significant (Clark *et al.,* 2021).

Narrative analysis as the name suggests, analyses text in the form of story (e.g. fairy tales, ancient myths, fables, literary classic or personal narrative) (Robson and McCartan, 2016; Denscombe, 2021). The focus of *narrative analysis* is to study: the impact of such narratives to construct social world (in fables, parables and fairy tales) and personal identity (in personal narrative) (Fellows and Liu, 2022); and how stories purvey beliefs, morals and cultural significance (Saunders *et al.,* 2019). Unlike *thematic analysis*, *content analysis* and *grounded theory analysis* that analyse original data by fragmenting and coding into different themes and concepts, *narrative analysis* preserves the narrative data and analyses it as a whole unit (Clark *et al.,* 2021).

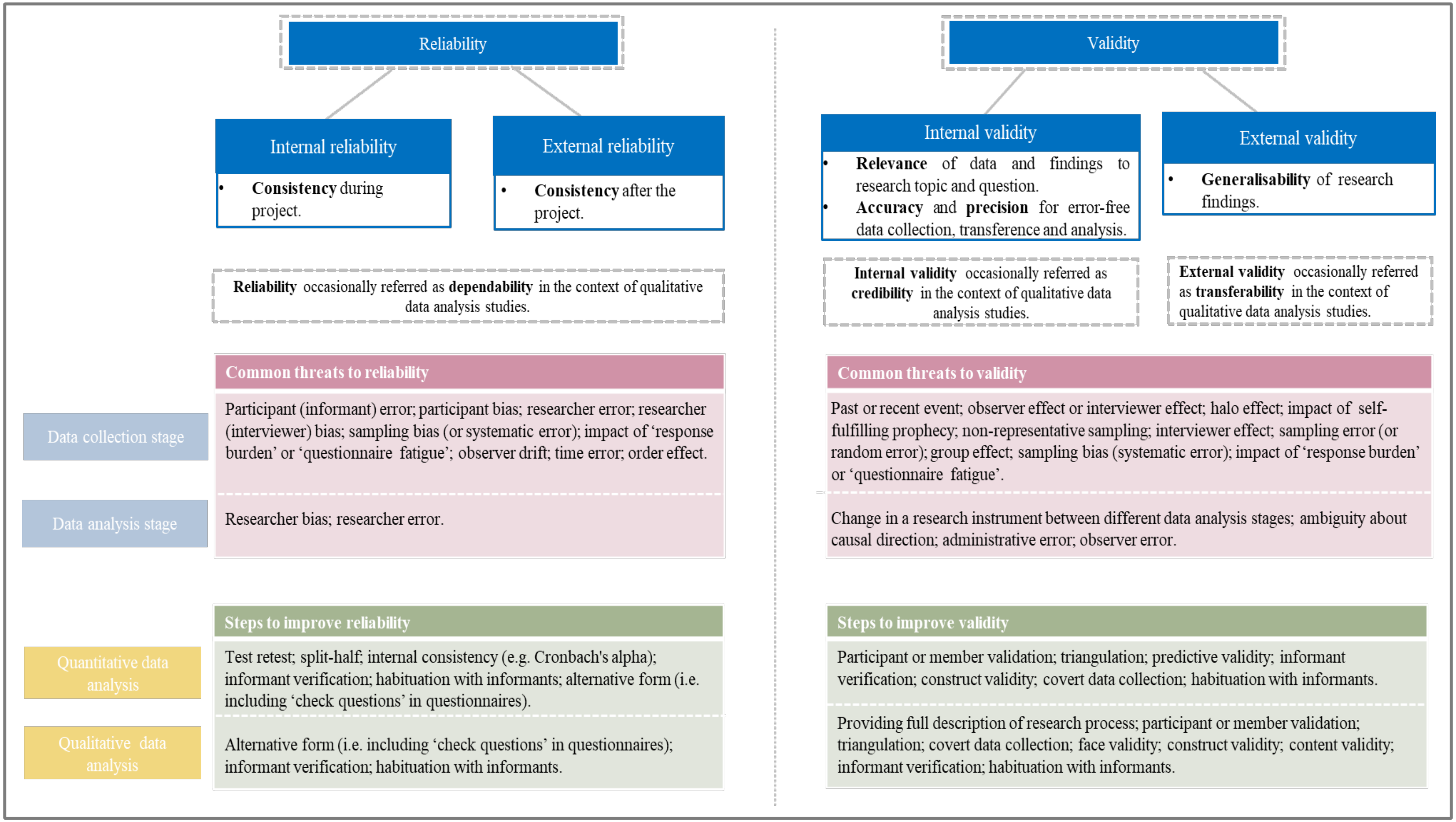
5.6. RESEARCH QUALITY AND ASSESSMENT CRITERIA

Quality of research is incumbent upon: the use of systematic and rigorous approach; selection of appropriate data collection and data analysis tool; and most importantly, quality of data collected (Robson and McCartan, 2016; Saunders *et al*., 2019; Fellows and Liu, 2022). Quality of data denotes different things to different sources and types of data: whether the data is factual or opinion-based and/or quantitative or qualitative (Robson and McCartan, 2016). There are different criteria upon which the quality of findings and trustworthiness of research are measured such as validity (similarly credibility), reliability (similarly dependability), generalisability (similarly transferability) and objectivity (similarly confirmability) (Saunders *et al*., 2019; Collis and Hussey, 2021; Denscombe, 2021).

However, the most commonly used criteria (in both quantitative and qualitative analysis techniques) for assessing the trustworthiness of the research findings are validity and reliability (Robson and McCartan, 2016; Collis and Hussey, 2021). Data *validity* is concerned with accuracy, precision and relevance of the data, whereas data *reliability* emphasises the consistency of data (Collis and Hussey, 2021; Denscombe, 2021). Both of these assessment criteria are key characteristics of good research quality; however, *reliability* of research will be the first criterium to be assessed, since lack of *reliability* will automatically invalidate the research (Saunders *et al*., 2019). Figure 5.4 showcases: both criteria with their relevant characteristics; common threats to these criteria (on data collection and data analysis stages of research process); and steps that can be taken to improve them (based on quantitative and qualitative data and analysis techniques).

Reliability is concerned with consistency aspect of research, *viz.*, whether the research design can be replicated and the same result can be achieved using the same research design (Saunders *et al*., 2019; Clark *et al*., 2021; Collis and Hussey, 2021). This is also referred to as *external reliability* which is mainly concerned with the consistency of research after the project (*ibid*). Threats to *reliability* can stem, for instance, from participant error, participant bias, researcher error and researcher bias (as exemplified in Figure 5.4) or any inconsistency that could emerge if the research is conducted on another occasion or by another researcher (Robson and McCartan, 2016; Saunders *et al.*, 2019; Denscombe, 2021). A number of approaches can be adopted to establish the *reliability* of research that demonstrates consistency (Robson and McCartan, 2016). Examples are: 1) *test-retest*, when the same research tool is used on a later occasion to test if the same result can be achieved (Saunders *et al*., 2019; Clark *et al.,* 2021); 2) *split-half*, when data are split into half and the findings of both dataset are compared (Robson and McCartan, 2016; Fellows and Liu, 2022); 3) *observation schedules* (as a way of achieving inter-observer reliability) to compare whether a different researcher will arrive at a similar conclusion (Denscombe, 2021; Clark *et al.,* 2021).

Figure 5.4 - Main research quality assessment criteria.



Saunders *et al*. (2019) also differentiate *internal reliability* which denotes ensuring consistency during a research project. Examples of achieving *internal reliability* are through: writing memos throughout the stages of research (e.g. notes about coding process, data selection criteria, data analysis) (Robson and McCartan, 2016; Denscombe, 2021); or involving more than one researcher within a single research project whenever possible (Saunders *et al*., 2019). Compared to *reliability* that focuses on research consistency during and after project, *validity* incorporates many tiers of metrics such as relevance, accuracy, precision and generalisability (Saunders *et al*., 2019; Denscombe, 2021). Therefore, those metrics are grouped as *internal validity* and *external validity*. The relevance is the first factor of *internal validity* that is concerned with the bearing of the data (collected and in the findings) on a research topic and research question(s) (Denscombe, 2021). In other words, relevance assesses whether the measures chosen in the research are appropriate for intended purpose of the research (Saunders *et al*., 2019). Justification of relevance can be achieved through: 1) *face validity* by basing the work on good sense of judgement of what appears reasonable, obvious and logical (Clark *et al.,* 2021; Collis and Hussey, 2021); or 2) *construct validity* by referring to existing theories, knowledge and previous studies in the field (Robson and McCartan, 2016; Denscombe, 2021). Precision and accuracy in *internal validity* are focused achieving error-free process in data collection, data transference and data analysis stages (Denscombe, 2021). On data collection stage precision and accuracy factors assess for potential systematic bias which for instance, can be prevented by: piloting data collection process (before actual data collection stage); or adding 'check questions' to verify the validity of participants' responses. Similarly, the concerns for precision and accuracy arise on data analysis stage that require ensuring that no administrative error impacts the data entry and data analysis.

In terms of *external validity*, the data and findings are judged according to generalisability (Collis and Hussey, 2021). Generalisability is focused on how fit the data and findings are to be applicable in similar occasions and assesses the ability of data and findings to explain similar phenomena in general (Robson and McCartan, 2016). In the context of qualitative data analysis generalisability is referred as transferability (Saunders *et al.,* 2019).

5.6.1. Assessment criteria for quantitative and qualitative data analysis techniques

Most of the common methods of achieving internal and external *validity* as well as *reliability* may vary in qualitative and quantitative analysis techniques (Robson and McCartan, 2016; Saunders *et al*., 2019; Clark *et al.,* 2021). This difference extends to their way of being termed, *viz.*, *reliability* in qualitative data analysis techniques is occasionally referred as dependability, *internal validity* as credibility and *external validity* as transferability (*ibid*) (as described in Figure 5.4). Techniques to assess data quality and the findings in quantitative analysis are well-established and steps and metrics for quality assessment are commonly included within the same computer aided data analysis software tools. Therefore, presenting the findings of quantitative analysis with an optimal level of *validity* and *reliability* is easier with statistics, graphs, formulae and tables and findings that contain crisp numbers which are rarely disputable (Clark *et al.,* 2021; Denscombe, 2021). However, techniques to assess the *reliability* and *validity* of data in qualitative analysis techniques is not as solid as in quantitative analysis techniques, since the data in the form of text is open to different interpretations and the findings presented can be easily questioned (*ibid*). Another reason of difference is that qualitative analysis techniques are iterative and unsystematic, where steps followed to analyse qualitative data may vary from one researcher to another depending on their personal values, interpretation and background knowledge. Therefore, to tackle these ambiguities around qualitative data analysis, a researcher must strive to systematise the data analysis process as far as practicably possible. Other practical steps to improve the quality of research in qualitative data analysis techniques are to: 1) use triangulation to enhance the *internal validity* (i.e. credibility) of findings (Saunders *et al*., 2019); 2) selectively present a finer detail and 'thick description' of the studied phenomenon to improve *external validity* (i.e. transferability or generalisability) (Collis and Hussey, 2021); 3) keep process of analysis transparent when presenting the findings of a study to establish *reliability* (i.e. dependability) (Denscombe, 2021); and 4) showcase open-minded approach by presenting outliers (data that are not neatly conformant with researchers' analysis) in the findings to demonstrate objectivity (i.e. confirmability) (Fellows and Liu, 2022).

5.7. RESEARCH PHILOSOPHY

The term research philosophy refers to system of views, beliefs and assumptions about knowledge development, which may vary depending on the research question, aim and objectives (Bryman, 2012; Saunders *et al*., 2019; Collis and Hussey, 2021). Every individual research stage involves making number of assumptions such as (including but not limited to) ontological, epistemological or axiological assumptions in the process of knowledge generation (Clark *et al.,* 2021; Fellows and Liu, 2022). *Ontology* is the assumptions about the nature of reality in social world which determines the research objects and phenomena as well as the way researchers see and approach them (Saunders *et al*., 2019; Collis and Hussey, 2021;

Denscombe, 2021). Whereas *epistemology* represents assumption made about human knowledge or knowing (namely, how researchers know what they claim to know) (Saunders *et al*., 2019; Clark *et al.,* 2021). *Epistemological* assumptions are concerned with what constitutes acceptable, legitimate and valid knowledge and how knowledge is communicated (Collis and Hussey, 2021). Therefore, an *epistemological* assumption that researchers make determines the sort of contribution to knowledge their research will generate (Clark *et al.,* 2021; Fellows and Liu, 2022). Views about how knowledge should be produced are known as *epistemological* positions. They raise questions about how the social world should be studied and whether the scientific approach advocated by some researchers (involving formulating a hypothesis and then testing it using precise measurement techniques) is the right one for social research. *Axiology*, on the other hand, denotes the extent and ways of researchers' values and beliefs might impact the research process (Collis and Hussey, 2021). This value-focused assumption determines how researchers deal with their own values (whether they openly let their values play a role in research process or strives to hold them back) and values of participants (Clark *et al.*, 2021).

Another less known dimension that has two opposing poles or extremes is the representation of the political and ideological perspective of a researcher. These two extremes are called regulation perspective (or sociology of regulation) and radical change (or sociology of radical change) (Saunders *et al.,* 2019). *Regulation perspective*, as the name suggests, is concerned with the regulation of society, the structure and underlying unity of societal systems and human behaviour and hence, researchers adopting a *regulation perspective* advocate status quo and order and look for integration, consensus and cohesion (*ibid*). Whereas researchers with a *radical change perspective* carry a vision for great potentials and better alternatives and hence they: question domination; embrace contradiction and conflict; looks for deprivation; seeks emancipation; advocates for radical change; and attempt to overturn existing state of affair and disrupt current practices (Clark *et al*., 2021). These two different perspectives that a researcher can adopt represent the study's purpose, however they are not as much common as to be a part of consideration to be included in the selection of philosophical stances (Saunders *et al*., 2019). Rather, the selection of philosophical stances are mainly constructed through assumptions about reality (*ontology* of the study) and acceptable knowledge (*epistemology* of study).

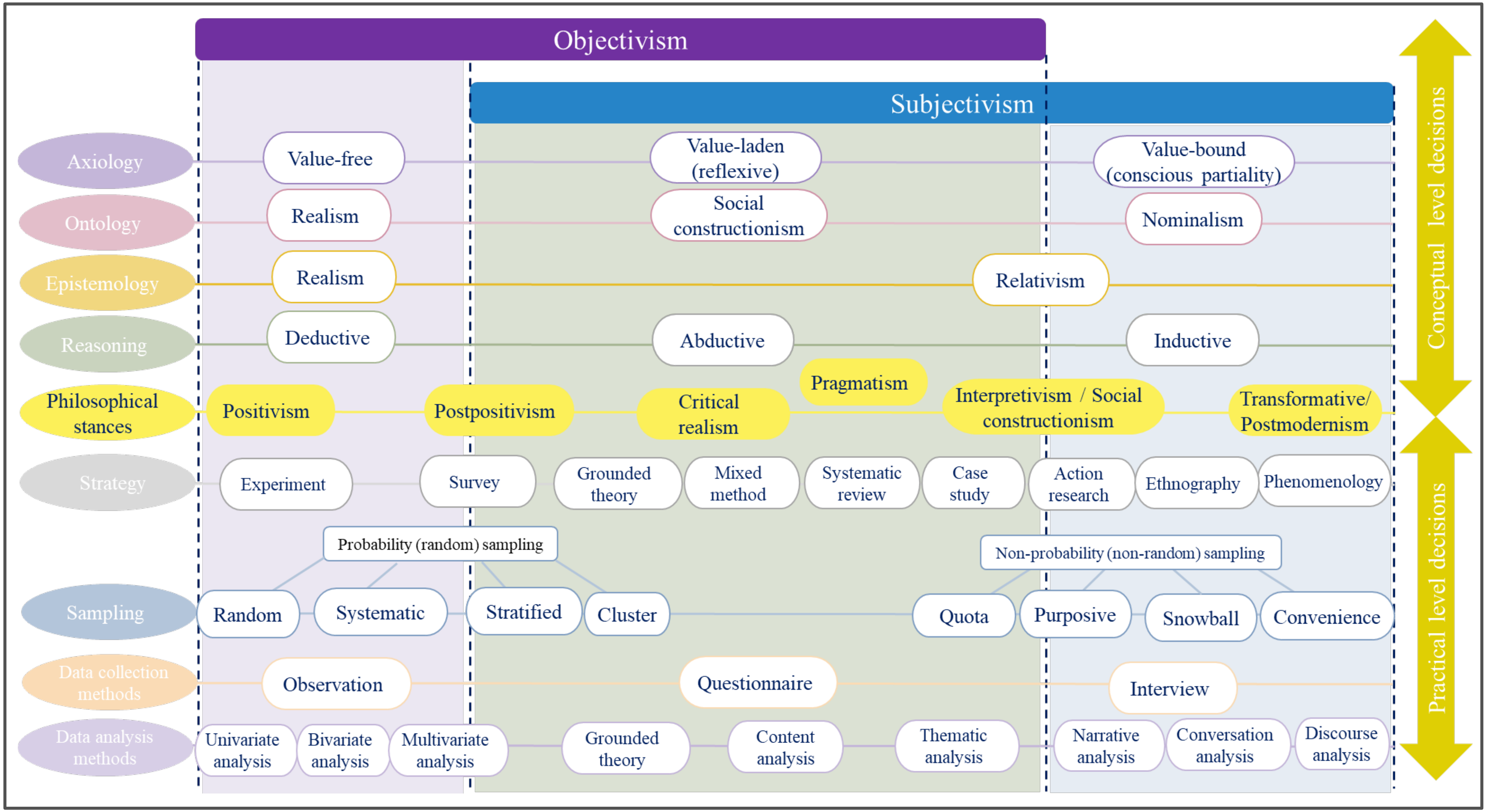
5.7.1. Objectivism and subjectivism in research

Similar to axiological assumption, the researcher's role in research process and findings is also reflected in the continua/dimension of research approach known as subjectivity and objectivity (Fellows and Liu, 2022). *Objectivism* holds the assumption that social reality is external to researchers and that the researcher's perceptions and beliefs do not impact the nature of reality (Saunders *et al*., 2019). Therefore, *objectivism* treats the social entities being studied as physical entities that exist in natural science and believes that there is only one true social reality experienced by all social actors (Clark *et al*., 2021). According to *objectivism* the social world is solid, granular and relatively unchanging and social phenomena taking place in the social world has universal and enduring character (Robson and McCartan, 2016; Saunders *et al.,*2019).

Subjectivism (alternatively called *constructionism* (Clark *et al*., 2021) in contrast asserts that social reality constitutes the perceptions, beliefs and actions of social actors and considers that the order and structure of social phenomena are created through use of language, perceptions and concepts (Saunders *et al*., 2019). Unlike *objectivism* which focuses on discovering universal reality and laws of explaining social behaviours, *subjectivism* is concerned with different opinions and interpretation (Robson and McCartan, 2016; Fellows and Liu, 2022). Therefore, *subjectivism* accepts multiple realities that represent difference of experiences and perceptions.

Different research philosophies can be differentiated in terms of their assumptions in the continua of objectivism-subjectivism. Figure 5.5 demonstrates earlier alluded three assumptions of philosophy (*axiology*, *ontology* and *epistemology*) and research reasoning on the continua of *objectivism* and *subjectivism* (which are conceptual level decisions), along with some examples of philosophical stances, research strategies, sampling techniques, data collection methods and data analysis methods (grouped as practical level decisions). The figure describes that objectivism *per se*, or research based on pure objectivity entails *realism ontology* which assumes that social entities exist in reality external to independent of social actors (Fellows and Liu, 2022). The research *epistemology* that is based on complete objectivity focuses on knowledge generation by means of measurable and observable facts, whereas the *axiology* adopts a value-free and detached approach (Clark *et al*., 2021; Fellows and Liu, 2022). Therefore, the *positivism* philosophical stance is located on pure objectivism area as an example that constitutes all alluded characteristics (realism *ontology* and *epistemology* and value-free *axiology*) of each assumption. All these elements of research design are grouped as conceptual level decisions, selection of which leads to further practical level decisions. *Experiment* research strategy, *random* and *systematic* sampling techniques, *observation* data collection methods and *univariate*, *bivariate* and *multivariate* data analysis methods are described as pure objectivity-based elements of research design.

Figure 5.5 - Elements of research design on the spectrum of objectivity and subjectivity.



Subjectivism, on the other hand, entails *nominalism ontology* (also called *conventionalist ontology*) which assumes that social reality and phenomena are generated through language, perceptions and beliefs of social actors (Saunders *et al*., 2019; Fellows and Liu, 2022). Accordingly, *epistemology* of complete *subjectivity-based* research is concerned with opinions, interpretations, narratives and experiences of social actors (Fellows and Liu, 2022). Hence, the *axiology* in such studies is value-bound which is also known as conscious partiality (Clark *et al*., 2021). *Transformative* or *postmodernism* philosophical stances are examples of the pure *subjectivism* approach to research as described in Figure 5.5. *Interpretivism* is also known to be a *subjectivism*-based approach however, it also strives for objectivity and attempts to avoid purely subjective approach (hence, it is located halfway at the middle area of the spectrum).

The middle of the spectrum in the Figure 5.5 represents the integration of both *subjectivism* and *objectivism* or characterises the approach when researchers disagree with the notion that only a single best approach can be a viable option to generate knowledge. Assumptions and philosophical stances located in this area strive to maintain both *subjectivism* and *objectivism* to use their strengths in one single research project (Fellows and Liu, 2022). Therefore, studies with such an approach predominantly adopt *mixed methods* research strategy which is based on pluralist methodological view (Collis and Hussey, 2021). *Axiology* is value-laden, meaning researchers acknowledge the impact of their own world views and seek to remain as objective as possible by minimising bias and error through practice of reflexivity (Clark *et al*., 2021; Fellows and Liu, 2022); whereas *ontology* is based on social constructionism which is a mildly subjectivist approach supplemented with the strive for objectivity (Saunders *et al*., 2019). *Ontology* of social constructionism assumes that reality is constructed intersubjectively, i.e. generated through social interaction where social actors create partially shared realities (*ibid*).

5.7.2. Characteristics of research philosophies

These three assumptions (*axiology*, *ontology* and *epistemology*) shape all aspects of the research being conducted (Fellows and Liu, 2022). Each choice of assumption collectively creates certain philosophical underpinning that facilitates shaping the research design and impacts the research findings and its interpretation (Bayramova *et al*., 2021; Clark *et al*., 2021). Therefore, selecting certain philosophical approach with well-thought-out assumptions will inevitably lead to certain methodological choice with specific research strategy, data collection and analysis techniques (as exemplified in Figure 5.5) that are relevant to the selected philosophical underpinning. Therefore, a researcher makes a philosophical commitment when selecting one research strategy over another, since every strategy involves specific way of gathering, interpreting and analysing data and deciding what constitutes acceptable, valid and legitimate knowledge (Denscombe, 2021). Table 5.2 presents some of the common philosophical stances by describing their related three assumptions and their apposite strategies along with their typical characteristics in componential synthesis.

Table 5.2 - Main characteristics of some common research philosophies.

Research philosophies	**Description**	***Ontology*-nature of reality**	***Epistemology*-nature of acceptable knowledge**	***Axiology*-role of (researchers') value**	**Common strategies**	**Typical characteristics of research in relevant research philosophy**													
						Reasoning			Purpose				Outcome		Type of data			Research design	
						Inductive	Deductive	Abductive	Explorative	Descriptive	Explanatory	Predictive	Basic	Applied	Qualitative	Quantitative	Mixed	Flexible design	Fixed design
Positivism	Relies on law-like generalisation and the knowledge produced known as basis for formulating general laws about causes and consequences. (Robson and McCartan, 2016; Collis and Hussey, 2021; Denscombe, 2021).	Realist approach which states that patterns and regularities exist independent of researchers in social world and researchers' role is to discover them through research (Denscombe, 2021).	Only observable and measurable things and firm facts that are empirically observed are considered to be a knowledge (Denscombe, 2021).	Value-free research where researchers maintain objective stance by remaining detached and neutral towards what is being studied (Robson and McCartan, 2016; Saunders *et al*., 2019).	Experiments; Structured observation; Surveys through questionnaires and structured interviews (Saunders *et al*., 2019; Collis and Hussey, 2021).		+				+	+	+			+			+
Postpositivism	Relies on law-like generalisation as well as on theories. Knowledge produced is known as provisional or approximation to truth (Robson and McCartan, 2016).	Reality exists external to individuals, but certain social realities (e.g. social injustice) are also accepted to exist beyond observable and measurable (Robson and McCartan, 2016).	Reliance on sole observable explanation is not sufficient and hence theoretical explanations are required to fill in the gaps (Denscombe, 2021).	Highly reflexive about the potential impact of researchers' values and world views on research outcome and hence strives to minimise that effect (Denscombe, 2021; Fellows and Liu, 2022).	Surveys through questionnaires; Systematic reviews of statistics and documents (Collis and Hussey, 2021; Fellows and Liu, 2022).		+				+		+			+			+
Critical realism	An approach studying mechanisms and structures leading to a phenomenon in its natural setting in order to generate specific to research	Reality is multi-layered; apart from observable and measurable, there is another layer (i.e. actual and causal layer) of structured reality explaining the	Knowledge is historically transient and facts are socially constructed (Relativistic view) (Robson and McCartan, 2016;	Value-laden research where researcher strive to remain objective and to minimise bias and error that stem from researcher's world	Combination of any two or three research strategies through mixed method or triangulation respectively (Robson and			+	+	+	+				+	+	+	+	

	problem explanations, solutions, findings and responses. Pluralist approach to research methods (as opposed to unitarist methodological view) (Robson and McCartan, 2016).	underlying factors of directly observable and measurable (i.e. empirical) phenomenon (Saunders *et al*., 2019).	Saunders *et al*., 2019).	view, cultural experience and background knowledge (Saunders *et al*., 2019; Fellows and Liu, 2022).	McCartan, 2016; Saunders *et al*., 2019).														
Interpretivism (Social constructionism)	Produces rich, in-depth study of small samples which enables the findings to be generalised from one setting to another similar setting (Collis and Hussey, 2021)	Reality is complex, rich, multitudinal (not universal) and socially constructed though multiple meanings and interpretation and variance in culture and language. Reality is flux of experiences, processes and practices (Saunders *et al*., 2019).	Knowledge is inter-subjective since it is constructed through interaction of social actors and by their perceptions, beliefs and actions (Robson and McCartan, 2016; Denscombe, 2021).	Subjectivity is integral part of research and researchers' values are assumed to exist (Robson and McCartan, 2016; Denscombe, 2021).	Case study; Action research; Surveys through unstructured or semi-structured interviews; Phenomenology Ethnography; Grounded theory; Systematic reviews (Saunders *et al*., 2019; Collis and Hussey, 2021)	+		+	+	+			+	+	+		+	+	
Pragmatism	Research problem driven, mixed methods research involving combination of more than one data analysis and collection techniques which enable using both quantitative and qualitative data in single study (Collis and Hussey, 2021)	Reality is practical consequences of ideas that are built through continuous change of experiences, processes and practices (Saunders *et al*., 2019).	Focus on problems, practices and relevance. Knowledge is acceptable and meaningful when it has a practical use in a specific context and when enables successful action (Saunders *et al*., 2019).	Value-laden research where researchers remain reflexive of their impact on research. Research initiated and sustained through researchers' doubts and beliefs (Robson and McCartan, 2016; Fellows and Liu, 2022)	No specific research strategy. Any one or combination of two or three research strategies that are appropriate for research problem can be adopted (Saunders *et al*., 2019).	+	+	+	+	+	+	+		+	+	+	+	+	

5.7.2.1. Positivism

Positivism is a classic scientific approach to research which aims to investigate properties of real-world using methods that allow drawing impartial and objective conclusions without researchers' influence (Robson and McCartan, 2016; Collis and Hussey, 2021; Denscombe, 2021). The impartiality feature of *positivism* prompts that *axiology* is based on value-free approach where a researcher maintains neutral and detached stance (Robson and McCartan, 2016; Fellows and Liu, 2022). The ontology in *positivist* paradigm states that the reality of social world exists independent of the researcher in the form of patterns, rules and regularities similar to the laws in natural science (Saunders *et al*., 2019). Therefore, the purpose of research in *positivistic* approach is to discover those patterns and regularities that represent one true reality (Collis and Hussey, 2021). In terms of epistemology, *positivism* accepts only observable and empirical evidence as a viable source to study and explain the properties of social world (Gillham, 2000; Denscombe, 2021). Hence, the *positivistic* approach is mainly associated with the use of quantitative data that can be observed, recorded and measured, the findings of which allow formulating law-like generalisation about causes and consequences of studied phenomenon (Saunders *et al*., 2019; Collis and Hussey, 2021). Studies with a *positivistic* approach commonly adopt replicable and testable scientific methods or strategies such as *experiments* and *systematic observations* that promise unambiguous and accurate knowledge (*ibid*).

5.7.2.2. Postpositivism

Postpositivism, as the name suggests is rooted in a *positivist* philosophical approach and aims to find causes and consequences of events through empirical observations (Robson and McCartan, 2016). According to the *postpositivist* approach the reality in the form of patterns and rules exist in the social world independent of individuals' perception (Denscombe, 2021). Therefore, similar to *positivism*, *postpositivism* strives to generate an outcome that is based on impartial discovery of those law-like regularities. However, the significant difference of these two is that *postpositivism* is flexible compared to *positivism* in terms of the objectivity of research and completeness of findings (Robson and McCartan, 2016). *Postpositivism* accepts that relying solely on observable things is not enough to explicate social phenomenon and hence, theoretical ideas must be used to fill in the gap (Robson and McCartan, 2016; Denscombe, 2021). Therefore, reliance on theories in *postpositivism* introduces some traces of subjectivity, since theories to a degree influenced by researcher's perception (Denscombe, 2021). However, *postpositivism* does not entirely abandon objectivity but rather strives to follow it as a goal alongside the realisation that absolute objectivity is not possible (Robson and McCartan, 2016). This entails openly acknowledging the impact that researchers' value and perception can have on the outcome of research, by using reflexivity and self-awareness (Clark *et al*., 2021; Fellows and Liu, 2022). Similarly, reliance on theories to explain the phenomenon also influences epistemology of *postpositivism*, namely the status of the knowledge produced through research. Since the knowledge generated from research is not based on direct observation but is mediated through theories, it is considered as provisional knowledge rather than 'universal truth' about the social world (Denscombe, 2021). Therefore, a *postpositivistic* approach recognises that the knowledge generated is approximation of truth that can change in the light of new evidence or explanation (Robson and McCartan, 2016).

5.7.2.3. Critical realism

Critical realism is comparable to the *postpositivism* research approach. In the same way as *postpositivism*, *critical realism* accepts that not all social phenomena can be readily discernible (with bare eyes) and hence, relies on theories to address the gaps but pursuing the goal of sustaining objectivity (Denscombe, 2021). Likewise, *critical realism* most commonly uses survey and questionnaire data, official statistics and documents but also embraces other strategies and research methods of hard facts and quantitative data (*ibid*). Therefore, both *critical realism* and *postpositivism* are known to have the features of *positivism* as well as *interpretivism*, respectively representing strive for objectivity but also acknowledging that not all things in social world are based on observable hard facts (Fellows and Liu, 2022). Robson and McCartan (2016) and Saunders *et al*. (2019) differentiate *critical realism* from its earlier version known as *naïve* or *direct realism*; the application of which (just as *positivistic* approach) received severe criticism due to its incompatibility to be used in social research. However, this recent version, *critical realism* has restored its applicability as an apropos philosophical approach in both natural and social science (*ibid*).

The ontology in *critical realism* takes important place, since it claims that reality does not only constitute what social actors (i.e. researcher and participant) see and experience, but there is the second layer of *ontology* that contains underlying structures of reality that shapes the observable events (Robson and McCartan, 2016; Saunders *et al*., 2019). The first layer of *ontology* or the first step of understanding the social world is social actors' empirical and direct experience based on sensations (Saunders *et al.,* 2019). Sensations are manifestations of the things in social world that can be directly seen, observed and experienced rather than actual things (*ibid*). However, the second layer of *ontology,* which is the step of sensemaking the reality, goes beyond direct observations and involves mental processing by reasoning backwards to reveal the underlying reality that have caused the manifestations of observed phenomenon (Denscombe, 2021; Fellows and Liu, 2022). *Positivistic* (and *naïve/direct realism*) philosophical stance, on the other hand, is engaged on first layer of *ontology* by focusing on merely observables and measurables and their causal interaction, but not on the underlying structures that cause the phenomenon (Robson and McCartan, 2016; Saunders *et al*., 2019).

5.7.2.4. Interpretivism (Social constructionism)

Interpretivism is concerned with the way the social world is constructed based on people's lived experiences and their way of understanding their experiences (Fellows and Liu, 2022). Therefore, *interpretivism* is closely associated with *social constructionism* (Robson and McCartan, 2016). According to *interpretivism* social reality exist only in so far as it is constantly constructed and reconstructed by the actions, interpretation and beliefs of people (Saunders *et al*., 2019; Collis and Hussey, 2021). For this reason, *interpretivism* is known to subjectively construct reality (Collis and Hussey, 2021). However, this *subjectivity* is not solitary or isolated but has to be collective representing shared beliefs and interpretations (Saunders *et al*., 2019; Denscombe, 2021). Therefore, *interpretivism* embraces the approach that social world consists of multiple realities (that are inter-subjective and) constructed by different groups and society in different ways (Collis and Hussey, 2021). This means that reality in *interpretivism* is inter-subjective, namely each reality constructed by collective people based on shared beliefs and actions (Saunders *et al*., 2019; Denscombe, 2021). *Interpretivism* is premised upon the assumption that complete objectivity is unachievable, since the formulation of research question, selection of research strategy, data collection and analysis techniques or the conclusion drawn from the research are all influenced by researchers' own values, perceptions and background knowledge (Robson and McCartan, 2016; Clark *et al*., 2021).

Interpretivism characteristically relies on qualitative data and is associated with strategies such as *ethnography*, *phenomenology*, *case studies*, *grounded theory* and small-scale *surveys* (Saunders *et al*., 2019; Collis and Hussey, 2021; Denscombe, 2021). However, it is not an entirely qualitative data-based approach (Fellows and Liu, 2022). Therefore, data collection methods used in an *interpretivist* approach such as questionnaires, participant observation or study of documents may also involve quantitative type data (Saunders *et al.,* 2019; Denscombe, 2021).

5.7.2.5. Pragmatism

As a philosophical stance, *pragmatism* is discrete from other research paradigms by the way of not adhering to a single best approach to research, but rather stressing the practical usefulness of research methods and strategies for a research problem (Robson and McCartan, 2016; Saunders *et al*., 2019; Collis and Hussey, 2021). Therefore, *pragmatism* does not follow any specific *ontology*, *epistemology* or *axiology* but stays open to adopt any approach that fits for the specific nature of the research problem (or any approach that generates practical application and improves practices) (Robson and McCartan, 2016; Fellows and Liu, 2022). In terms of objectivity, *pragmatism* aligns with the standpoint of *postpositivism* and *interpretivism* which recognise the limitation of achieving complete objectivity (Denscombe, 2021; Fellows and Liu, 2022). More than that, *pragmatism* stresses that any knowledge or explanation generated bear the influence of time and place, meaning the knowledge is a product of that specific historical era and cultural context it has been generated in (Denscombe, 2021). Therefore, echoing *postpositivism*, *pragmatism* acknowledges that the knowledge generated is provisional and approximation that might change with the impact of new knowledge in different time (Robson and McCartan, 2016).

In terms of research strategy or data analysis methods, *pragmatism* acknowledges that specificity of one research problem might require adopting research strategies and data analysis methods associated with for instance *positivist* approach while other research problem is appropriate to be used in *interpretivist* approach-based strategies and data analysis methods (Robson and McCartan, 2016). However, most significantly *pragmatism* is known *for mixed-methods* research strategy which permits to integrate more than one research strategy and data analysis methods in a single study (Saunders *et al*., 2019; Collis and Hussey, 2021). This potential of *pragmatism* also allows integration of both quantitative and qualitative data types in one research (Robson and McCartan, 2016; Collis and Hussey, 2021; Fellows and Liu, 2022).

5.7.2.6. Other philosophical stances

Unlike other research philosophies that have leeway of selecting the target (or topic) to study, two remarkably similar research philosophies *transformative* and *postmodernism* are explicitly and exclusively focuses on the study of power dynamics that causes structural inequalities in the social world (Denscombe, 2021; Fellows and Liu, 2022). Both philosophical approaches emerged in the late twentieth century in an attempt to challenge accepted ways of thinking and enhance the knowledge of views, experiences of marginalised groups that are not emphasised enough when conventional approaches to study are used (Saunders *et al*., 2019; Denscombe, 2021).

Research based on *transformative* and *postmodernism* philosophy focus on particular groups that experience discrimination or marginalisation and aim to expose those injustices associated with race, religion, social class or gender (*ibid*). This approach aligns with *ontological* positions of *critical realism* and *postpositivism* which treat social reality as having an existence external to individuals. External reality here denotes that certain phenomenon such as gender inequality or institutional racism exist independent of individuals' perception and bear an impact on individuals' lives irrespective of their desire to believe in it or not (Denscombe, 2021).

Transformative approach tends to focus not on one but multiple realities to identify the way of certain social groups obtain their vision of social reality which is treated as more important than other groups (*ibid*). This approach towards treating the social world as having multiple realities in its turn, resonates with the *interpretivism* approach. However, *postmodernism* and *transformative* research philosophies go even further than *interpretivism* in a way that they reject *objectivism* and *realism ontology*, by emphasising that any sense of order is provisional and the reality is flux and chaotic (Saunders *et al*., 2019; Denscombe, 2021). *Postmodernism* assumes that there is no order in social world beyond which social actors give to it through language (Saunders *et al*., 2019). Research in *postmodernism* approach study power relations by deconstructing dominant realities and searching for instabilities such as silences, absences and supressed voices within that widely accepted truth (*ibid*).

Similarly, a *transformative* paradigm has affinity with the *pragmatism* approach in a way that it selects the best fitting approach (rather than clutching to one specific method only) to show how dominant groups impose their vision of reality over other groups (Fellows and Liu, 2022). The prominent significance of *transformative* paradigm is that it treats the research itself as the important tool to instigate change. The example is *emancipatory research* that encourages to use research to empower the disadvantaged groups and communities (Denscombe, 2021). Therefore, both *transformative* and *postmodernism* research openly accept abandoning the notion of *objectivity* in order to serve as a facilitator of change and to give a ‘voice’ for social groups whose interests are poorly represented or understudied (Fellows and Liu, 2022). Researchers using these approaches take sides and become advocates for minorities who are suffering from injustice and hence, the studies in such paradigm are occasionally referred as advocacy research (Saunders *et al*., 2019; Denscombe, 2021). *Participatory research* (i.e. study based on action research or participatory action research strategy) is another example of the *transformative* paradigm-based study, where power is given to those groups who are intended to benefit from the research (Denscombe, 2021). Contrary to the conventional research process where a researcher is in control, in *participatory research* the disadvantaged group have control on research agenda (Collis and Hussey, 2021).

Another philosophical approach that is similar to the *transformative* philosophy is the *indigenous* philosophy (Le Grange and Mika, 2018). However, the focus of the studies in the *indigenous* paradigm is only on the interest of indigenous people and to represent their culture and world view (Denscombe, 2021). This particular research philosophy allows true representation of indigenous people and their lives, where conventional research paradigm might have unintended consequences of distorting the reality (*ibid*). Therefore, studies based on *indigenous* approach facilitate promotion of indigenous people on their own terms and protect their interest through their vision of things.

5.8. SUMMARY OF CHAPTER 5

Types of research methodology elements that are discussed in this chapter cannot represent an exhaustive list due to their multiplicity, but rather the narrative presented constitutes only the most well-known and commonly used techniques, methods and philosophical stances (Saunders *et al.,* 2019; Clark *et al*., 2021). Furthermore, types of research strategy, data analysis or collection techniques mentioned in this work are predominantly appertain to social science, since the research problem delineated in this thesis is within the realm of social interaction. The object and target being studied in natural science is materials or substances, whereas in social science the focus is on complex relationships of social phenomena. Another difference is in the expectation or outcome of the research; meaning in natural science the expected research outcome is the closest identification of absolute truth about the studied phenomenon (Fellows and Liu, 2022). However, phenomena being studied in social science are complex and linked to multiple bodies of knowledge and hence, explaining the phenomena solely through one perspective or one approach is impossible. Therefore, different studies will find different explanation of the same phenomenon in social science. Similarly, the outcome(s) of this present thesis will be a unique contribution that are different from other research in the field and will serve as a valuable input towards understanding the safety phenomenon. That is, the research design adopted for the current study will be heavily influenced by the research problem or phenomenon (i.e. occurrence or maintenance of safety or unsafety in complex sociotechnical systems such as construction workplaces) and selection of research methodology elements (e.g. research strategy, data collection method and data analysis method) will be problem-driven and flexible to ensure research outcomes bear higher practical application.

CHAPTER SIX – RESEARCH DESIGN AND PROCESS OF THE STUDY

6.0. INTRODUCTION

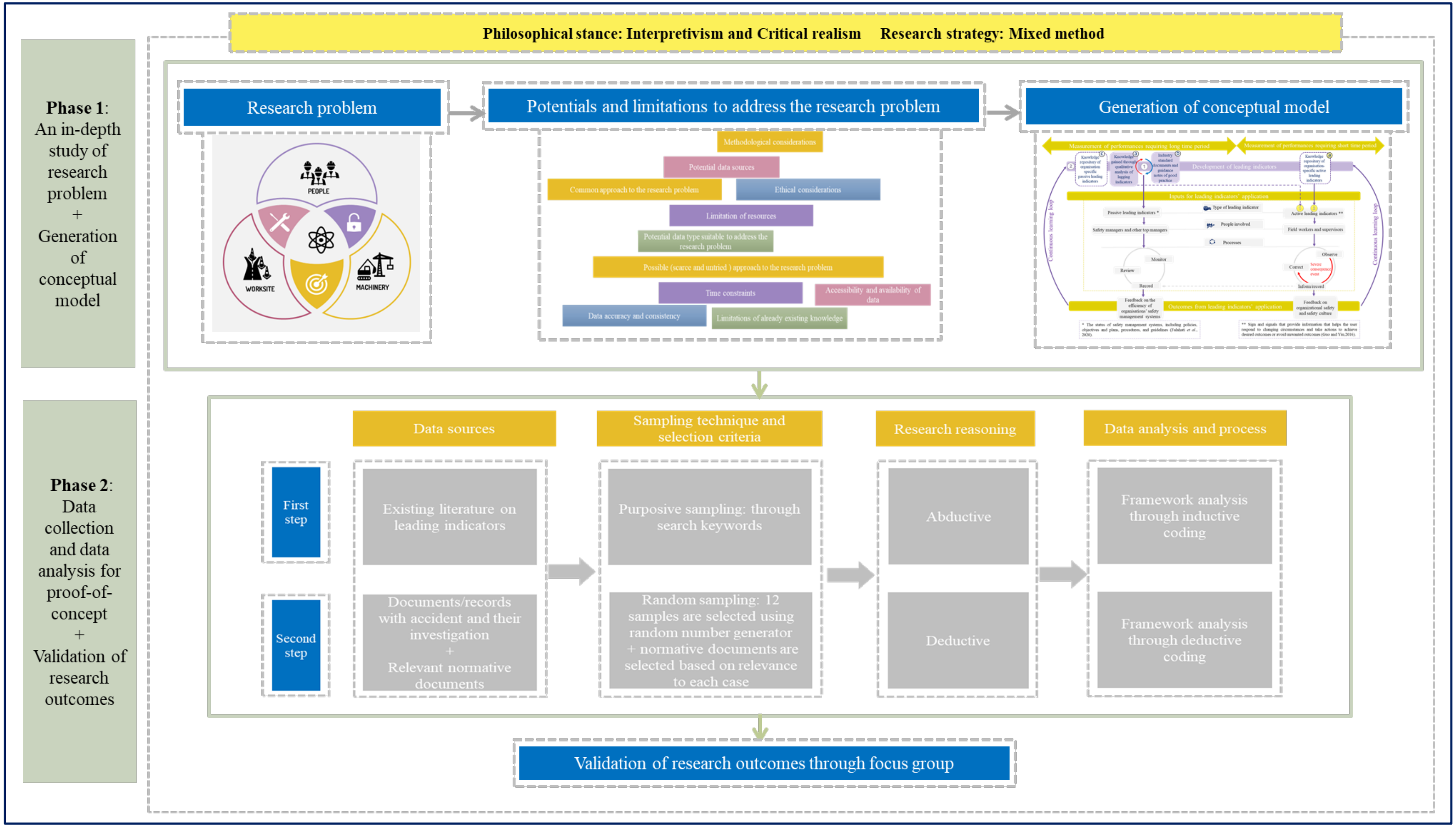
Selecting elements of research design (i.e. methodological elements of current work) is required to be academically grounded and justified, given the presence of a large variety of different philosophical underpinnings, strategies, data analysis and collection methods and data types and sources. The research problem (delineated in the introduction and literature review sections previously) is one of the factors impacting on the formulation of research design. Subsequently, study and definition of the research problem, data availability (e.g. access to data or data type available, status of existing knowledge (that is, the knowledge available in pertinent research and existing gaps in the literature)) and limitations in terms of time and resources allocated for a research project altogether impact upon formulation of research questions, research aim and objectives. Accordingly, selected research questions, aim and objectives inform the selection of research philosophy, research reasoning, research strategy, data type to be included, sampling techniques, data collection and data analysis methods. Cumulatively, all these selections and choices create bespoke research design specific to research project.

Research phenomenon (i.e. occurrence or maintenance of safety or unsafety) studied in this current research project requires a holistic approach, since the phenomenon occurs because of multilevel, multigranular elements and manifests at their interaction rather than with the influence of one single element (i.e. one of the WMS). Therefore, emphasis on maintaining holism throughout the research was the main factor in the process of research focus (i.e. safety management through LIs) identification (Fellows and Liu, 2022). These and other methodological choices described in the current chapter cumulatively generates this present study's research design.

6.1. RESEARCH DESIGN OF THE STUDY

Research design is a general plan constituting: a clearly defined research objectives (derived from research questions); sources and methods of data collection; techniques of data analysis; considerations for ethical issues and other constraints in terms of data access, time, location and resources (Fellows and Liu, 2022). A clear and coherent research design must also indicate alignment or pertinence of selected data type and data source, sampling and data collection method, data analysis technique and philosophical approach with research questions, aim and objectives. In the current study the construction of a research design, formulation of research questions, research aim and objectives are performed based on preliminary study of the pertinent literature which establishes existing knowledge and any research gaps apparent. Figure 6.1 describes these constituent elements of research design in two phases.

Figure 6.1 - Overview of the research design.



The first phase commences with defining the study's research problem, followed by identification of constraints and limitations to address the research problem which eventually leads to formulation of research focus with research aims and objectives. Consequently, the outcomes of the first phase lead to the second phase where data collection and data analysis are performed to establish the proof-of-concept. The overall research design adopts the following construct: research philosophy of interpretivism and critical realism; research strategy of sequential mixed method combining systematic literature review and case study; and data analysis method of framework analysis of inductive coding followed by framework analysis of deductive coding. A combination of research reasonings is adopted, *viz*. inductive reasoning predominates in the first phase, whereas on the second phase an analytical framework is developed using abductive reasoning and followed by the adoption of this framework using deductive reasoning. Consequently, research outcomes from this research design will be tested in a validation step by adopting focus group interview with experts.

6.1.1. Research philosophy and strategy

The study adopts an overarching epistemological design of interpretivism and critical realism. Interpretivism predominates in the first phase, where classification, selection and grouping of publications and decisions taken on their relevance or otherwise to the study are performed through interpretation and inference. Although not stated explicitly, an interpretivist epistemological view is an extensively adopted philosophical stance in construction literature (Borys, 2011; Alsamadani *et al.,* 2013; Hallowell *et al*., 2013; Sherratt, 2014) that yields studies explaining a phenomenon from diverse points of view. However, rather than depending on complete subjectivity (reflected from interpretivism), combining this philosophical position with critical realism introduces objectivity (Robson and McCartan, 2016). That is, interpretivism explains and interprets a phenomenon under investigation from different perspectives in a subjective way, whereas critical realism entails using objectivity to enhance critique and appraisal of analysis undertaken (Clark *et al*., 2021). Specifically, applying objectivity instigates the practice of reflexivity and self-awareness to reduce researcher bias by constantly referring to research aims and objectives (Denscombe, 2021).

Critical realism, as a philosophical underpinning, strives for impartiality by pursuing the goal of sustaining objectivity, but also equally acknowledging that not all things in the social world are based on observable hard facts and emphasising the reliance on different explanations and theories to address any knowledge gaps (Saunders *et al*., 2019; Clark *et al*., 2021). Therefore, the critical realism philosophical approach serves as a foundation to inductively generate a new theoretical conceptual model based on the insights emanating from the data (Denscombe, 2021). Critical realism focuses on explaining what is seen and experience accrued in terms of the underlying structures of reality that shape the observable events (*ibid*). This philosophical approach is most appropriate to study complex structures of social phenomenon that is replete with unseen underlying factors and nuances intertangled to cause the observable occurrences (Robson and McCartan, 2016). Studies based on critical realism tend to undertake historical analyses of changing or enduring societal and organisational structures, using a variety of methods.

The research strategy adopted is sequential mixed method which combines systematic literature review and case study strategies. Systematic review (also referred as meta-analysis) is a strategy which allows structured analysis of the existing knowledge in pertinent-to-phenomenon literature (Clark *et al*., 2021). In the presence of sufficient research and publication in the literature of the studied area, this strategy is a feasible approach to developing new understanding by synthesising and contrasting both shared and uncommon perspectives (Denscombe, 2021). While systematic literature review strategy facilitates the study of the discourse in the literature, case study strategy enables a detailed analysis of a phenomenon in its natural setting (Yin, 2018). A case study strategy is propitious to reveal finer subtleties of complex social phenomenon (such as management and maintenance of safety) and suitable to study a phenomenon under investigation by adopting flexible research design (Robson and McCartan, 2016; Fellows and Liu, 2022). The structure of the case study materials can be described as *multiple case studies* (i.e. 12 different accident records sampled) *embedded in a single case* (i.e. in one organisation) (Yin, 2018; Saunders *et al*., 2019).

6.1.2. Research reasoning and data analysis method

Similarly, in consonance with the research aim and objectives, the present study consecutively follows combination of inductive, abductive and deductive reasonings for a deeper comprehension of the research context and importantly, to premise the development of new and insightful theory that can be later expanded upon and deductively tested in case studies of practice (Robson and McCartan, 2016). Inductive reasoning adopted at the outset of the study enables identification of new insights and understanding from existing knowledge. Inductive reasoning preponderates in phase 1 where the research focus is established based on identification of gaps or evidence in the literature. Whereas in phase 2, the first step of analysis is conducted by adopting abductive reasoning to develop analytical framework through iteration (i.e. reviewing the literature on LIs and reviewing the framework); and at the second step of phase 2 the research implements deductive reasoning with a purpose of identifying LIs in the qualitative dataset by using the analytical framework. Abductive reasoning involves combination of processes from inductive and deductive reasonings *viz*., by revealing new insights embedded in the dataset or observation (as in inductive reasoning); and subsequently by testing the insights, concepts or theory derived in an empirical application (as in deductive reasoning) (Collis and Hussey, 2021). In studies based on abductive reasoning these steps of inductive and deductive reasoning are performed iteratively (Fellows and Liu, 2022).

The selection of research reasoning is inextricably linked with method of data analysis. A framework analysis is adopted to: review extant literature to uncover embedded knowledge on LIs; generate an analytical framework for a systematisation of insights about LIs; and subsequently, apply the framework developed on case study materials to identify LIs in a systematic manner (Fereday and Muir, 2006; Posillico *et al.,* 2021). Framework analysis is a subset of thematic analysis which aims to draw descriptive conclusions clustered around themes by identifying similarity and differences in a qualitative dataset (Gale *et al*., 2013). Thematic clustering is performed through *inductive coding* (i.e. themes and categories are directly derived from qualitative data, in current case from selected items in pertinent literature) which engenders a framework (Fereday and Muir, 2006). This coding process, which forms the basis of the framework is performed iteratively. Subsequently, the framework is used as an analytical tool and applied to qualitative data (case study materials that are sampled through randomised sampling and relevant-to-each case study normative document) through *deductive coding* (Haas and Yorio, 2016). *Deductive coding* strives to code qualitative data based on *a priori* themes and categories (in this case a priori themes and categories are generated from systematic literature review and structured into a framework) (Fereday and Muir, 2006; Dixon, 2011).

6.2. TYPOLOGY OF SELECTED RESEARCH DESIGN

As per research typologies (mentioned in Chapter 5 Figure 5.1), the current study's research design can be described as *flexible*, since the selection of research methodology elements (i.e. research strategy, data analysis method or sampling technique) is not constrained to exact steps to be followed, as is the case in positivistic studies (Robson and McCartan, 2016). The study begins to investigate the phenomenon (i.e. occurrence or maintenance of safety or unsafety) inductively, with no prior theory or premise for proving or following. In terms of the purpose, this research starts as an *exploratory* study, because the research focuses on providing a general understanding about the phenomenon being investigated in order to uncover the need or viability for future studies (Saunders *et al*., 2019; Collis and Hussey, 2021). Such an *explorative* approach at the beginning of the study enabled a detailed review and assessment of existing theories and concepts around safety management (Fellows and Liu, 2022), while also facilitating the definition of the research problem and research focus and accordingly leading to formulation of research questions (Saunders *et al*., 2019). Furthermore, the study developed into *descriptive* research, where an in-depth examination of research focus (i.e. safety management through LIs) led to the development of conceptual model (Collis and Hussey, 2021). The conceptual model generated at the *descriptive* step of the current study facilitates deeper theoretical understanding about the research focus and creates 'clearer picture' of managing safety through LIs (Fellows and Liu, 2022). Subsequently, further steps undertaken (i.e. proof-of-concept step) can be described as *explanatory* research, where viability of developing LIs from case study materials (as proposed in the conceptual model) was tested (Clark *et al*., 2021). At this *explanatory* step, the study is concerned with applying the knowledge and insights generated in the earlier *explorative* and *descriptive* steps.

Based on the research outcomes, it can be classified as *basic* at the outset (in phase 1) and *applied* as the research was unravelling (in phase 2). *Basic* research type, similar to *exploratory* type research, aims to make contribution to the knowledge by studying issues, challenges and shortcoming associated with the phenomenon under investigation (Saunders *et al*., 2019; Fellows and Liu, 2022). Therefore, the outcome of *basic* type research will be in the form of theoretical contribution and knowledge synthesis which can serve as a novel understanding or an in-depth explanation of the studied object (Saunders *et al*., 2019). Whereas *applied* type research aims to solve the identified problem area by applying the research findings and obtained knowledge (Saunders *et al*., 2019; Collis and Hussey, 2021).

6.3. RESEARCH PROCESS IN PHASE 1 AND PHASE 2

The processes followed in each phase are described in Figure 6.2. The figure provides more details of the process in both phases of the research programme, by elucidating on the focus of study at each step, data analysis method used, keywords and data source selected to source the data for each step of current study and number of items included.

Figure 6.2 – Details of research process in phase 1 and phase 2.

		Focus of the study	Data analysis method	Search keywords and source of data	Data included for analysis
Processes in phase 1	1	Embedding training and competence within an organisation's safety culture: a systematic literature review.	Thematic analysis; Content analysis.	TITLE-ABS-KEY (training AND for AND occupational AND health AND safety AND in AND construction) in **Scopus** journal database	281 items in thematical analysis; 64 items in content analysis.
	2	Enhanced safety in complex socio-technical systems via safety-in-cohesion.	Thematic analysis; Content analysis.	TITLE-ABS-KEY (safety AND management AND in AND construction AND industry) AND (LIMIT-TO (DOCTYPE, 'ar')) in **Scopus** journal database	2,227 items in thematic analysis; 253 items in content analysis (143 from 'safety of workers' cluster; 34 from 'safety of machinery' cluster and 76 from 'safety of sites' cluster).
	3	Constructs of leading indicators: a synthesis of safety literature.	Cross componential analysis; Content analysis.	TITLE-ABS-KEY ("leading indicator", "safety management") AND (LIMIT-TO (LANGUAGE, "English")) AND (EXCLUDE (PUBYEAR, 1998) OR EXCLUDE (PUBYEAR, 1991) OR EXCLUDE (PUBYEAR, 1990)) in **Scopus** journal database	80 items in cross componential analysis; 93 items (13 more research items are added through snowballing) in content analysis.
Processes in phase 2	4	Uncovering the genome of leading indicators from lagging indicators and normative documents: a proof-of-concept study.	Framework analysis: (inductive coding + deductive coding)	TITLE-ABS-KEY ("leading indicators") OR TITLE-ABS-KEY ("proactive indicators") OR TITLE-ABS-KEY ("upstream indicators") OR TITLE-ABS-KEY ("predictive indicators") OR TITLE-ABS-KEY ("heading indicators") OR TITLE-ABS-KEY ("positive indicators") AND TITLE-ABS-KEY (develop* OR identif*) AND (LIMIT-TO (LANGUAGE, "English") in **Scopus** and **Web of Science** journal databases	448 items (327 from **Scopus** and 121 from **Web of Science** journal database) in framework analysis of inductive coding; 12 different case study materials with different number of documents in them and relevant to each 12 case normative documents in framework analysis of deductive coding.
	5	Unravelling the Gordian knot of leading indicators	Thematic analysis Deductive content analysis	TITLE-ABS-KEY ("leading indicators") OR TITLE-ABS-KEY ("proactive indicators") OR TITLE-ABS-KEY ("upstream indicators") OR TITLE-ABS-KEY ("predictive indicators") OR TITLE-ABS-KEY ("heading indicators") OR TITLE-ABS-KEY ("positive indicators") AND TITLE-ABS-KEY (develop* OR identif*) AND (LIMIT-TO (LANGUAGE, "English") in **Scopus** and **Web of Science** journal databases	3451 items (2291 from **Scopus** and 1160 from **Web of Science** journal database) in thematic analysis; 468 items (449 from 'health and safety' cluster and 19 through snowballing) in deductive content analysis.

Consequently, all the steps in phase 1 cumulatively enabled the establishment of research focus (which is safety management through LIs). Accordingly, processes at phase 2 (in Figure 6.2) follows the research design described in Figure 6.1 to test the outcome from phase 1 with real life data. The first column of Figure 6.2 illustrates how the foci of the current study were evolving, starting with a focus on the human element and training and moving towards safety-in-cohesion and then LIs' use as a measurement/data type or concept combining all three elements (WMS) of complex systems. During phase 2, the focus moves towards testing the conceptual model from phase 1, where viability of LI's development or identification from case study materials is tested. In other words, the foci of studies evolve from being *basic* and *descriptive* towards being *applied* and *explanatory*. The figure's second column describes adopted data analysis methods in each step. The first two steps identically involve thematic analysis and consecutive content analysis. Such combination of data analysis methods allows identification of main themes within the given dataset by clustering them thematically, from which, subsequently, the most relevant dataset or thematic cluster to the research aim can be selected for further analysis in content analysis. Thematic analysis is performed in Microsoft Excel by manually reviewing the bibliometric data of sourced secondary data (i.e. publications in journal database), whereas content analysis is conducted using computer-assisted qualitative data analysis software (CAQDAS) called NVivo. The third step of phase 1 involves similarly two steps of data analysis but through combination of cross componential analysis and content analysis. Cross componential analysis here denotes the process of dividing the sense of a word or concept into its minimal distinctive features (i.e. semantic components) in contrast to another word or concept (Widyastuti, 2016). Componential analysis strives to dissect the inferential, implicational and core meaning of two or more words, concepts or lexemes being analysed, by identifying and comparing their semantically related common and distinctive components (*ibid*). Data analyses in phase 2 comprise of framework analysis, thematic analysis and content analysis. Framework analysis (through inductive coding) was adopted in the proof-of-concept step at phase 2 to develop a new analytical framework based on a dataset included from pertinent literature and to apply the framework (through deductive coding) to identify LIs from sampled data of case study materials and relevant normative documents.

Secondary data obtained from pertinent literature serve as a unit of analysis in thematic, content analysis, cross-componential analysis as well as at the first step of framework analysis. Therefore, details of data source (i.e. journal database) and keywords selected to obtain the items included in each step are elaborated in the third column of Figure 6.2. Subsequently, the fourth column in the figure describes number of items included for each data analysis.

Consequently, resultant research outcomes are tested through a focus group interview with industry and academic experts. This final validation step will appraise the scientific soundness of research findings and enhance their applicability in the practice of safety science (Bockstaller and Girardin, 2003).

6.4. RESEARCH ETHICS

As the research design suggests, the project entails collecting and analysing not only secondary data from extant literature, but also primary data from various sources (i.e. focus group interview with experts) or organisation specific sensitive data (i.e. case study materials). To ensure that the research is conducted based on appropriate ethical and professional frameworks, '*Ethical approval application*' provided by Birmingham City University (BCU) has been reviewed and acknowledged. Following this familiarisation step, in order to obtain ethical approval from the Computing, Engineering and the Built Environment's Faculty Academic Ethics Committee, ethical pro-forma was completed after close work with and the approval of Director of Studies, First and Second Supervisors. Consequently, the ethical approval was reached on 17.09.2022. Therefore, every stage of this research (which consists of various processes and choice of methods) has been accurately assessed against any potential ethical issues to: remain compliant with principles of university research ethics; and produce outcomes conformant with relevant disciplinary legal requirements and guidelines. Data collection methods and processes for this research are selected, designed and organised in accordance with ethical, legal and regulatory requirements. In case of identification of any potential hazard to a researcher or participants, the course of study or research design processes were flexible to be customised to fit the regulation based on discussion with study leader and supervisors. However, as a general statement: signed informed consent are collected from study participants; all participants are informed that they have the right to withdraw from the study at any time and without notice; all digital data obtained (case study materials) are secured on BCU's OneDrive; accordingly all data will be securely disposed of post submission of the thesis; all participants personal and other details are kept strictly confidential and their anonymity are preserved; and participants will be given the opportunity to access results of the study as the work is published to ensure good dissemination.

6.5. SUMMARY OF CHAPTER 6

Details of research design adopted for this thesis were described in this chapter in order to: discuss their strengths and weaknesses; and explicate their alignment with the research aim, objectives and questions of the study. Identification of research focus was performed with the view of holism, due to the multigranularity of the phenomenon being investigated (i.e. occurrence or maintenance of safety or unsafety). The presence or absence of safety (shifts in safety conditions of construction projects) takes place as a result of interactions or interrelationships of system elements, *viz*., WMS. Moreover, shifts in safety condition of construction projects occur dynamically and implicitly, where these fluctuations in safety conditions are difficult to trace (or to meaningfully observe the changes until an accident occurs) or to correlate to one particular element of system. Given such abstruseness and evasiveness of the phenomenon under investigation, safety management through LIs is selected as research focus of current research programme. Therefore, selection of research design elements (i.e. research strategy, data collection and analysis method, as well as philosophical stance and research reasoning) were performed based on the literature on LI in safety management and the content and availability of data in this literature. The chapter also elaborates on the selection of each research methodology element in research design and delineates on typology of the doctoral work. In addition, the chapter presents the details of research process in phases 1 and 2 and highlights the ethical considerations included in the process of data collection, storage and in interaction with study participants.

CHAPTER SEVEN - RESULTS, FINDINGS AND DISCUSSION FROM PHASE 1

7.0. INTRODUCTION

Post-incident investigations undertaken typically conclude that ‘human error’ represents the root cause of incidents’ occurring, which then triggers the implementation of additional safety controls and stringent regulations (Wang *et al*., 2020). However, such oversimplification of the system into its componential parts and searching for a faulty element by isolating one part from others leads to reductionism. Such an approach divides componential elements of complex systems and tackles their inherent challenges and risks in isolation, disregarding the fact that events are occurring because of their interaction. However, despite the plethora of publications on safety management in the construction industry (cf. Chan and Chan, 2011; Lee *et al*, 2014; Li *et al*., 2015; Oswald *et al.,* 2018 a; Swallow and Zulu, 2019), there is a dearth of studies that focus on concurrently combining all three construction worksite components (i.e. WMS), their interrelationship or indeed any existing tool, concept or technique that can be applied to simultaneously improve WMS interaction and discharge their role harmoniously. Therefore phase 1 of this present thesis begins with the focus on the pertinent literature in terms of the role of human aspect and training programmes both of which is analysed through a Safety-I and Safety-II perspective. Accordingly, the chapter presents the findings from respective analyses and discusses insights emanating from these findings. Furthermore, the study follows systems thinking view in order to: contrast and combine best practices of Safety-I and Safety-II; amalgamate safety of sites, safety of machinery and safety of human aspect; merge design and operation stages; and integrate people involved, work mode adopted and data source used. As a consecutive step of this phase, the study turns into the main research focus of the study, which is the role of LIs in proactive safety management. Therefore, at this juncture the study seeks to identify the main constructs of LIs which enable realisation of such concept.

7.1. THE ROLE OF HUMAN ASPECT AND TRAINING PROGRAMMES IN SAFETY MANAGEMENT THROUGH SAFETY-I AND SAFETY-II PERSPECTIVE

Content analysis in NVivo proceeds by categorising all 64 research papers selected (i.e. data included in the first step of phase 1 described in Figure 6.2 as 1) by examining their content according to attributes of ‘*concept*’ (left-hand side) and ‘*theme*’ (right-hand side) as illustrated in Table 7.1. The ‘*concept*’ attribute has three categories of ‘*Safety-I’*, ‘*Safety-II*’ or ‘*Not applicable*’ where papers are classified based on the prominent features of Safety-I and Safety-

II (which were identified via a cross-comparison analysis in Table 2.1 of Chapter 2). Whereas '*theme*' attribute incorporates number of categories based on emerging themes that each article is representing.

Table 7.1 - Articles clustered according to concept (left-hand side) and emerging themes (right-hand side).

Number of emerging themes grouped in the concepts of Safety-I, Safety-II and Not applicable group	
Concepts and themes within	**Count of reference**
Not applicable	**39**
10 h OSHA training	2
Alternatives: general	1
Alternatives: prevention through design	3
Andragogical approach	1
BIM-enabled training module	1
Competency	1
Construction fatal four programs	1
First aid training	2
Hazard recognition training	2
Induction training	1
Induction training: actor-based EPIC	1
Personalised training	3
Safety leadership	2
Safety training park	1
Smart mark hazard awareness training	1
Tacit knowledge in training	1
Tool-box training	1
Training effectiveness	5
Training reinforcement through text messaging	1
Training-within-industry	1
Visual cues training	1
Visual cues training: interactive videos	1
Visual cues training: posters	1
VR training	4
Safety I	**5**
Alternatives: behaviour-based safety management	2
Alternatives: pay for safety scheme	1
Safety behaviour	1
Training through cartoons	1
Safety II	**20**
Alternatives: prevention through design	2
Competency	2
Factors impacting safety and health	1
Gaming approach	2
Latest training approaches	1
Matriosca model	1
Participatory training	1
Safety leadership	4
Safety training park	1
SAVE program: 7 unit	1
Tool-box training	1
Training assessment	1
Training effectiveness	1
VR training and HFST	1
Grand total	**64**

Number of emerging themes clustered in groups	
Themes	**Count of reference**
Safety leadership:	**8**
Safety leadership	5
Site manager training	1
Tool-box training	2
Training effectiveness	**6**
Virtual reality training:	**5**
VR training	4
VR training and HFST	1
Alternatives: prevention through design	**5**
Safety behaviour:	**4**
Alternatives: behaviour-based safety management	2
Safety behaviour	1
Visual cues:	**4**
Visual cues training: posters	1
Visual cues training: interactive videos	1
Visual cues training	1
Training through cartoons	1
Competency	**3**
Personalised training approach	**3**
First aid training	**2**
Gaming approach	**2**
Induction training:	**2**
Induction training	1
Induction training: actor- based EPIC	1
Safety training park	**2**
Hazard recognition training	**2**
10 h OSHA training	**2**
Miscellaneous:	**14**
Matriosca model	1
Participatory training	1
Smart mark hazard awareness training	1
SAVE program: 7 unit	1
Alternatives: general	1
Latest training approaches	1
Alternatives: pay for safety scheme	1
Tacit knowledge in training	1
Training assessment	1
Training reinforcement through text messaging	1
Andragogical approach	1
BIM-enabled training module	1
Construction fatal four programs	1
Factors impacting safety and health	1
Training-within-industry	1

When categories are grouped according to concepts, most articles (f = 39 papers) represent neither Safety-I nor Safety-II concept and hence, they are assigned to '*Not applicable*' category. However, there are more Safety-II concept-based publications (f =20 papers) as compared to Safety-I (f = 5 papers). When the years of publication were examined, the trend of Safety-II concept based articles began to emerge in 2012 (f = 3 papers), while 2019 (f = 5 papers) and 2020 (f = 4 papers) were the peak years of this trend. Such growing popularity of the Safety-II approach in recent years perhaps reflects attempts to tackle the soaring statistics for accidents risk. Regarding the themes prevalent in each publication, the '*safety leadership*' theme is identified as the most frequently occurring theme (*f* = 8 papers), where studies are advocating for training and enhancing competency of safety managers rather than focusing on frontline workers only. This approach is seen as a panacea to the predicament called 'conflict of goals' where workers 'borrow' from safety to enhance productivity and quality. According to Safety-II (Antonio *et al*., 2013; He *et al*., 2019; Goldenhar *et al.,* 2019; Ismail *et al.,* 2021), competently trained managers and foremen will succeed in balancing all three aspects (i.e. productivity, quality and safety), without jeopardising workers' safety and/or project success. Preceded by the '*training effectiveness'* thematical cluster, clusters '*virtual reality trainings'* and *'visual cues'* are the next frequent themes, in which studies delineate on developing technology augmented training programmes. Such programmes are claimed to be highly engaging and therefore enhancing trainees' competency (Price *et al*., 2008; Harvey *et al*., 2020; Albert and Routh, 2021).

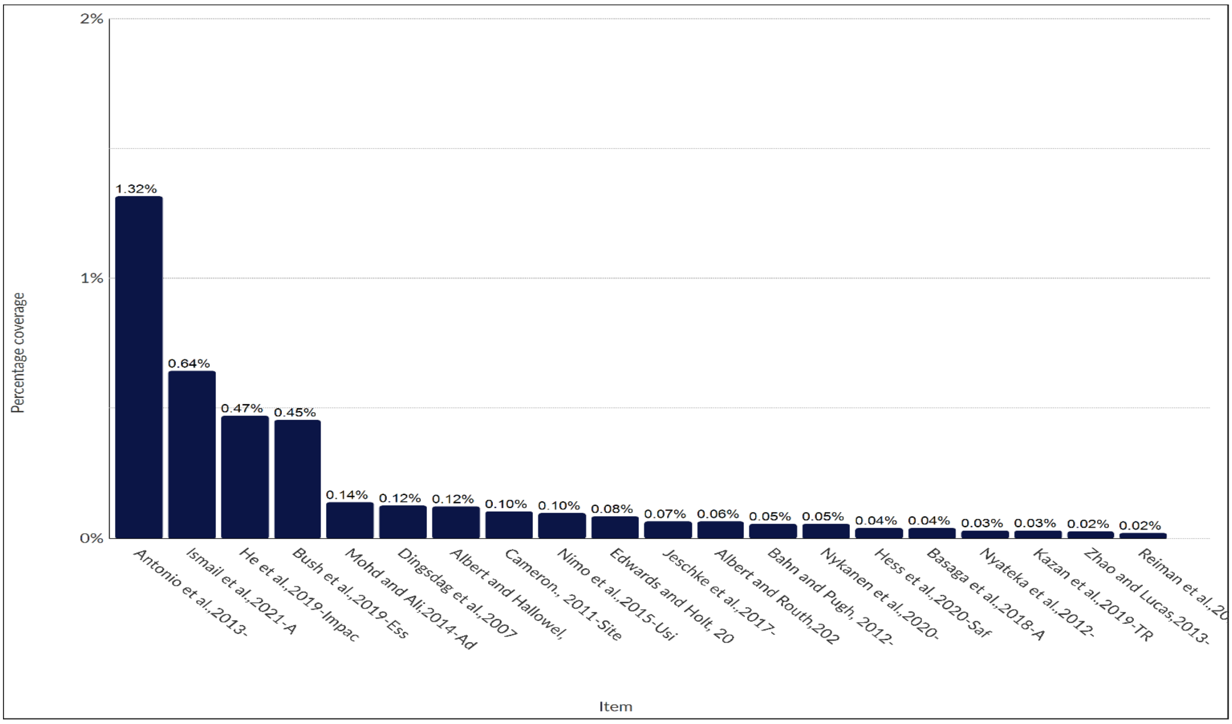
7.1.1. Competency in safety training programmes

After the analysis of articles' semantics and pragmatics, a word frequency analysis was conducted in NVivo by selecting 1,000 most frequent words to display and grouping them through exact matches (in Figure 7.1).

Figure 7.1 - Results of word frequency query in word cloud depiction.

The words displayed in red represent the most frequently occurring words, justifiably describing the search keywords of the topic (i.e. safety training programmes in construction work). When the summary list of words in the word cloud is examined, the term ‘competencies’ appears 242nd on the list and word ‘competence’ appears 322nd with a weighted percentage of 0.06% and 0.05% respectively. This indicates to the dearth of studies in pertinent literature that focus on competency. Such observation in the process of analysis prompted for a greater detailed analysis and hence, a further analysis of the word ‘competency’ was conducted through text search query by selecting ‘with stemmed words’ option in NVivo. Figure 7.2 presents the word search results with their percentage of coverage and their respective sources.

Figure 7.2 - Results of text search query of the term ‘competency’.



7.1.2. Discussion: advantages and disadvantages of different training types

A number of training programmes have been developed to counteract industry-related and human aspect challenges. Table 7.2 describes some example of training programmes through cross-comparison of their advantages and disadvantages. Some examples of training interventions in the table are differentiated by: their method of delivery (e.g. online based training, virtual reality-based training); materials and content delivered (e.g. focus four); and testing method adopted (e.g. personalised adaptive training, metacognitive prompts based training).

Table 7.2 – Cross-comparison of training types.

Training type	Description	Advantages	Disadvantages	Citations
Lecture-based training *	Lecturer-centred and classroom-based, passive way of transferring the information where lecturer is actively involved in lecturing whilst trainees are in passive learner role.	Lecture based training is cheaper than other emerging high technology-based training delivery methods. Some studies advocate its efficiency by contrasting it with online trainings.	Low engagement, passive and trainer-centred method leads to low knowledge retention and one-size fits-all training approach can instil negative attitude amongst workers towards safety issues.	Price *et al*., 2008; Jeelani *et al.,* 2017; Shendell *et al*., 2017; Tixier *et al*., 2018; Kazan *et al*., 2019; Nykänen *et al*., 2020; Albert and Ruth, 2021.
Multimedia based training *	Videos, animations and photographs that recreate previously experienced incidents; these materials are used as a part of online learning practice.	A cost-effective means for training which drives engagement of trainees providing different scenarios of previously occurred accidents.	One-size fits-all training approach that fails to consider individuals need.	Price *et al*., 2008; Cherrett *et al*., 2009; Mohd and Ali, 2014; Shendell *et al*., 2017; Gao *et al.,* 2019; Albert and Ruth, 2021.
Online based training (e-learning) *	Content delivery method using online platforms without face-to-face interaction.	Availability of the training material through any internet-connected device, ability to repeat the training experience on-demand—as and when needed at the preferred location for the workers and the ability to save training progress make this training type especially flexible means of training.	Absence of opportunities for any interaction or discussion online leaves this type of training to be limited to the provided content only where trainees have no option to clarify questions that may occur during the course.	Ho and Dzeng, 2010; Shendell *et al*., 2017; Kazan *et al*., 2019; Albert and Ruth, 2021.
Personalised adaptive training*	Bespoke training programme that is tailored based on the needs of each trainee. Designing such programmes proceed with identification of learners' knowledge first, then customisation their learning experience accordingly.	Such training approach ensures that resources are used efficiently to target specific learning needs without repetition, while also reducing inattention, frustration, and boredom among the training participants. Higher return investment, time-efficiency and optimised trainee satisfaction generate tangible benefits and incentivise employers.	Time consuming and expensive way of training, as studying each trainee's weaknesses and strengths and generating bespoke content require more time and resources.	Jeelani *et al*., 2017; Lu and Hasan, 2018; Albert and Ruth, 2021.
Naturalistic injury simulations and physical demonstrations*	A training approach targeted at yielding emotional response among trainees to a physical demonstration of injuries after accidents using hyper realistic replicas of human body parts and common construction tools.	This type of training intervention promotes risk aversion and increases trainees' perception of risk to a higher level.	This type of trainings might not suit all trainees due to their high sensitivity and emotional reactions to such demonstrations and could have adverse impact on participants.	Bhandari and Hallowell, 2017; Bhandari *et al.,* 2019; Hasanzadeh *et al.,* 2020; Reiman *et al.,* 2020; Albert and Routh, 2021.
Serious games and gamification- based training *	Simulation based setting emphasising experiential learning through entertainment and competition that can be applied to training in a physical, classroom-based environment and in 3D space with virtual objects.	Concepts such as goal, challenge, level-ups and rewards in game-based training augments trainees' engagement, motivation and therefore superior learning. Gaming construct enables trainees to break down complex tasks into more manageable parts whilst the immediate feedback in learning process allows to experiment with the content and evaluate the outcome.	The immediate feedback embedded in gamification trainings might not be relevant to daily work operation, since most of the risk and hazards are latent and difficult to identify in real life workplaces and consequences occur long after the unsafe behaviour takes place.	Greuter *et al.,* 2012; Guo *et al.,* 2012; Mohd and Ali, 2014; Albert *et al*., 2014; Gao *et al*., 2019; Albert and Routh, 2021.
Virtual reality training*	Training interventions based on virtual reality (VR) refers to learning environment that is computer-generated	The primary advantage of these environments is to simulate dangerous workplace conditions that are necessary as part of the training that cannot be	Some individuals can experience simulator sickness syndrome (similar to motion sickness)	Zhou, *et al*., 2012; Albert *et al*., 2014; Zhao and Lucas, 2015; Bhoir and Esmaeili, 2015; Nykänen *et al*.,

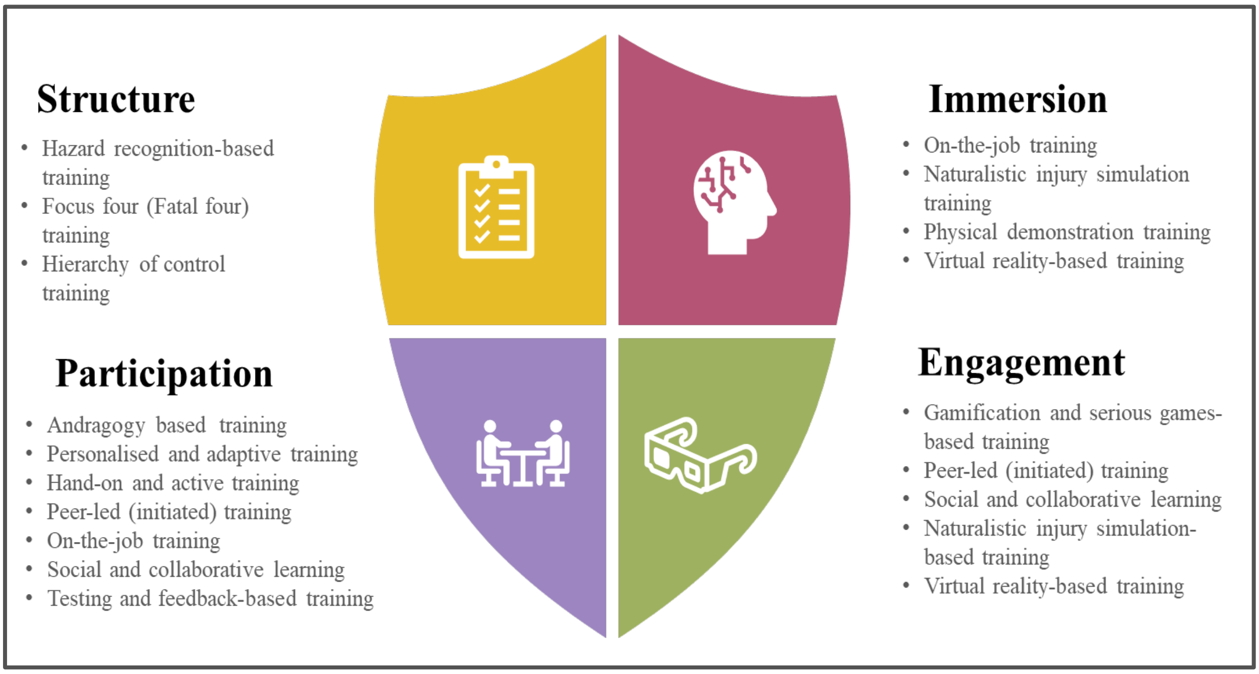
	artificial 3D environment. This technology allows to develop engaging methods of safety trainings and offers potential for emphasising the active role of learners during safety training activities.	replicated in real workplaces due to the safety risks. These high-engagement training experiences translate into superior training outcomes and has stronger impact (compared to other conventional training delivery methods) on safety motivation, self-efficacy and safety-related outcome expectancies.	which can limit the efficacy of VR based trainings.	2020; Hasanzadeh *et al.,* 2020; Jeelani *et al*., 2020; Albert and Routh, 2021.
Hazard recognition training **	Focused on improving workers' ability to mentally envision and recognise safety hazards associated with future work tasks using hazard-recognition methods and visual cues (i.e. Haddon's energy release theory).	It has two approaches: predictive and retrospective. Retrospective method provides a systematic and structured way to generalise knowledge obtained from past injuries and to prevent future safety incidents.	In predictive method tasks as expected and visualised are often significantly different from how they are actually performed in the field.	Albert and Hallowel, 2013; Albert *et al*., 2014; Jeelani *et al*., 2017; Tixier *et al*., 2018; Uddin *et al*., 2020; Albert *et al*., 2020; Albert and Routh, 2021.
Focus four (also known as Fatal Four) hazards training **	Safety training programme based on four types of accidents such as falls, struck-by incidents, caught-in/between incidents, and electrical incidents.	Structured approach to hazard recognition allows to identify four common and major hazard sources. The elements of this training programme also included as a guidance in tool-box meetings led by workers in real workplace scenarios.	Limited focus to only four common types of accidents and fails to recognise other types of accident sources such as temperature, chemicals, pressure, radiation or sound hazards.	Olivencia *et al*., 2017; Albert *et al*., 2020; Uddin *et al*., 2020; Albert and Ruth, 2021

* Training type based on delivery methods

** Training type based on content

Unlike a conventional classroom-setting and lecture-based training programmes (that have the lowest engagement level), most training delivery methods described in the table are focused on: improving engagement and participation during the course delivery stage; and achieving higher knowledge transfer after the training interventions (Bhoir and Esmaeili, 2015; Nykänen *et al*., 2020; Bayramova *et al*., 2021a). Equally important as the delivery method for training intervention is the content element of training programmes, which is emphasised by many academics (Wilkins, 2011; Perlman *et al*., 2014; Namian *et al*., 2016; Bhandari *et al*., 2019). Examples of training that is directed for content efficiency are: andragogy-based training (cf. Albert and Hallowel, 2013; Bhandari *et al*., 2019); focus-four hazards training (cf. Taylor, 2015; Albert *et al*., 2020); and energy-based mnemonics (Albert *et al*., 2014; Perlman *et al*., 2014). However, all these training interventions are not mutually exclusive nor is there one specific best training approach and hence, different training design approaches (delivery method focused design assigned as * or content-focused design assigned as ** in Table 7.2) might be utilised in one training programme. For example, Jeelani *et al.* (2017) propose personalised training programmes based on hazard recognition (**) and a metacognition method (*); Albert *et al.* (2020) report upon the impact of hazard recognition training interventions (**) based on focus four hazards (**); Nykänen *et al.* (2020) contrast the impact of lecture-based training (*) with virtual reality-based training (*) both of which were complemented by human factor safety training (HFST) approach (**). Therefore, training intervention (identified in Table 7.2) can be categorised into four broad thematic clusters based on their advantages and strengths as demonstrated in Figure 7.3.

Figure 7.3 - Training types classified based on their strengths.



First the ‘*structure*’ thematic cluster describes training programmes designed to provide systematic and structured training content that are vivid, memorable and easy for knowledge retention and further application in daily work operations (Albert and Ruth, 2021; Bayramova *et al*., 2021a). For example, incorporating Haddon’s energy release theory based visual cues into hazard recognition trainings provides more detailed and structured way of learning that is based on ten potential sources (i.e. gravity, motion, mechanical, electrical, pressure, sound, radiation, temperature, chemical and biological) of accident occurrences and hence, enables better hazard recognition of trainees (Bayramova *et al*., 2021a). The ‘*participation*’ thematic cluster characterises trainings that are intended for trainees to take a central part in their learning experience through introspection and goal-setting practice (Albert and Hallowel, 2013; Jeelani *et al*., 2017). Examples may include personalised and adaptive training (Jeelani *et al*., 2017), testing and feedback-based training (Demirkesen and Arditi, 2015) and peer-initiated training (Namian *et al.,* 2016). The ‘*engagement*’ thematic cluster of training interventions are focused on experiential learning by inducing participants into a ‘flow’ and engagement through motivation, entertainment and rewards (Mohd and Ali, 2014; Harvey *et al*., 2020). Such may include gamification and serious games based training and virtual reality-based training, both of which are targeted to capture trainees’ interest in the training through entertainment and drive for reward and goal achievement (Guo *et al.,* 2012; Jeelani *et al.,* 2020). The ‘*immersion*’ thematic cluster is a much deeper version of ‘*engagement*’ thematic group, that aims to evoke emotional reaction by which long-lasting improvement of participants' situation awareness and risk-aversion are achieved (Greuter *et al*., 2012; Bhandari and Hallowell, 2017). A notable example of *'immersion'* thematic cluster is naturalistic injury simulation and physical demonstration training which illustrates previously occurred real-life injuries using physical dummies, construction materials, tools and equipment (Bhandari *et al.,* 2019; Albert and Ruth, 2021).

7.1.3. Discussion: elements for impactful training design and development

Despite prevailing scholarly discourse on the superiority of one concept over other (i.e. Safety-I or Safety-II) (Dekker, 2015; Busch, 2019; Cooper, 2020), there is a plethora of other academics (Patterson and Deutsch, 2015; Sujan *et al.,* 2017; Jones *et al*., 2018; Wang *et al*., 2020) proposing a synergetic combination of the two concepts to augment workers' health and safety. Safety-I-type training programmes are primarily intended to build risk aversion, enhance control and raise awareness (Wang *et al*., 2020; Albert and Routh, 2021). Conversely, Safety-II-based training programmes are developed to build resilience, improve decision-making and create the adaptation capacity of trainees (Dekker, 2015; Chen *et al*., 2017; Sujan *et al*., 2019). Therefore, based on the findings deduced from extant literature, a conceptual model in the form of 'training efficacy assessment tool' was developed as a theoretical basis (and presented in Figure 7.4). This model combines seven core elements of training programmes that are required to improve their efficacy and to achieve superior outcomes. Moving from the right-hand side in a clockwise direction, the first two elements represent a pre-development stage of training programmes that describe conceptual and cultural considerations to be included. The next three elements pertaining to development stage are 'theoretical', 'technical' and 'structural' elements.

Figure 7.4 - Training efficacy assessment tool.

Implementation element

Even after successful completion of training courses, trainees might struggle to apply the learning outcomes in a working context. Using tools such as checklists, booklets, pocket cards or text messaging that can be used in a post training setting represents an effective approach to transfer the knowledge attained from training to worksites (Namian *et al.*, 2016).

Conceptual element

Both Safety-I and Safety-II concepts need to be included in the formation of training programmes. Safety-I type training programmes are primarily developed based on building risk aversion, enhancing control and raising awareness (Wang *et al.*, 2020; Albert and Ruth, 2021). Safety-II based training programmes are developed to build resilience, improve decision-making and create adaptation capacity (Dekker, 2015; Sujan *et al.*, 2019).

Assessment element

Assessing the theoretical knowledge of trainees lacks applicability of a content provided to the worksite job. Asssessing competency of participants through apprenticeship programmes, hands-on and on-the-job training results in desirable safety related behaviour (Eggerth *et al.*, 2018).

Cultural element

Most studies concerning training programmes development analyse fieldworkers' training to change their safety behaviour; whilst training safety managers to coordinate safety, productivity and quality is more effective to create safety culture and culture of learning, and to prevent goals-conflict (Holt and Edwards, 2013)

Structural element

The structure and the content of training programmes must be personalized and constantly updated through a bottom-up approach with feedback from trainees. Personalized adaptive trainings, andragogical principles-based trainings are examples of structuring trainings according trainees' identified needs that will be benchmarked on completion of the training (Albert and Hallowell, 2013).

Technical element

Methods of training delivery must be designed to increase engagement and participation. Gamification-based trainings, naturalistic injury simulations, virtual reality -based training are some examples of immersing trainees into a training experience which translates into superior outcomes (Albert and Ruth, 2021).

Theoretical element

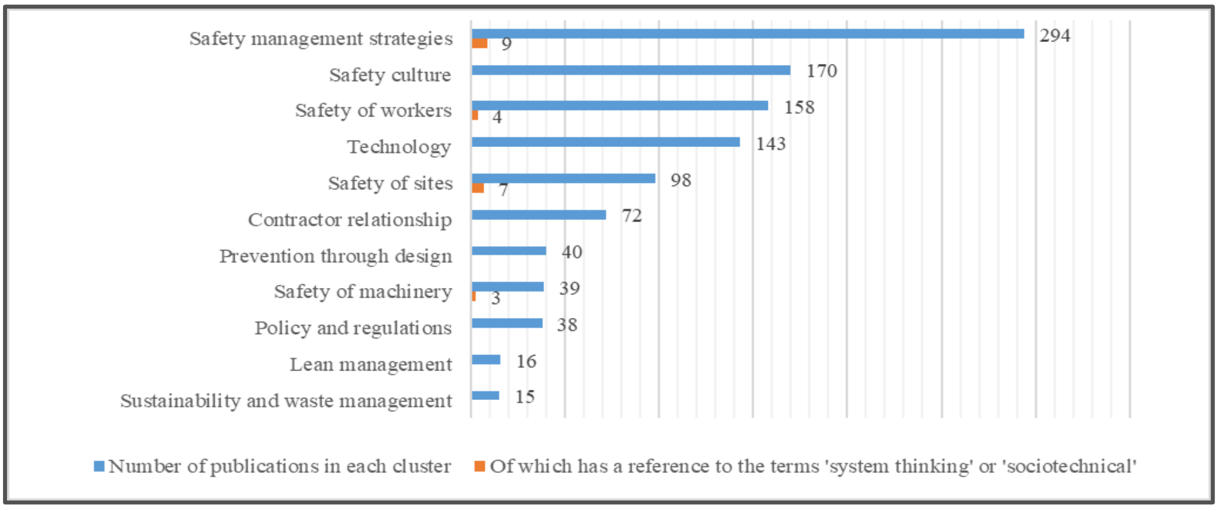
Materials used for developing training should be easily memorable, applicable and relatable. Haddons energy release theory, hierarchy of control or using videos and animations that recreate previously experienced incidents are examples of mental schemas and mnemonics to include in training programmes for higher knowledge retention of participants (Perlman *et al*., 2014).

The ‘theoretical’ element describes the materials used for efficient training intervention development. Haddon’s energy release theory or hierarchy of controls are some examples of using mental schemes and visual cues to enhance knowledge acquisition, retention and application on site (Cherrett *et al*., 2009; Perlman *et al.,* 2014). The ‘technical’ element delineates the delivery methods of training programmes that are targeted at raising participation and engagement to improve trainees’ competency (Gao *et al*., 2019; Albert and Routh, 2021). The ‘structural’ element outlines the advantages of trainees’ involvement in the process of learning by goal setting, identifying their own weaknesses and translating their strengths into opportunities to improve (Albert and Hallowell, 2013; Albert and Routh, 2021). Benchmarking their desired level of performance (set by their pre-training) against the performance achieved post-training drives participants’ openness and readiness to learn and motivates them to acquire and retain further knowledge (*ibid*). That leads to the model’s ‘assessment’ element, which elucidates the advantage of testing participants’ competency instead of theoretical knowledge for facilitating the transfer of training to the workplace (Edwards and Holt, 2008). The model’s final ‘implementation’ element embraces implementation of the knowledge and skills acquired during the training courses and transferring them into competency in terms of job-specific skills and safety management proficiency. It corroborates that the potential impact of training programmes can be extended even after the completion of the actual knowledge transference. Examples of such practices include creating contents such as checklists, booklets and pocket cards to be used at the worksites to ensure knowledge acquired is applied (Namian *et al*., 2016) or communicating with the trainees after completion of actual training by using text messaging (with or without required response) to reinforce trainees’ implementation of the learning content (Kincl *et al.,* 2020).

7.2. SYSTEMS THINKING BASED SAFETY MANAGEMENT: SAFETY-IN-COHESION

Based on sourced 2,227 publications (2 in Figure 6.2), thematical analysis generated eleven distinct thematic clusters, *viz., ‘contractor relationship’*, *‘lean management’*, *‘policy and regulations’*, *‘prevention through design’*, *‘safety culture’*, *‘safety management strategies’*, *‘safety of machinery’*, *‘safety of sites’*, *‘safety of workers’, ‘sustainability and waste management’* and *‘technology’*. Figure 7.5 describes number of publications that each of those eleven clusters contains in a bar graph, arranged in descending order.

Figure 7.5 - Eleven clusters and coverage of the terms 'system thinking' and 'sociotechnical' in them.



Additionally, the figure contains the details which illustrate the number of items referring to STS in each cluster accordingly. Themes emerging in the thematic analysis are simultaneously diverse and overlapping. For instance, '*sustainability and waste management*' and '*lean management*' clusters, and '*contractor relationship*' and '*prevention through design*' clusters are closely interrelated areas. Similarly in the process of clustering the items into different thematical groups, many studies had overlapping themes in their title and abstract; in such cases however, classification was performed guided by the keywords of that study. A greater number of publications in the '*safety management strategies*' cluster showcases divergence and uniqueness of safety management in every organisation. The presence of '*technology*' and '*regulations*' themes suggests the popularity of technology and regulation as a control tool to improve safety performance in construction projects. Indeed, technology and enforcement are often seen as a panacea to construction safety management issues arising (Zhou *et al.,* 2012).

To discover the coverage of STS thinking in selected literature, a text search of '*sociotechnical*' and '*systems thinking*' keywords was conducted in a Microsoft Excel workbook containing all eleven themes. Full text articles containing those keywords were retrieved and analysed in Text Search Query using the NVivo analytical tool. Results illustrate extremely low coverage of these subjects which underlines the need for such studies. These results with more details of the studies, their reference and coverage are included in Table 7.3.

Table 7.3 - Coverage of the terms 'system/s thinking' and 'sociotechnical' in respective clusters.

Authors in 'safety of workers' cluster	References to 'systems thinking'	Coverage of 'systems thinking'	References to 'sociotechnical'	Coverage of 'sociotechnical'
Whiteoak and Mohamed, 2015	16	0.22%	8	0.10%
Guo *et al.*, 2015	16	0.14%	2	0.01%
Duryan *et al.*, 2020	1	0.01%		
Abas *et al.*, 2020			1	0.02%
Authors in 'safety of machinery' cluster	**References to 'systems thinking'**	**Coverage of 'systems thinking'**	**References to 'sociotechnical'**	**Coverage of 'sociotechnical'**
Gautam *et al.*, 2021	3	0.04%		
Sadeghi *et al.*, 2021	1	0.01%		
Zhou *et al.*, 2018	2	0.02%	19	0.15%
Authors in 'safety of sites' cluster	**References to 'systems thinking'**	**Coverage of 'systems thinking'**	**References to 'sociotechnical'**	**Coverage of 'sociotechnical'**
Bridi *et al.*, 2021	16	0.17%		
Hughes *et al.*, 2014	4	0.02%		
Rowlinson and Jia, 2015	2	0.02%		
Saurin, 2015	16	0.18%		
Chan and Chan, 2011			2	0.02%
Guo and Yiu, 2015			4	0.03%
Kleiner *et al.*, 2008			6	0.10%
Authors in 'safety management strategies' cluster	**References to 'systems thinking'**	**Coverage of 'systems thinking'**	**References to 'sociotechnical'**	**Coverage of 'sociotechnical'**
Woolley *et al.*, 2019	29	0.31%	10	0.09%
Bas, 2013	24	0.24%		
Mohammadi and Tavakolan, 2020	13	0.10%	1	0.01%
Woolley *et al.*, 2020	11	0.13%	2	0.02%
Mohammadi and Tavakolan, 2019	9	0.10%	1	0.01%
Han *et al.*, 2014	7	0.09%		
Mohammadi *et al.*, 2018	7	0.10%	1	0.01%
Zhang *et al.*, 2018	3	0.05%	5	0.07%
Zhao *et al.*, 2015			7	0.08%

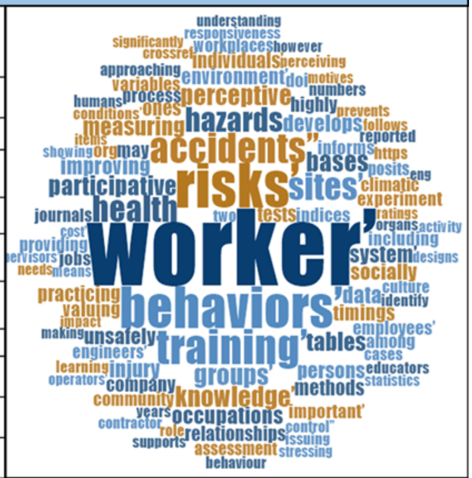
7.2.1. Three elements of complex sociotechnical systems: workers, machinery and sites

Three clusters *viz.,* '*safety of workers', 'safety of machinery'* and *'safety of sites'* clusters were selected through purposive sampling and publications in those three clusters were selected for further scrutiny in content analysis. In the final screening for content analysis the cluster '*Safety of workers'* constitutes 143 articles, whereas '*safety of machinery'* and '*safety of sites'* clusters contain 34 and 76 publications respectively (as detailed in Figure 6.2 in Chapter 6). Upon full text retrieval of articles for each of these three clusters, three individual projects were created in the NVivo analytical tool to analyse publications through content analysis. Figure 7.6 describes the results of content analysis, i.e. the word frequency analysis in NVivo, which was conducted by selecting default criteria *viz.*: grouping the words with stemmed words; and selecting to display the first 1,000 most frequent occurring words with minimum length of three.

Figure 7.6 - Word frequency analysis of clusters.

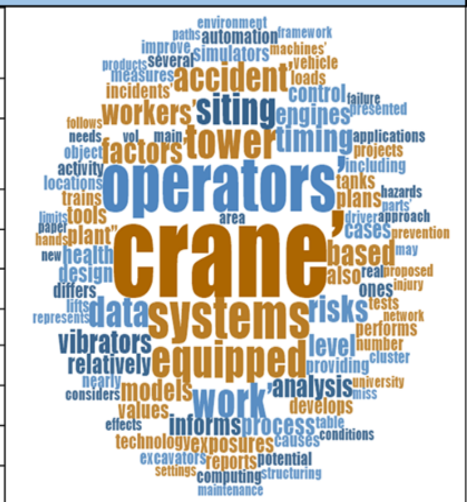
'Safety of workers' cluster

Word	Similar words	Length	Count	Weighted percentage (%)
worker'	worker, worker', workers, workers', workers'	7	10513	1.19
risks'	risk, risk', risking, risks, risks'	6	5961	0.68
behaviors'	behavior, behavioral, behaviorally, behaviorism, behaviors, behaviors'	10	5508	0.63
training'	train, trained, training, training', trainings, trains	9	4554	0.52
accidents''	accid, accident, accident', accidently, accidents, accidents', accidents''	11	3891	0.44
sites'	site, site', sites, sites'	6	3410	0.39
health	health, health'	6	3246	0.37
hazards	hazard, hazardous, hazardousness, hazards	7	2985	0.34
knowledge	knowledge, knowledge', knowledgeable	10	2438	0.28
bases	base, based, based', bases, basing	5	2415	0.27



'Safety of machinery' cluster

Word	Similar words	Length	Count	Weighted percentage (%)
crane'	crane, crane', cranes, cranes', craning	6	2452	1.28
operators'	operable, operate, operated, operates, operating, operating'', operation, operational, operations, operations', operations'', operative, operatives, operatives', operator, operators,	10	1520	0.80
systems	system, system', systemic, systems	7	1218	0.64
equipped	equip, equipment, equipments, equipments', equipped	8	1019	0.53
tower	tower, towers	5	973	0.51
work'	work, work', work'', worked, working, works, works'	5	929	0.49
siting	site, sites, siting	6	850	0.45
data	data	4	833	0.44
accident'	accident, accident', accidents, accidents'	9	780	0.41
risks	risk, risks	5	724	0.38



'Safety of site' cluster

Word	Similar words	Length	Count	Weighted percentage (%)
siting	site, site', sites, sites', siting	6	3573	0.83
accident'	accid, accidence, accident, accident', accidents, accidents'	9	2987	0.70
workers'	worker, workers, workers', workerś, workers'	8	2776	0.65
projects'	project, project', project'', projected, projects, projects', projects'	9	2444	0.57
system'	system, system', system'sperformance, systemic, systems, systems', systems'	7	2324	0.54
model'	model, model', modeled, modeler, modeling, modelled, modeller, modelling, modelling', models, models'	6	1937	0.45
risks	risk, risk', risked, risking, risks, risks'	5	1925	0.45
factors	factor, factor', factored, factoring, factors, factors'	7	1729	0.40
hazard'	hazard, hazard', hazardous, hazards, hazards'	7	1643	0.38
data'	data, data'	5	1560	0.36

Words such as 'safety', 'management', 'construction', 'industry' were eliminated from the word cloud and table, as they constitute keywords of this literature search. Numbers (such as year of publication or number of observations) and non-relevant or trifling words (such as within, such as, 'also', 'research', 'study' and 'figure') were added to 'stop words list' to eradicate *white noise* from the ensuing analysis. The tables on the left-side of Figure 7.6 describe the first top ten frequently occurring keywords only, whilst each 'word cloud' (on the right-hand side of Figure 7.6) demonstrates top 1,000 most frequently occurring keywords by their size (the higher the frequency of words, the larger in size they are). The predominance of keywords such as 'worker', 'risk', 'behaviour', 'training' and 'accident' in the *'safety of workers'* cluster divulges the penchant for studies that are grounded on accident prevention and/or risk control targeting workers' behaviour. Specifically, these include those associated with behaviour-based management or improving proficiency and competency of workers through training programmes. The Pay for Safety Scheme (PFSS) introduced by the Government of the Hong Kong (Choi *et al.,* 2011) and the 'Surprising Incentive System' in an Iranian power plant construction project (Ghasemi *et al.,* 2015) are examples of behaviour-based management which attempt to incentivise construction workers to eliminate accidents caused by unsafe behaviour and acts.

The *'safety of machinery'* cluster comprises 'crane', 'operators', 'systems', 'tower' and 'data' keywords on its top ten list. These words illustrate the trend for research on tower crane accident mitigation to preserve their operators and workers operating alongside them and includes a particular focus on blind spots that occur in machinery utilisation. Some prominent developments to tackle the accident types involving plant and machinery are: Intelligent Construction Equipment Planner (ICE-Planner) motion planning system for construction equipment (Albahnassi and Hammad, 2012); Global Positioning System (GPS) and Radio Frequency Identification (RFID) based real-time monitoring system for mobile/tower cranes (Li *et al*., 2013); and GPS only based fleet telematics system for heavy earthwork equipment (Lee *et al.,* 2018). In a similar manner, 'site', 'accident', 'system', 'model', 'factors' and 'data' keywords in the *'safety of sites'* cluster characterise the studies on designing and developing early warning systems, human and machinery positioning and monitoring systems. Such works highlight the significance of data integration utilising digital sensors and network connection systems and sharing real time spatiotemporal information to improve visibility between system components (WMS).

Scanning and coding prominent insights in each publication (of each cluster) have revealed prominent concepts (as described in Tables 7.4, 7.5, and 7.6) that emerged by aggregation of nodes/codes using NVivo. Table 7.4 demonstrates that the content of publications in the 's*afety of workers'* cluster reviews human aspects of safety management in terms of: behaviour-based safety management (Ghasemi *et al.*, 2015; Guo *et al.*, 2018; Basahel, 2021); impact of in-group and inter-group communication and safety knowledge sharing (Edwards and Holt, 2008; Fargnoli *et al*., 2011; Goodbrand *et al.,* 2021); LIs about human aspects and their risk perception on an individual level (Meng *et al*., 2019; Abas *et al.,* 2020); and safety culture, safety climate and safety leadership within a group or organisational level (Lu *et al*., 2016; Yamauchi *et al*., 2019). Furthermore, other widely studied subjects include: workers' unsafe acts and/or behaviours (Choi *et al.,* 2017; Huang *et al*., 2021); external psychosocial factors (Manyard *et al*., 2020; Pérez-Alonso *et al.,* 2021); and personal substance abuse influences (Loudoun and Markwell, 2017; Flannery *et al.,* 2021).

Table 7.4 - Content analysis of 'safety of workers' cluster.

Emergent concepts and themes	Brief description	Citations
Technology	Application of technology such as virtual reality for improving safety training outcomes, alert systems and wearable devices for worker safety, mixed reality and eye-tracking for enhancing safety risk communication and hazard recognition on construction sites.	Acar *et al*., 2008; Goulding *et al*., 2012; Hasanzadeh *et al*., 2020; Chan *et al*., 2020; Dai *et al*., 2021.
Leading indicators	The concepts such as safety climate, safety culture, safety effectiveness indicators, near misses and antecedents of safety behaviour are used to annotate safety level measurement as a predictor for prevention.	Dingsdag *et al.*,2008; Biggs and Biggs, 2013; Guo *et al*., 2015; Lu *et al*., 2016; Yamauchi *et al*., 2019; Winge *et al*., 2019; Kwon *et al*., 2019; Mazzetti *et al*., 2020; Duryan *et al*., 2020.
Unsafe acts and unsafe behaviour	Safety risk tolerance; safety and risk perception; social identity and social capital; safety awareness and safety consciousness are described as the main reason of unsafe behaviour occurrences.	Wang *et al*., 2016; Anderson *et al*., 2015; Carriço *et al.,* 2015; Choi *et al.*,2017; Abbas *et al.*, 2018; Meng *et al*., 2019; Abas *et al.,* 2020; Meng and Chan, 2020; Yao *et al*., 2021; Andersen and Grytnes, 2021; Huang *et al*., 2021.
Substance abuse	The impact of substance (alcohol and drug) misuse on safety behaviour and safety performance of workers.	Wickizer *et al*., 2004; Minchin *et al.,* 2006; Loudoun and Markwell, 2017; Flannery *et al.*,2021.
Psychosocial risk factors	The impact of work-related stress factors such as productivity pressure, fatigue and working hours on workers' health safety and wellbeing.	Wu *et al*., 2018; Yamauchi *et al.*,2019; Yang *et al*., 2020; Ni *et al*., 2020; Xing *et al.,* 2020; Manyard *et al*., 2020; Pérez-Alonso *et al.*,2021; Huang *et al*., 2021.
Training and education	Different training interventions such as e-learning, induction training, hazard recognition training, toolbox safety training as well as impact of proficiency, competency level and safety knowledge of workers on safety management.	Edwards and Holt, 2008; Dingsdag *et al*., 2008; Bahn and Barratt-Pugh, 2012; Biggs and Biggs, 2013; Acar *et al.*,2014; Demirkesen and Arditi, 2015; Eggerth *et al*., 2018; Bust *et al.*,2019; Kraft, 2019; Wang *et al*., 2021.
Communication	Impact of issues such as communication amongst migrant workers, safety knowledge sharing, timely and efficient communication, visibility level in construction field on safety management.	Edwards and Holt, 2008; Fargnoli *et al*., 2011; Chan *et al*., 2016; Bust *et al*., 2019; Irfan *et al*., 2019; Kraft, 2019; Lyu *et al.,* 2020; Dai *et al*., 2021; Goodbrand *et al.,* 2021.
Behaviour based safety	Studies on cognitive factors and personal trait; human error and inattentional blindness; safety leadership; incentives and sanctions for safety behaviour improvement	Choi *et al.*,2011; Jitwasinkul and Hadikusumo, 2011; Biggs and Biggs, 2013; Choudhry, 2014; Guo *et al.,* 2015; Ghasemi *et al.*, 2015; Guo *et al*., 2018; Basahel, 2021; Huang *et al*., 2021; Gong *et al*., 2021.
People-plant interface	Equipment specific safety; safety distance between workers and mobile equipment; workers' distance from static hazard; safety work zones, rules for proximity related hazards	Kumar *et al*., 2013; Hobson *et al*., 2014; Chan *et al.,* 2020.

The 'technology' theme in '*safety of workers'* cluster reviews the application of technology predominantly for training intervention improvements, whereas the 'technology' theme in the *'safety of machinery'* cluster (in Table 7.5) refers to advanced digital technologies in the form of sensors, outdoor connection network layers for plant-to-plant and plant-to-human connectivity, spatiotemporal data sharing (Li and Liu, 2012; Zhong *et al.,* 2014) and real time plant and equipment monitoring/tracking systems (Azarian *et al*., 2011; Guo *et al.,* 2012; Lee *et al*., 2018).

Table 7.5 - Content analysis of 'safety of machinery' cluster.

Emergent concepts and themes	Brief description	Citations
Technology	Real time machinery localisation and tracking systems; Automated machine guidance (AMG); automated machine control (AMC); fleet management systems and fleet telematics systems; sensors; computer-vision based technology for equipment monitoring; and challenges and opportunities using such technologies for safety improvement	Azarian *et al*.,2011; Guo *et al.*,2012; Li and Liu, 2012; Zong *et al.*, 2014; Azar and Kamat, 2017; Vahdatikhaki *et al*., 2017; Lee *et al*.,2018
Accidents and injury types	Accidents (such as struck-by-object, caught-in-between) and near-misses occurring in blind spots, collision risk and accident-prone conditions such as blind lifting and loading; as well as other health conditions such as hand-arm vibration (HAV) or whole-body vibration (WBV)	Coggins *et al.*, 2010; Neitzel *et al*., 2010; Riaz *et al.*, 2011; Li *et al*., 2013; Sauni *et al*., 2015; Raviv *et al*.,2017; Raviv *et al*.,2017a; Raviv and Shapira, 2018; Sadeghi *et al*., 2021; Hoz-Torres *et al.*, 2021
Regulations	Workplace health and safety law and regulations such as Control of Vibration at Work Regulations (CVWR); Control of Substances Hazardous to Health Regulations (CSHHR); Construction (Design and Management) Regulations, 2007 (CDMR); Provision and Use of Work Equipment Regulations (PUWER); Lifting Operations and Lifting Equipment Regulations (LOLER)	Edwards and Holt, 2007; Edwards and Holt, 2008; Riaz *et al.*,2011; Sauni *et al.*, 2015; Hoz-Torres *et al.*, 2021
Cranes	Accident types and challenges (such as collapse and overturning of cranes) and solutions for using hydraulic, crawling, tower and robotic cranes.	Neitzel *et al.*, 2010; AlBahnassi and Hammad, 2012; Guo *et al*.,2012; Li and Liu, 2012; Swuste, 2013; Li *et al*.,2013; Zhong *et al*., 2014; Raviv *et al*., 2017; Raviv *et al*., 2017a; Zhou *et al*., 2018; Kim *et al.*,2021; Sadeghi *et al*.,2021;
Excavators	Health and safety issues relating to construction excavators and examples of solutions	Edwards and Holt, 2008; Edwards and Holt, 2009; Coggins et al.,2010; Goh and Ali, 2016; Azar and Kamat, 2017; Vahdatikhaki *et al.*, 2017;
Plant and equipment maintenance	Maintenance and repair of plant and equipment for safety and productivity	Edwards *et al.*, 2002; Edwards and Holt, 2009; Neitzel *et al*., 2010; Riaz *et al*., 2011; Zhou *et al*., 2018.

Table 7.6 - Content analysis of 'safety of site' cluster.

Emergent concepts and themes	Brief description	Citations
Technology	Localisation, positioning, tracking and monitoring systems for site safety; Dynamic site layout planning.	Esmaeili and Hallowell, 2013; Lui *et al.,* 2013; Lee *et al.*, 2014; Li *et al.*, 2015; Golovina *et al.*, 2016; Tsai, 2017; Li *et al.*, 2017; Arslan *et al.*, 2019; Chen and Luo, 2019; Ismail, 2019; Shafiq and Afzal, 2020.
Accident and injury types	Accidents, injuries and near-misses occurring in blind spots; collision risk areas; accident and hazard prone conditions.	Wu *et al.*, 2010; Lee *et al.,* 2012; Rowlinson and Jia, 2015; Golovina *et al.,* 2016; Soltanzadeh *et al.,* 2016; Carrillo-Castrillo *et al.,* 2017; Jeelani *et al.,* 2017; Winge and Albrechtsen, 2018; Whiteoak and Appleby, 2019; Pham *et al.,*2020.
Communication	Communication means and modes, timeliness and efficiency of safety communication.	Alsamadani *et al.,* 2013; Albert *et al.,* 2014; Tsai, 2014; Sparer *et al.*, 2015; Edirisinghe and Lingard, 2016; Shafiq and Afzal, 2020.
Safety facilities and safety signs	Planning and positioning of site layout objects such as safety facilities and signs.	Chan and Ng, 2010; Chan and Ng, 2010a; Chan and Chan, 2011; Yi *et al.,* 2012; Sadeghpour and Andayesh, 2015; Winge and Albrechtsen, 2018; Pham *et al.*, 2020.
Site layout planning	Identification and coordination of temporary safety facilities, security fences; storage areas of material and equipment; access roads for safety and productivity improvement.	El-Rayes and Khalafallah, 2005; Esmaeili and Hallowell, 2013; Hallowell, *et al.,* 2013; Terwel and Jansen, 2015; Sadeghpour and Andayesh, 2015; Ismail, 2019; Schwabe *et al.,* 2019; Pham *et al.,*2020.
Leading indicators	Leading indicators for site safety such as measuring hazardous proximity or interactive hazardous near miss situations between workers-on-foot and heavy construction equipment.	Mikkelsen *et al.,* 2010; Sparer *et al.,*2015; Golovina *et al.,* 2016; Guo and Yiu, 2016; Versteeg *et al.*, 2019; Whiteoak and Appleby, 2019.
Regulations	Standards, legislations and regulations for site safety.	Rawlinson and Farrell, 2010; Borys, 2012; Sherratt *et al.,* 2013; Kanchana *et al.,* 2015; Manu *et al.,* 2014; Tepaskoualos and Chountalas, 2017; Oswald *et al.*, 2018; Swallow and Zulu, 2019.

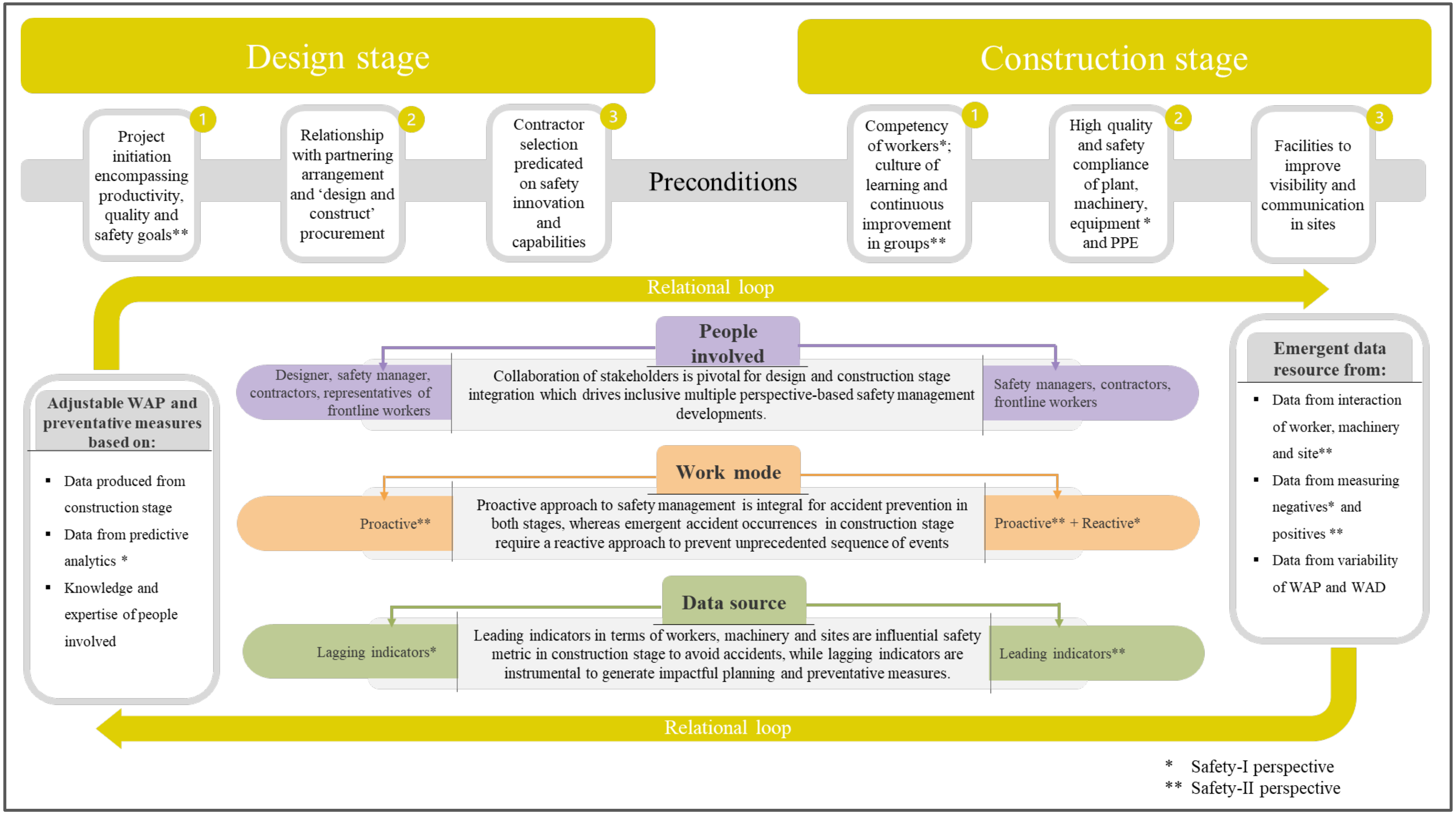
An expansion of plant and machinery utilisation has increased site productivity, efficiency and safety concerns in equal measures (Kumar *et al.,* 2015; Hoz-Torres *et al*., 2021). Accidents and injury types involving plant and machinery collapse or overturn, struck-by or caught-in-between objects are broadly studied subjects in the '*safety of machinery'* cluster (Raviv and Shapira, 2018; Edwards *et al.,* 2019; Sadeghi *et al.,* 2021). The *'safety of sites'* cluster (in Table 7.6), on the other hand, incorporate studies on models, frameworks and technological developments for site layout planning (Sadeghpour and Andayesh, 2015; Schwabe *et al.,* 2019; Pham *et al.,* 2020). Therefore, themes such as 'technology', 'accident and injury types', 'communication', 'safety facilities and safety signs', 'site layout planning', 'leading indicators' and 'regulations' dominate in the *'safety of sites'* cluster.

7.2.2. Discussion: 'Safety-in-cohesion' model

As the findings of thematic and content analysis disclose, the literature is replete with studies focusing on WMS components of construction projects in isolation. However, similar to the existence of blind spots in construction workplaces, there exist some gaps in the literature of safety management in the construction industry. The extensive research on individual system components (i.e. WMS) addresses each element's inherent challenges and proffers solutions that tend to neglect their complex relationships (Mohammadi and Tavakolan, 2020). This necessitates studies to combine all three components with a holistic research design and approach such as: system dynamics - to generate knowledge explaining non-linear behaviour of such complex systems (Guo *et al.,* 2015); and predictive analytics - to enhance the impact of preventative measures which encompass factors of WMS relationship. Another apparent shortcoming observed in the construction safety management literature (Atkinson and Westall, 2010; Terwel and Jansen, 2015; Manu *et al.,* 2014) is the dearth of studies and practices that integrate design and construction stage of projects. This intrinsic limitation of construction projects (particularly in traditional procurement paths) emerges at the project initiation stage where selection of contractors is founded on segregation (i.e. separate 'design' contract and 'construct' contract procurement) and project-length relationship (*ibid*). This in turn, inadvertently complicates communications and obscures responsibilities between parties in the following design and predominantly construction stage. Integration of the design and construction stage (e.g. via Design and Build procurement) will not only augment communication and integration of stakeholders but will also unravel the conflict of goals concerning the trade-off between productivity, quality and safety (PQS) – the conundrum that influences construction workers' decision-making at worksites (Atkinson and Westall, 2010; Oswald *et al.,* 2020). In addition to the procurement path chosen, other factors may further impact upon (positively or negatively) the safe system of work employed on site. For example, the construction knowledge of other stakeholders (including the client and designer) (Jin *et al.,* 2019), legislative developments (Mohammadi *et al.,* 2018), macroeconomic or black swan events (Haghani *et al.,* 2020) and disruptive technologies used (Chatzimichailidou and Ma, 2022). To explore each and every factor individually (or in combination) an infinitum is required for further investigative research, which is beyond the purpose of the present study.

To address all above mentioned shortcomings observed in the construction safety management literature (i.e. prevalence of segregated studies of WMS system aspects; or iconoclastic debates between Safety-I and Safety-II concepts) and unfavourable practices of construction safety management alluded to (e.g. unidirectional and sequential nature of design and construction stages; or goals conflict), a novel conceptual model is generated (by embedding the emergent findings from the literature) as illustrated in Figure 7.7. This model presents a holistic overview that encapsulates the design and construction/operation stages together with example preconditions within. It also identifies the people involved, work mode and data sources used in each stage of construction project and presents how these elements cumulatively support a relational loop as a vital organisational learning opportunity. In doing so, it provides new hypothesis to be deductively tested using case studies in practice.

Figure 7.7 - A conceptual model ‘Safety-in-cohesion’.



The model's title 'Safety-in-cohesion' is predominately founded on both Safety-I (*in model) and Safety-II (** in model) principles that are pervasive in extant safety management literature. However, in contrast to previous studies, this STS-based model seeks to avert the mutually iconoclastic view of Safety-I and Safety-II proponents and attempts to deduce the most propitious views and practices from both concepts that are relevant to construction safety management. The model emphasises the integration of design and construction stage: by highlighting compulsory preconditions (1, 2 and 3 in Figure 7.7) of each stage first; followed by consolidation of two stages via a relational loop which showcases their interdependence for overall success in terms of PQS.

The necessary preconditions of the design stage depict three factors starting from the top left-hand side (in Figure 7.7): 1) 'project initiation encompassing productivity, quality and safety goals' design stage precondition denotes goal setting (by combining and balancing PQS) prior to project initiation; 2) 'relationship with partnering arrangement and 'design and construct' procurement' design stage precondition indicates long-term relationship building of owners and contractors; and 3) 'contractor selection predicated on safety innovation and capabilities' design stage precondition represents alternative (to conventional price-driven and accident records reputation-based selection criteria) and unconventional contractor selection criteria predicated on safety innovation and adoption capacities of companies. Construction stage preconditions, on the other side, describe three factors related to three system components (WMS) accordingly. As cited by many studies (cf. Edwards and Holt, 2008; Biggs and Biggs, 2013; Abdullah *et al.,* 2018), and illustrated in the result of word frequency analysis of '*safety of workers*' cluster (i.e. terms such as 'behaviour', 'training', and 'knowledge' in Figure 7.6) the first pivotal factor prior to and during construction stage involves enhancing workers' competency on an individual level and promoting 'culture of learning and continuous improvement' on group and organisational level. Therefore, this point (i.e. 'competency of workers; culture of learning and continuous improvement in groups') is assigned to be the first precondition of the construction stage in the model, which addresses the workers (i.e. W in WMS) system component. Similarly, 'high quality and safety compliance of plant, machinery, equipment and PPE' is described as the second construction stage precondition and 'facilities to improve visibility and communication in sites' is defined as the third precondition of construction stage. These three construction stage preconditions are respectively targeted to mitigate or prevent accident occurrence factors related to WMS (that were identified in the literature and illustrated in Tables 7.4, 7.5 and 7.6 respectively); *viz.*, unsafe act or behaviour of workers (Carriço *et al.,* 2015; Wang *et al*., 2016; Choi *et al.,* 2017; Meng and Chan, 2020; Yao *et al.*, 2021; Andersen and Grytnes, 2021); unsafe conditions due to machinery failure (Edwards *et al*., 2002; Edwards and Holt, 2009; Neitzel *et al*., 2001; Riaz *et al*., 2011; Zhou *et al.,* 2018); and proximity factors due to tight coupling of sites (Wu *et al*., 2010; Lee *et al.,*2012; Esmaeili and Hallowell, 2013; Edirisinghe and Lingard, 2016; Shafiq and Afzal, 2020).

Whilst the top part of the model sets the foundation for success of each stage (*viz*., design and construction), the inner part of interrelation loop demonstrates similarities and variances (of design and construction stages) in terms of people involved, work mode and data source. 'People involved' continues the integration principle, advocating for participation of construction workers and safety supervisors during the design stage. Inclusion of expertise, knowledge and experience of people who are engaged in worksite jobs creates the groundwork for embedding both buildability and safety within the project.

'Work mode' depicts proactive (Safety-II) and reactive (Safety-I) approaches to safety management practices during both design and construction stages. As stated in the Safety-II concept, a proactive approach to accident prevention improves preparedness and alleviates adverse impact and disruption of possible accident occurrence (Patterson and Deutsch, 2015; Dekker, 2019; Wang *et al.,* 2020). However, the proactive work mode is more practicable in the design stage rather than the construction stage; in the design stage *work-as-planned* (WAP) can be proactively generated through accumulated knowledge and safety countermeasures can be designed and planned with the help of predictive data (generated through accident records analysis) acquired from previous projects. Whereas the environment of the construction stage does not allow constant proactive functioning due to its unpredictability and requires an adaptive and responsive approach to tackle the entropy state of this stage. Therefore, a combination of reactive and proactive work modes (assigned in the model) during the construction stage lends dynamic flexibility to adapt to ongoing occurrences and to deviate from WAP if needed.

Observed from the content analysis findings (refers to Figure 7.6, Table 7.4,7.5 and 7.6), *'safety of workers'* and *'safety of sites'* clusters contain studies with 'leading indicators' as a recurrent theme. Utilisation of LIs (which combine WMS aspects and their interrelationship) as a 'data source' in construction stage engenders reliable and accurate depiction of safety status of an ongoing project and hence, enhances informed decision-making of participants during the construction stage (Guo and Yiu, 2015; Versteeg *et al.,*2019). Contrary to the Safety-II view, the model includes lagging indicators as a 'data source' for the design stage. Utilised correctly and efficiently, lagging indicators (data from accident records) are a valuable resource for predictive analytics (Bortey *et al.,* 2021), the outcomes of which serves as a groundwork for generating preventative measures in the design stage. Therefore, the quality and record-keeping practice of lagging indicators become pivotal for overall organisational learning and safety performance improvement.

The final and crucial element of the model, the relational loop of stages, describes another void in the current approach to construction safety management. The construction stage of a project generates invaluable data about success and failure of planned work arrangements and provides vital insights about WMS's complex interaction. Frameworks such as: Accimap (Zhou *et al.,* 2018; Sadeghi *et al.,* 2021); Systems-Theoretic Accident Modelling and Processes (STAMP) (Woolley *et al*., 2020); Human Factor Analysis Classification System (HFACS) (Zhang *et al.,* 2019); and Functional Resonance Analysis Method (FRAM) (Waterson *et al.,* 2015; Woolley *et al.,* 2019) are examples of STS based analytical tools described in the literature that foster examining accident occurrence of WMS interaction. These systems thinking based accident analysis methods generate invaluable knowledge about complexity of WMS interaction which facilitates an understanding of holonic nature of system components and fosters identifying conditions and set of events that lead to accident occurrence. Additionally, data about success (measuring positives as promoted by Safety-II) and failure (measuring negatives promoted by Safety-I) are accumulated in the process of construction/operation stage. Similarly, data emerging on WAP and WAD disparity in a construction process serves as a vital source of constructive insight to enhance preparedness and planning in the design stage. All three sources of knowledge and data generated during the construction stage are illustrated as 'emergent data resources' on the right-hand side of the model from which relational loop heads towards design stage.

Nevertheless, all the alluded data emerging from the construction stage in the model (comprising of: 1) data on WMS interaction; 2) measurement of negatives and positives; and 3) data of WAP and WAD discrepancy) are not being proactively leveraged for the design stage. The current relationship between the design and construction stages in the practice of the construction industry is unidirectional (i.e. design stage followed by construction stage) with no feedback loop occurring between the stages. Whereas, directing emergent data from the construction stage to the design stage through a knowledge management loop will generate evidence-based, scrupulous and practical planning and preventative measures to reduce future risk and/or assess the success (or otherwise) of measures adopted. Therefore, the model promulgates leveraging invaluable data that engender learning opportunities from the construction stage and utilise them in the design stage of a construction project. Feeding all the data generated and insights learnt from the construction stage back into the design stage of both current and future projects will serve as a foundation of constructing WAP and generating preventative measures (as illustrated on the design side of relational loop of the model).

7.3. DEVELOPMENT AND IMPLEMENTATION OF LEADING INDICATORS

The ubiquity of lagging indicators implementation as a safety performance indicator by most organisations is ascribable to the ease of collecting, recording and analysing them (Lingard *et al.,* 2017). Numerous tools, theories and methods exist to analyse past events of reportable and recordable accident occurrences; epitomised by the fishbone diagram, five whys, root-cause analysis that attempt to determine cause and underlying reasons of recorded cases, namely lagging indicators (Hughes and Ferrett, 2020). Whereas recent applications of machine learning and predictive/classification analytics (both stochastic or deterministic modelling variants) are more sophisticated methods that attempt to identify systemic vulnerabilities and determine accident predictors (Shrestha *et al*., 2020; Bortey *et al.,* 2021; Erkal *et al.,* 2021). However, studies on LIs reside within an incipient stage of development only (Mearns, 2009). Table 7.7 illustrates the results of cross-componential analysis (based on 80 items included from the pertinent literature detailed in Figure 6.2 as 3) of the concepts leading and lagging indicators.

Table 7.7 - Cross-componential analysis of leading and lagging indicators.

Features	Leading indicators	Lagging indicators
Definition	Current situation that can affect future performance (Mearns, 2009).	Outcomes that result from our actions (Mearns, 2009).
	Precursors of failure or success (Swuste *et al.*, 2016).	Occurrences of failures (Schmitz *et al.*, 2021).
Examples	Safety culture, safety climate, near-misses, safety training, toolbox talks, safety training and orientation, safety inspections (Falahati *et al.*, 2020).	Total recordable injury rate (TRIR), lost workday rate (LWDR), worker compensation rate (WCR), lost time cases (LTC) (Jazayeri and Dadi, 2017; Floyd, 2021).
Function and use	For monitoring and responding (Guo and Yiu, 2016).	For recording, reporting and learning from past mistakes (Alruqi and Hallowell, 2019).
	For internal use of a company (Reiman and Pietikäinen, 2012).	
	-	For external use of a company (Elsebaei *et al.*, 2020).
Underlying concept	Safety-II and Resilience engineering (Patriarca *et al.*, 2019; Pęciłło, 2020).	Safety-I (Hollnagel, 2014).
Risk assessment	Proactive and reactive (Sheehan *et al.*, 2016).	Retrospective and introspective (Lingard *et al.*, 2017).
Focus	Safety performance now and near future (Yorio *et al.*, 2020).	Safety performance of the past (Alruqi and Hallowell, 2019).
	Safety status before accident occurrence (Haas and Yorio, 2016).	Safety status at the moment of accident (Neamat, 2019).
Measures (what)	Negative status of safety, i.e., absence of safety (Sheehan *et al.*, 2016).	
	Negative and positive precursors: signs and signals of upcoming failure or success (Reiman and Pietikäinen, 2012; Patriarca *et al.*, 2019; Xu *et al.*, 2021).	Negative outcomes only: failures, errors, mistakes, accidents, near misses, dangerous occurrences (Lingard *et al.*, 2017).
Measures (how)	Quantitatively (Grecco *et al.*, 2013).	
	Qualitatively (Reiman and Pietikäinen, 2012).	-
Advantages	Timely safety performance measure enables to prevent accident occurrences (Floyd, 2021).	Lesson learnt from the past enables data-driven and informed generation of preventative countermeasures (Oswald, 2020).
	Drive continuous improvement and error correction (Grabowski *et al.*, 2007).	Great introspection practice for continuous learning organisation (Oswald, 2020).
	Measuring success ("*things going right*") enables recognition and encouragement of workers' good safety practices (Hinze *et al.*, 2013; Sheehan *et al.*, 2016).	Sophisticated analysis methods have a potential to identify systemic vulnerabilities and to detect accident precursors (Hallowell *et al.*, 2019).
Disadvantages	Ambiguity around leading indicator's definition, application and functions impedes its adoption by companies (Kenan and Kadri, 2014; Guo and Yio, 2015).	Recording of lagging indicators becomes distorted from the actual events, when used as a benchmarking criterium (Costin *et al.*, 2019; Floyd, 2021).
	Elements of leading indicators are unique and identified leading indicators are not readily generalisable to other organisations or projects (Xu *et al.*, 2021).	Past mistakes and accidents are mostly non-generalisable for future construction projects (Elsebaei *et al.*, 2020; Floyd, 2021).
	Sole quantification-based safety performance indicators (leading and lagging indicators) fail to holistically indicate a safety performance (Oswald, 2020).	
	Recording and analysing only high severity and high frequency occurrences and ignoring seemingly statistically insignificant data obstructs the learning opportunity (Hopkins, 2009; Floyd, 2021).	
	The emergent nature of most leading indicators that are only discernible in the operation stage of projects makes the process of knowledge transfer (and adoption of developed leading indicators) difficult (Haas and Yorio, 2016).	Outcomes of analysing (lagging indicators) based on basic analysis methods are invalid to identify systemic failures or to have predictability (Hughes and Ferrett, 2020). Whereas sophisticated analysis methods (of lagging indicators) are not affordable and widely adopted and only statistically significant events can be analysed in sophisticated analysis methods, hence there is a lack of empirical studies proving such methods' credibility (Erkal *et al.*, 2021).

The cross-componential analysis identifies that the focus, function, definition, underlying concept, risk assessment, what and how metrics are measured as well as advantages and disadvantages to be the main features describing both indicators. Both leading and lagging indicators have their own merits in terms of the function they serve *viz.*: monitoring safety or unsafety respectively (Reiman and Pietikäinen, 2012); measuring different level of precursors (e.g. safety behaviour of workers and near misses) or consequences (e.g., near misses or dangerous occurrences) (Swuste *et al.,* 2019); and responding by correcting in the moment or by learning and preventing in the future (Hinze *et al*., 2013). Table 7.7 illustrates that most of the features used to contrast leading and lagging indicators differ for each indicator, except for five overlapping or common features (that are highlighted with light yellow shading in Table 7.7). These commonalities appear: once in *function and use* feature (i.e. for external use of a company); once in *what they measure* (i.e. negative status of safety); once in *how they measure* (i.e. quantitatively) and twice in the *disadvantages* feature. These two overlapping features in *disadvantages* are: 1) sole quantification-based safety performance indicators (leading and lagging indicators) which fail to holistically indicate a safety performance; and 2) recording and analysing only high severity and high frequency occurrences and ignoring seemingly statistically insignificant data obstructs the learning opportunity. The findings demonstrate that lagging and LIs emerge from two different safety concepts *viz.*, Safety-I and Safety-II, which (similar to the leading and lagging indicators) are frequently contrasted in safety science literature. However, like the Safety-II concept, the notion of a LI is relatively new concept in safety management that possesses some ambiguity in terms of functions, deviations in definition and unclarity in application – this being one of the disadvantages explained (in Table 7.7) to hinder the adoption of LIs.

7.3.1. Constructs of leading indicators

Premised upon the findings of cross comparison analysis in Table 7.7, the next content analysis step focused on aggregating the definition of LIs and their development methods in pertinent literature. The content analysis scrutinised 93 items selected from the literature of LIs in safety management that are sourced from Scopus journal database (as detailed in Figure 6.2). Because content analysis aims to identify the constructs of LIs, three main constructs are selected to explain this concept *viz.*: 1) the definition; 2) classification types; and 3) development methodologies. These constructs are respectively presented in Tables 7.8, 7.9 and 7.10. Table 7.8 describes a compilation of LIs' definitions (arranged from early to recent years).

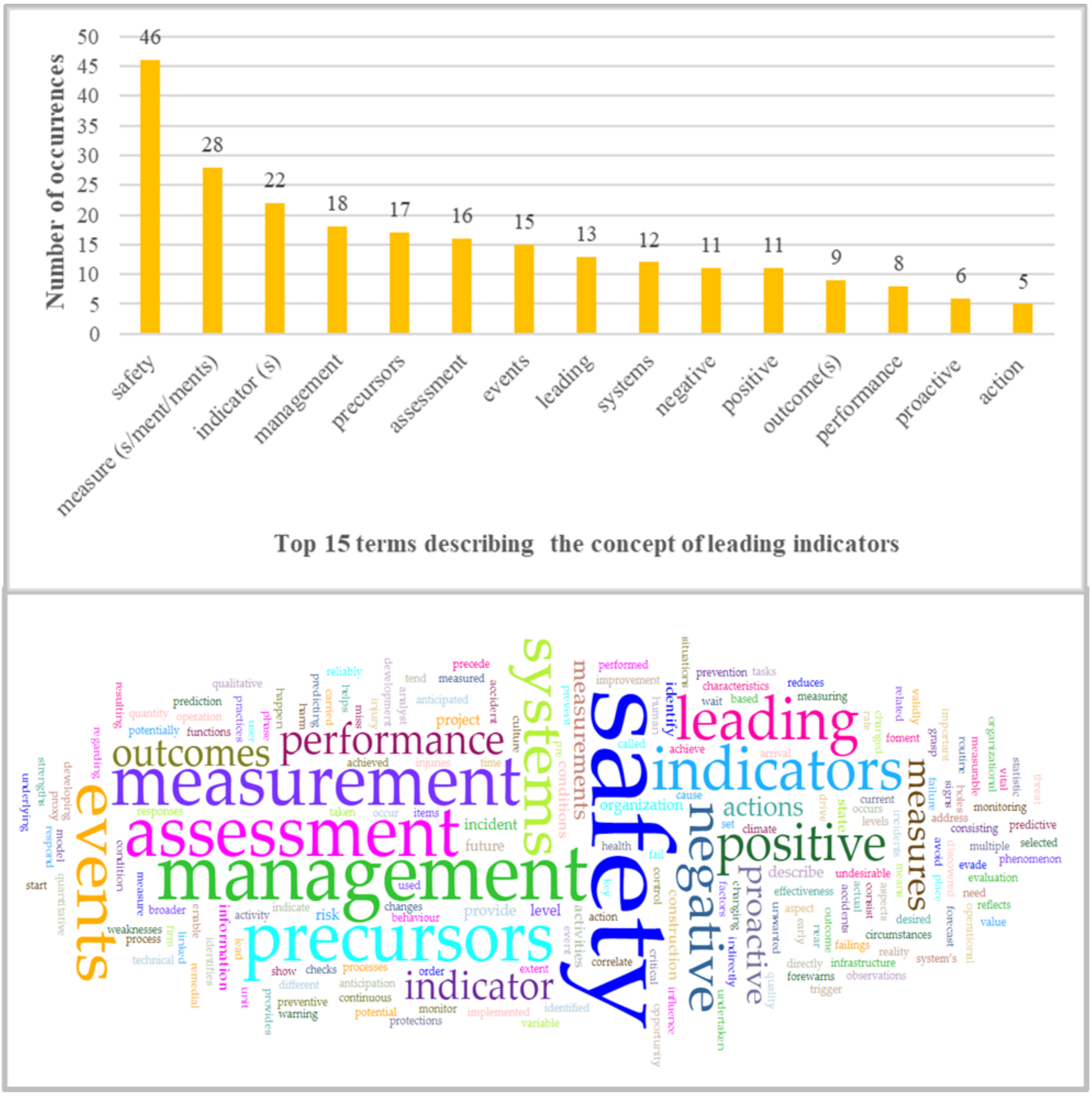
Table 7.8 - Etymology of leading indicator.

Definitions	Citation	Semantics
A safety indicator is a statistic or other unit of information that reflects directly or indirectly the extent to which an anticipated outcome is achieved or the quality of the processes leading to that outcome.	NOHSC, 1999 (cited in Guo and You, 2015)	Outcomes; Precursors; Measurement of positive events; Assessment of safety management systems
Leading indicators provide information about developing or changing conditions and factors that tend to influence future human performance.	EPRI, 2000 (cited in Jazayeri and Dadi, 2017)	Precursors; Measurement of positive and negative events
Measurements linked to preventive or proactive actions.	Toellner, 2001 (cited in Xu *et al.*, 2021)	Precursors;
A safety indicator is a measurable/operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality.	Øien, 2001b (cited in Guo and You, 2015)	Measurement of positive and negative events;
The leading indicator identifies failings or 'holes' in vital aspects of the risk control system discovered during routine checks on the operation of a critical activity within the risk control system.	Health, and Safety Executive (HSE), 2006	Measurement of negative events;
Leading indicators are conditions, events, or measures that precede an undesirable event and that have some value in predicting the arrival of the event, whether an accident, incident, near miss, or undesirable safety state.	Grabowski *et al.*, 2007	Precursors; Measurement of negative events;
A safety performance indicator is a means for measuring the changes in safety level over time resulting from actions taken.	OECD, 2008	Outcomes; Measurement of positive and negative events;
An indicator that changes before the actual risk level of the organisation has changed.	Kjellén, 2009	Precursors;
Leading indicators are proactive measures of performance before any unwanted outcomes have taken place.	Dyreborg, 2009	Precursors; Measurement of and negative events;
A safety indicator is a proxy measurement for items identified as important in the underlying model(s) of safety.	Wreathall, 2009	Assessment of safety management systems
An indicator should measure the state of the safety management system.	Hopkins, 2009	Assessment of safety management systems
Safety indicators are measures of the effectiveness of safety management tasks.	Cipolla *et al.*, 2009 (cited in Guo and You, 2015)	Assessment of safety management systems
Lead safety indicators indicate either the current state or the development of key organisational functions, processes and the technical infrastructure of the system.	Reiman and Pietikäinen, 2012	Precursors; Outcomes; Assessment of safety management systems
Positive performance indicators that address health and safety climate.	Agumba and Haupt, 2012	Outcomes; Measurement of positive events;
Leading indicators of safety performance consist of a set of selected measures that describe the level of effectiveness of the safety process.	Hinze *et al.*, 2013	Assessment of safety management systems
Proactive and predictive measurements that enable safety condition monitoring, which reduces the need to wait for the system to fail to identify weaknesses and to take remedial action.	Eaton *et al.*, 2013	Precursors; Assessment of safety;
Indicators that enable anticipation of performance evaluation are called leading indicators.	Grecco *et al.*, 2013	Precursors;
Leading indicators are safety-related practices or observations that can be measured during the construction phase, which can trigger positive responses.	Hallowell *et al.*, 2013	Assessment of safety management systems; Measurement of positive events;
Characteristics that foment safety behaviour, such as safety culture or safety climate.	Navarro *et al.*, 2013	Assessment of safety and safety culture;
Something that provides information that helps the user respond to changing circumstances and take actions to achieve desired outcomes or avoid unwanted outcomes.	Step-Change in Safety, 2014 (cited in Guo and Yio, 2015)	Precursors; Measurement of negative and positive events

A set of quantitative and/or qualitative measurements that can describe and monitor validly and reliably the safety conditions of a construction project.	Guo and Yio, 2015	Assessment of safety
Precursors to harm that provide early warning signs of potential failure.	Shea *et al.*, 2016 (cited in Xu *et al.*, 2021)	Precursors; Measurement of negative events;
Safety leading indicators are proactive, pre-incident measurements consisting of multiple levels of safety protections carried out before the start of (or during) the construction phase, at both the organisation and project levels.	Karakhan *et al.*, 2018 (cited in Xu *et al.*, 2021)	Precursors; Assessment of safety management systems;
Safety leading indicators are measures of the safety management system that correlate with injury rate.	Alruqi and Hallowell, 2019	Measurement negative events; Assessment of safety management systems;
Forewarns the analyst about potentially different actions to be undertaken in order to grasp an opportunity or to evade a threat.	Patriarca *et al.*, 2019	Precursors; Measurement of negative and positive events;
The quantity of safety management activities performed to prevent injuries	Hallowell *et al.*, 2020	Assessment of safety management system;
Leading indicators show the activities of an organisation regarding the prediction and prevention of accidents before they occur.	Falahati *et al.*, 2020	Precursors; Assessment of safety management systems;
Leading indicator are safety measurement which provide a future forecast of the safety performance based on the activities and practices implemented not incidents. So, it is proactive measure to what might happen in the future.	Elsebaei *et al.*, 2020	Precursors; Assessment of safety management systems;
Safety leading indicators are measures that indicate the current performance of a safety management system of a project or firm. They can: 1) identify the system's weaknesses and strengths, 2) identify situations that might cause incidents and injuries, and 3) drive proactive actions to prevent an incident or injury before it occurs and achieve continuous improvement.	Xu *et al.*, 2021	Precursors; Assessment of safety management systems. Measurement of positive and negative events;

The definitions of LIs included in Table 7.8 are arranged in chronological order from the earliest to the most recent to show their development in safety science. Moreover, a semantics column was added to reveal how the definitions (and understanding) of LIs have evolved over time. The definitions starting from 1999 to 2012 describe LIs as an outcome, *viz.,* indicator of events that has occurred (alongside the description as precursors, *viz.*, indicators predicting events that are going to occur); albeit outcome is defined as the main feature of lagging indicators according to the Bowtie diagram (Swuste *et al.*, 2016). These early formative descriptions of LIs as 'outcomes' and/or 'precursors' represent some examples of LIs that are considered to be simultaneously lagging and leading (Lingard *et al.,* 2017). However, post 2012 and until recent years, this description changes to precursors only, which signifies the increasing focus on the main function of LIs as antecedents. Table 7.8 is supplemented with the word cloud illustration of the definition and semantics columns (in Figure 7.8), which identifies the most frequent words used to describe and define LIs. Additionally in Figure 7.8, the frequency of occurrences of the terms used to define LIs are congregated in a bar chart.

Figure 7.8 – Frequency of occurrence and word cloud depiction of terms defining leading indicators.



Apart from the keywords themselves (*viz.,* '*safety*', '*leading*', '*indicators*'), the terms such as '*precursors*' (f=17), '*proactive*' (f=6), '*outcomes*' (f=9), '*negative*' (f=11), '*positive*' (f=11), '*measure/ment*' (f=28) and '*assessment*' (f=16) are the most frequent words used to describe LIs. Contrary to lagging indicators that measure negative events, LIs are defined to measure both negative and positive events - a feature that is pivotal for recognition of positive events and learning from success (Reiman and Pietikäinen, 2012; Patriarca *et al.,* 2019). Therefore, the terms '*negative*', '*positive*' and '*events*' are frequently occurring words in the word cloud depiction. Regards the target these indicators are measuring, there is a dichotomy between *safety management systems* on one side and *safety, safety culture* on the other side.

This ambiguity around what is the target of LIs' measurement can be elucidated upon by the different types of LIs described in Table 7.9. Four (out of six) dichotomous clusters of classification with two subgroups within each cluster in Table 7.9, *viz*., 1) PLIs and ALIs; 2) structural and operational LIs; 3) safety management system indicators and indicators of abstract safety constructs; and 4) predictive proactive indicators and monitoring proactive indicators focus on measuring and monitoring safety management systems and safety culture respectively.

Table 7.9 - Typologies of leading indicators.

Types of leading indicators		Definition
Classification based on the length of time leading indicator takes to measure and respond to observed event	Active	Indicators that can be readily changed during the construction phase, they measure quality of implementation (Alruqi and Hallowell, 2019).
		Measurements or information streams that provide an indication of the probable safety performance to be realised within a firm or on a project. They are dynamic and thus more subject to change in a short period of time. ALIs may be characterised as the "pulse" of the construction project in terms of daily safety behaviours and practices (Costin *et al.,*2019).
		Indicators that can be measured within a shorter period (Falahati *et al.,* 2020).
		Active leading indicators are those which are more subject to change in a short period of time (Hinze *et al*., 2013).
		Active indicators are those that can be subject to change in a short period (Jazayeri and Dadi, 2017).
	Passive	Passive indicators are those that cannot be altered in a short period of time (Jazayeri and Dadi, 2017).
		Measurements or information streams that provide an indication of the probable safety performance to be realised within a firm or on a project. They are predictive on a macro scale but have limited predictive value after a certain point in time or once a threshold is reached (Costin *et al.,* 2019).
		An indication of the probable safety performance to be realised within a firm or on a project. The process being monitored by passive leading indicators cannot generally be altered in a short period of time. Passive leading indicators can be used to predict, on a larger or long-term basis, the likely safety performance to be realised by a company or on a particular project (Hinze *et al.,* 2013).
		Indicators that take a long time to measure (Falahati *et al.,* 2020).
		Indicators that are typically implemented before work begins and remain relatively static once a project has begun (Alruqi and Hallowell, 2019).
Classification based on the target of measurement.	Operational	Evaluate the effectiveness of the internal processes of safety and health management systems (Falahati *et al*., 2020).
		Indicators that provide information on the status of individual processes within the management system. Such indicators provide information on progress of change within the management system and assist in forecasting future status and planning (Podgórski, 2014).
		The level of integration and of influence of formal processes on the practices and the working environment of people (Cambon *et al.,* 2006).
	Structural	Show the status of safety management systems, including policies, objectives and plans, procedures, and guidelines (Falahati *et al*., 2020).
		Indicators being applied for the evaluation of system compliance with a given specification. They measure whether individual components of the system are properly designed or evaluating the extent to which system procedures are implemented and being followed in the enterprise (Podgórski, 2014).
		The formal description of all the efforts that are made by the company into managing health and safety at the workplace (Cambon *et al.,* 2006).
Classification based on the target of measurement	Indicators of abstract safety constructs	Indicators that measure safety constructs such as management commitment, safety motivation or social support. Collecting information about abstract safety constructs often requires qualitative interviews and surveys (Guo and Yio, 2015).
	Safety management system indicators	Indicators that measure individual safety practices and activities, providing information about safety management system implementation and thus directing remedial actions (Guo and Yio, 2015).

Classification based on function of measurement	Leading monitor indicators	Indicators of organisational potential to achieve safety. They do not directly predict the safety-related outcomes of the sociotechnical system since these are also affected by numerous other factors such as external circumstances, situational variables and chance (Reiman and Pietikäinen, 2012).
		Monitor indicators reflect the potential and ability of a given organisation to operate safely (Podgroski, 2013).
	Leading drive indicators	Indicate development activities aiming at improving safety (Reiman and Pietikainen, 2012).
		Drive indicators allow the measurement of the degree of execution of selected actions in priority areas of the management system, such as leadership, competence management, hazard control, change management, etc (Podgorski, 2013).
Classification based on severity of observed event	Tier 3 leading indicators	An actual event or discovery of a potentially unsafe situation, e.g. near miss. They are failure of process safety management systems that give an excellent road map to what part needs to be strengthened (Kenan and Kadri, 2014).
		Represents events involving challenges to safety systems, such as safe operating limit excursions, inspections of primary containment outside acceptable limits, etc (Murray, 2015).
		Events that are considered to be a challenge to a safety management system that exceed safe operating limits (SOL) (Stauffer and Chastain-Knight, 2021).
	Tier 4 leading indicators	Indicators that monitor the health of important aspects of the process safety management system which give early indication of deterioration in the effectiveness of key safety system and enable remedial action to be undertaken to restore the effectiveness of these key barriers, before any loss of containment event takes place (Kenan and Kadri, 2014).
		Indicators that categorise operating discipline and management system performance (Murray, 2015).
Classification based on the target of measurement	Predictive proactive indicators	Predictive proactive indicators supply information on the types of managerial actions that have been taken to reduce workplace risk (Haas and Yorio, 2016).
	Monitoring proactive indicators	Monitoring proactive indicators include health and safety related outcomes observed prior to the occurrence of a major incident such as small releases of hazardous substances or near misses, the results of safety inspections and behavioural observations, the results of safety audits, and safety attitudes (Haas and Yorio, 2016).

These varieties of dichotomous LI groups (with different functions and focuses) create confusion around LIs' nature, function and application potentials and leads to the absence of their unanimously accepted and operationally crisp definition. For example, variations in: definitions (whether they measure safety management systems or safety and safety culture); time period to measure (whether they measure safety performances occurring in the long time or short time period); and function they fulfil (whether they are used only for measuring recording and learning or for monitoring and timely correcting) are respectively associated with PLIs and ALIs types. Therefore, it is pivotal to differentiate the two types of LIs, namely: PLIs (similarly, structural LIs and safety management system indicators) which focus on monitoring and measuring safety in terms of adopted organisational safety management systems over an extended timeframe to correct and obtain feedback; and ALIs (similarly, operational LIs and indicators of abstract safety constructs) which are intended to monitor and measure an organisation's safety and safety culture in the operation stage which provides real time feedback of current safety status. Within literature, generic description of LIs are predominantly associated with PLIs function and nature and thus their capability to mitigate incipient risks posed in a timely manner remains unknown.

The last construct of LIs is the methodologies used to develop LIs. Content analysis revealed prominent studies that develop and identify LIs using various methodologies (such as Delphi method (Erkal *et al*., 2021); cross-sectional analysis (Manjourides and Dennerlein, 2019); and Analytical Network Process (ANP) (Ebrahimi *et al.,* 2021)). Table 7.10 identifies 17 studies (i.e. 18.28 %) out of 93 that use varying methodologies to develop LIs.

Table 7.10 – Methodologies used for leading indicators development and identification.

Methods used to develop leading indicators	Source being analysed (leading indicators are developed from)	Developed/identified leading indicators	Citation	Element/aspect of system
Analytic Hierarchy Process (AHP)	Pertinent literature and normative documents on OSH MS (ILO-OSH 2001, OHSAS 18001).	20 leading indicators (Key performance indicators)	Podgorski *et al.*, 2013	Human; Procedures.
AHP and Bayesian network	OHSAS 18001: 2007 management system components; and ongoing construction project operations.	19 structural, 27 operational and 33 active leading indictors	Falahati *et al.*, 2020	Human; Machinery; Sites.
Functional Resonance Analysis Method (FRAM)	Ongoing construction project (difference between WAP and WAD).	Not specified	Costantino *et al.*, 2020	Not available.
Selection by research team of experts	Triangulation of case studies, project descriptions of safety award–winning projects and expert brainstorming.	13 passive leading indicators	Hallowell *et al.*, 2013	Human.
Review of the literature	Pertinent literature (18 articles).	15 leading indicators	Neamat, 2019	Human.
Content analysis and Natural language processing (NLP)	Accident investigation reports.	11 leading indicators (upstream precursors)	Shrestha *et al.*, 2020	Human; Machinery; Sites.
Ranking survey answers	Hazard factors identified by Centre for Chemical Process Safety.	10 leading indicators	Baek *et al.*, 2018	Human.
Hybrid method consisting of Delphi method and Focus groups	Data obtained from structured brainstorming of selected experts in focus group study.	41 leading indicators	Erkal *et al.*, 2021	Human; Procedures. Sites.
Authors' conceptual model (based on two Rasmussen's safety models: the model of migration and the sociotechnical system view (STS))	Pertinent literature and Hypothetical project.	32 leading indicators	Guo and You, 2015	Human.
Machine learning	Records of project performance and safety-related data.	Not specified	Jafari *et al.*, 2019	Not available.
Machine learning	Seven years period data of project performance and safety-related records (i.e. monthly inspection records, accident cases, monthly project-related data).	Not specified	Poh *et al.*, 2018	Not available.
Survey of Centre for Chemical Process Safety (CCPS) members	Responses from survey.	23 leading indicators	Kenan and Kadri, 2014	Human; Machinery; Procedures.
Cross sectional analysis	Recordable cases (RC) and days away restricted or transferred (DART).	6 passive leading indicators	Manjourides and Dennerlein, 2019	Procedures.
Ranking through fuzzy model based on experts' opinion and Pareto principle	Health and Safety documents (i.e. industry white papers, standards, recommendation and guidance publications) and reports of major accident analysis.	44 leading indicators	Santos *et al.*, 2019	Human; Machinery; Procedures; Sites
Systematic literature review	32 pertinent articles.	16 leading indicators	Xu *et al.*, 2021	Human; Sites; Procedures.
Longitudinal Logistic Regression and Longitudinal Count Regression models	Safety records of 2006-2017 years from Mine Safety and Health Administration (MSHA) database.	3 leading indicators	Yorio *et al.*, 2020	Procedures.
Human Factors Analysis and Classification System (HFACS) approach (to identify human factor) followed by Decision- Making Trial and Evaluation Laboratory (DEMATEL) method and the Analytical Network Process (ANP)	42 safety records of 2007-2018 years from Transportation Safety Board of Canada.	3 leading indicators	Ebrahimi *et al.*, 2021	Human.

The source of materials used for developing and identifying LIs ranges from pertinent scientific literature to industry standards and survey responses. The most frequently used data source is '*past accident records*' *viz.*, lagging indicators; eight out of these 17 studies used organisations' past accident records to identify company specific LIs. The next frequently used material source is '*pertinent literature*' (*f*=4), followed by '*industry specific white papers and recommendations*' (*f*=3) and '*survey responses*' (*f*=2). All developed indicators from each study were reviewed to identify which element of the STSs they represent. Most of the developed LIs (*f*=12) refer to '*human*' aspect of STSs, followed by '*procedures*' (*f*=7).

The most common methodology used to develop, identify or select LIs from a given source of materials is based on opinions (*f*=4) by congregating or ranking survey responses, through Delphi method or Focus groups method; followed by multi-criteria decision making (MCDA) methods (or multi-criteria decision analysis (MCDM) methods) (*f*=3) such as Analytic Hierarchy Process (AHP), Decision-Making Trial and Evaluation Laboratory (DEMATEL) or Analytical Network Process (ANP). This observation identifies that the methodologies for LIs' development predominantly rely on subjectivity and/or opinion or interpretation-based approach. However, such an approach must be combined with testing and revision in pilot or case studies to develop the most apposite LIs for a specific organisation and remain open to adjustments even after the adoption.

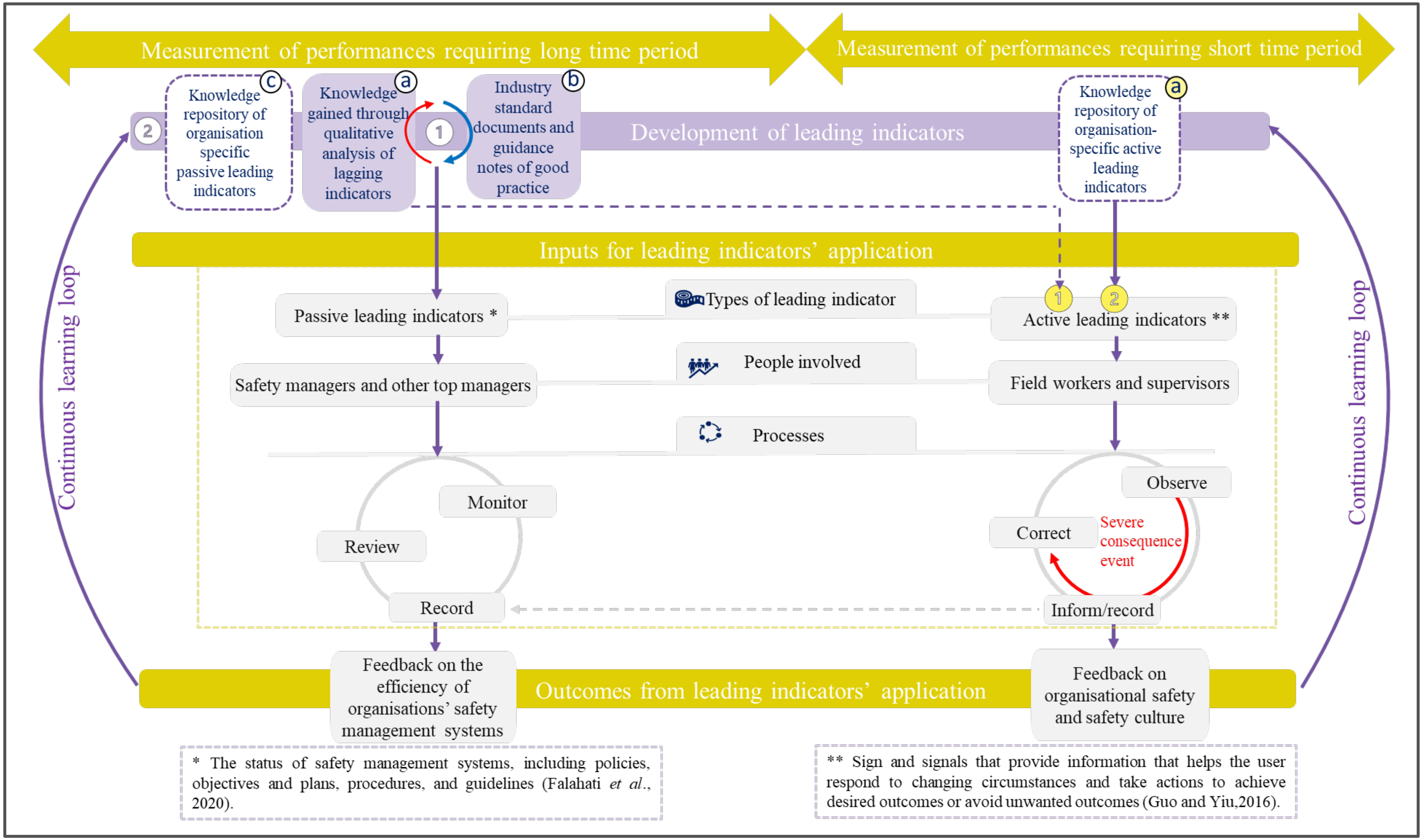
7.3.2. Discussion: conceptual model to develop and adopt leading indicators

The results of cross-componential analysis (in Table 7.7) identify the main features of both leading and lagging indicators - both of which have inherent (and dissimilar) pros and cons, barriers and misinterpretation of their purpose, function and application. Lagging indicators constitute a mainstream measurement of safety, widely adopted by many safety-critical organisations in various industry, yet the function and purpose of using lagging indicators have been distorted from serving altruistic learning purposes to being recklessly promoted as one of the predominant success criteria of companies (Oswald, 2020). Where lagging indicators are recorded comprehensively for learning and understanding the complex interaction of system elements and contextual factors in complex STSs, they can excoriate the mistakes, early signs, gaps in the safety management systems and safety. Moreover, they can augment the development of precursors of undesirable events, namely LIs (Elsebaei *et al.,*2020).

7.3.2.1. New theory development

The process of developing LIs from past safety performance records is depicted in a new theoretical conceptual model presented in Figure 7.9 which is premised upon the rich synthesis of literature analysed. The model proceeds with differentiation of application of PLIs (long double-sided arrow on the left side of the model) and ALIs (short double-sided arrow on the right side of the model) followed by the inputs for development (purple line) and application of (light yellow line) PLIs and ALIs down across the model. PLIs application is depicted as a long arrow ('measurement of performances requiring long time period'), since PLIs measure the efficiency of organisations' safety management systems, which takes a longer time period to obtain feedback and to adjust safety management systems (where correction is required). For example, training courses implemented (which is part of organisations' safety management systems) requires a longer time period to reveal its efficiency, i.e. the competency level of employees is revealed long after the completion of training courses (in the project stage). If the competency level is deemed to be inadequate, similarly a longer time period would be required to correct and adjust the training courses. However, ALIs application is illustrated as a shorter arrow ('measurement of performances requiring short time period') to convey the shorter time period ALIs take to measure safety and safety culture.

Figure 7.9 - Conceptual model of leading indicators development and application process for continuous learning organisations.



Because the study concludes that the list of LIs to be adopted for every organisation is unique and distinctive, lagging indicators are regarded as the most apposite and evidence-based source of material for development of both types of LIs (i.e. PLIs and ALIs). This introspective practice of deducing knowledge from past events (annotated with ‘a’) is a *terminus a quo* to understand and identify LIs that are most relevant to a specific company. Knowledge gained through analysing lagging indicators allows generation of company specific LIs which are predominantly of a negative nature such as the measurement of undesirable outcomes (i.e. accident occurrences that reveal gaps, failures and mistakes in organisational safety management systems) that organisations are planning to avoid. Therefore, the insights and conclusion reached from qualitative analysis of lagging indicators must be combined with the industry standard documents and latest guidance notes (annotated with ‘b’) which enables generation of (positive) expected performance metrics. The mixture of knowledge about conditions to avoid that are observed from lagging indicators (annotated with red half-circular arrow in the model) and normative or desired outcome metrics emerged from industry standard papers (annotated with the blue half-circular arrow), sets the foundation of initial PLIs’ development (annotated with white circled ‘1’ on the left side of the model).

Analysing lagging indicators and learning about organisational safety potentials from industry guidance papers helps to identify a large majority of PLIs (e.g. competency or incompetency of workers, *viz.,* quality and efficiency of organisation’s training programmes) which can be fed forward for application (left side of input element) as a first input. The second element of the input is people involved in the application of PLIs, followed by the third element, processes they need to adopt for application. Safety managers and other top managers (who are key decision-makers in company’s safety management systems) are the people responsible for PLIs’ application by using a cyclical process of ‘monitor-record-review’. As a result, application of PLIs generates the outcome (left side of outcome block in the model) of negative or positive measurement and feedback on the organisations’ safety management systems (and thus, also serves the functions of recording, assessing, reviewing and learning). The generated outcomes from PLIs’ application render a new knowledge for developing and reviewing the existing PLIs (annotated with white circled ‘2’ in the model). Consequently, these steps of development and application of PLIs engenders an unceasing loop of continuous learning by measuring and adjusting already adopted PLIs based on feedback obtained, all of which are collected in knowledge repository (annotated with ‘c’ in the model).

Similarly short time applications (right side of the model) proceed with identification of ALIs in the development stage. This is followed by forwarding identified ALIs for applications as the first element of input and frontline workers and supervisors (the second element of input) adopting the cyclical process of 'observe-inform/record-correct' (as the third element of input). This in turn, creates the outcome of feedback (positive or negative) for safety and safety culture through ALIs functions of monitoring, responding and learning. Similar to PLIs application, the outcome from ALIs application (i.e. feedback on organisational safety and safety culture) engenders a novel insight for organisation's knowledge repository of ALIs which allows continuous improvements of ALIs and knowledge generation about complex systems status and behaviour (annotated with yellow circled '2' on the right side of the model).

However, there are two main differences in the process of development and application of ALIs and PLIs. The first contrast to PLIs' development is that ALIs' development occurs in the process of application because it is an emergent LI. However, initial insights as to how to identify ALIs can be obtained from lagging indicators of that company (arrow heading to yellow circled '1' on the right side of the model). Therefore, the model adopts the definition of ALIs as a signs and signals that provide information that helps the user respond to changing circumstances and take corrective actions to achieve desired outcomes or avoid unwanted outcomes (Guo and Yiu, 2015).

The second difference is in the process element of ALIs' application, where depending on the observed element, different steps might be taken. In case of a positive event being observed (*viz.* success), the event must be recorded in the safety management system for recognition (arrow from inform/record step to record step on the long-time application side). Conversely, a negative occurrence of different severity and emergency level might require immediate action of correction (red arrow on processes element of ALIs application) followed by observation of that correction and then recording step. Alternatively, if the observer decides (to their best knowledge at that moment) that the negative occurrence has minor consequences and requires a team to correct it, then the observer must inform the workers who will be impacted by the action and then correct, observe and record the incident.

7.4. SUMMARY OF CHAPTER 7

Three consecutive steps in phase 1 have led to an establishment of research focus, a foundation of a novel theory and refinement of research objectives and questions. The first step, which sought to identify elements for impactful training programmes' design and development, supports the convergence of Safety-I and Safety-II perspective on the role of human aspect in complex systems. The second step concentrates on filling the void in the literature in terms of research concurrently including WMS by adopting systems thinking and seeks to achieve cohesion of concepts (i.e. Safety-I and Safety-II), stages (i.e. design and construction/ operation), people, work mode and data source or type. This step has especially become propitious in determining the research focus, *viz*., using LIs for proactive safety measurement and management, which holistically include WMS and monitors their status and performance whether the events are negative or positive thus, eventually enables the generation of safety intelligence for continuous learning. Therefore, the last step in phase 1 focalises on identification of main LIs' constructs, as a result of which a new conceptual model for LIs development and application grounded on the novel theory is proffered. The model of developing and implementing LIs (in Figure 7.9) attempts to change the common approach of trying to fit *work-as-done* (WAD) to WAP, to adapting the WAP based on the conditions and circumstances of work being performed. Since the condition and circumstances of STSs are dynamic and volatile, only guidance and feedback obtained through LIs can reveal the changing nature of work environment and complex interaction of system elements. However, without application and empirical studies, the model remains as a mere blueprint to what can be achieved through diligent collection of data observed from the complex and tightly coupled work environment. Therefore, the model developed through inductive reasoning (and premised upon pertinent literature) requires deductive application and validation using real-life case studies (as opposed to perceptual type studies implemented). For that reason, in the phase 2, premises offered in this theory and conceptual model are tested with application of real-life data to substantiate the study outcomes.

CHAPTER EIGHT - RESULTS, FINDINGS AND DISCUSSION FROM PHASE 2

8.0. INTRODUCTION

As delineated in Chapter 6, phase 2 involves two steps, *viz*., proof-of-concept and concluding work. The first step is the test of viability of the premises stated in the conceptual model (research outcome developed in phase 1, described in Figure 7.9 of Chapter 7) with real life case study data. Specifically, the process of this step entails following the development process described in the conceptual model in order to develop LIs from combination of lagging indicators (i.e. case study materials) and normative documents. Case study materials contain: textual documents in the form of a summary report and other supplementary documents (e.g. witness statements, risk assessment methods statement (RAMS) and email communication of staff) that extensively describe the incidents and site investigation reports that include photographic evidence of tools or machinery used or utility lines that are involved in the incident. To identify LIs from such a mass of qualitative data, a structured and systematic tool in the form of a framework or template is required to enable consistency. Therefore, to generate such a framework, pertinent literature was selected as a data source. The analytical framework is developed through an iterative process of reviewing the dataset by inductive coding of emerging themes and simultaneously updating the framework as new themes emerge. The framework enables identification of LIs from a qualitative dataset and classify them into eight types of LIs. In addition, in the process of content analysis of the dataset from the literature, a compendium of LI examples was collated which also serves as a source to develop and refine the framework as well as identifying LIs from case study materials.

The second step in phase 2 focuses on recapitulating existing knowledge about LI and explores its role in proactive safety management, continuous learning and safety improvement. Therefore, this concluding work of the doctoral study focuses on challenges, benefits and future potentials of using LIs in safety management. Additionally, the work offers a new theoretical explanation by elucidating the ambiguities between leading and lagging indicators and describing their role in safety management. This new theoretical explanation also incorporates safety management dynamics representing different levels of safety maturity. To accompany these outcomes, a summary of LIs functions are presented which also guides about the specific types of LIs and how to achieve each function provided.

8.1. PROOF-OF-CONCEPT STEP: developing leading indicators from lagging indicators and normative documents.

The process of framework analysis through inductive coding involves inductively identifying emerging concepts and categories within the dataset selected from pertinent literature (448 items as detailed in Figure 6.2 as 4). Table 8.1 illustrates emerging nodes from the dataset that are related to LIs' types (which represents their semantic differences) with citations and descriptions excerpted from literature.

Table 8.1- Leading indicator descriptions and characteristics in the literature.

LIs' categories and characteristics	**Citations**	**Descriptions of corresponding type and characteristics**
Active	Costin *et al*., 2019; Alruqi and Hallowell, 2019; Haji and Behnam, 2023; Haji *et al*., 2022; Akroush and El-adaway, 2017; Akroush and El-adaway, 2018; Hinze *et al*., 2013; Salas and Hallowell, 2016; Ting *et al*., 2019; Talebi *et al*., 2021; Beck-Krala and Klimkiewicz, 2016; Chen *et al*., 2019; Sinelnikov *et al*., 2015; Zwetsloot *et al*., 2020; Xu *et al*., 2021; Abubakar *et al*., 2021; Robson *et al*., 2017; Forteza *et al*., 2020.	ALIs are measurements or information streams that provide an indication of the probable safety performance to be realised within a firm or on a project. They have the potential to identify safety hazards and prompt immediate actions to prevent incident; they are dynamic and thus more subject to change in a short period of time. ALIs may be characterised as the "pulse" of the construction project in terms of daily safety behaviours and practices. To have predictive value, ALIs must be actively sought in terms of timely and accurate reports, measurements and observations.
		These indicators are generally continuous in that they occur at a frequency or are measures of quality of implementation. Each of these indicators can be readily modified during the construction phase if goals are not met. For example, the organisation can increase the frequency or quality of safety meetings, increase the involvement of upper management, and seek to improve safety audit scores. They are measured at a regular frequency (e.g. monthly) to indicate future performance on the same project (e.g. with a 3-month delay).
		They are measured and adjusted dynamically both in pre-construction and construction phases allowing real-time implementation of risk mitigation practices.
		ALIs are more subject to change in the short term and therefore having more potential for leading to intervening proactive action.
		They are associated with actions that influence the safety system, which are altered throughout the project to trigger positive responses. Unlike passive indicators, these are more likely to be changed in the short term with the change of daily activities on the site.
		ALIs are those which are more subject to change in a short period of time. They represent both a qualitative and quantitative measure of the actual implementation of the processes within a comprehensive safety management system.
		Active leading indicators represent safety in short term.
Passive	Alruqi and Hallowell, 2019; Costin *et al*., 2019; Haji *et al*., 2022; Akroush and El-adaway, 2017; Xu *et al*., 2021; Akroush and El-adaway, 2018; Hinze *et al*., 2013; Ali *et al*., 2022; Chen *et al*., 2019; Tang *et al*., 2020; Sinelnikov *et al*., 2015; Zwetsloot *et al*., 2020; Ting et al., 2019; Salas and Hallowell, 2016; Marks et al., 2013; Talebi *et al*., 2021; Robson *et al*., 2017; Shaikh *et al*., 2020; Forteza *et al*., 2020; Falahati *et al*., 2017.	Measures of these indicators are also generally dichotomous in that the organisation implements them or does not. These activities are not likely to change once a project begins and can be noted as implemented or not implemented before construction; The common data entry for these indicators is a binary yes/no response. They are typically implemented before work begins and remain relatively static once a project has begun.
		While PLIs have been reported to be predictive on a macro scale, they have limited predictive value after a certain point in time or once a threshold is reached. They are considered passive in nature because they are often measured as a precursor to people entering the work environment and updates are not actively sought out after they have been initially measured. That is, the process being monitored by PLIs cannot generally be altered in a short period of time.
		PLIs are often set in higher levels of the organisation and content of strategies adopted before the beginning of a project.
		They represent safety strategies that should be implemented before construction begins.
		PLIs typically represent practices that are not adjusted once the project begins.
		PLIs are measurements that can provide an indication of the probable safety performance to be realised within a firm or on a project.
		Passive indicators designate the likelihood of safety performance being achieved, usually through binary feedback.
		Passive leading indicators address the state of safety in long term or macro scale.
		PLIs are typically implemented before work begins and remain relatively static once a project has begun.
Subjective	Agumba and Haupt, 2012; Sinelnikov *et al*., 2015; Costin *et al*., 2019; Grabowski *et al*., 2007; Mashi *et al*., 2018; Ali *et al*., 2022; Haas and Yorio, 2016; Guo *et al*., 2017; Lingard *et al*., 2011; Schwatka *et al*., 2016; Karimi *et al*., 2021; Oswald, 2020; Johnsen *et al*., 2012; Cheng, 2019; Tomlinson *et al*., 2011; Hasanzadeh *et al*., 2017.	Subjective measures offer the advantage of capturing relative measures and perceptions, such as quality. As an example, employee satisfaction subjective measure with the feedback can provide important input on the relative quality of the feedback system. However, subjective measures are often more difficult or cumbersome to collect, monitor and maintain, since they are associated with participants' perceptions and opinions. For example, capturing opinions in surveys or questionnaires can be more difficult and costly to administer, although the data sets, once captured, can be monitored and maintained in the same way that the organisation maintains objective performance data. Another difficulty with subjective measures is that they can be difficult to link to quantitative performance in an organisation, and to demonstrate how improvements in non-financial or qualitative performance impact objective, quantitative measures. Despite these difficulties, however, subjective measures have often been used in measuring levels of safety in organisations.
		Subjective indicators measure the quality of execution that may change over time. Subjective measurement is based on perceptions towards activities implemented in studying a programme's effectiveness in reaching workers as a target group in organisations. It shows that subjective measurement through a perception measurement scale is the appropriate method for collecting proactive indicators that measure the quality of activity implementation.
		They are based on the values, attitudes, and observations of employees and may identify beneficial safety metrics not yet tracked by the organisation. This approach may be used when the organisation lacks sufficient metrics to use the objective leading indicators process.
		Safety climate scores were commonly compared between groups (e.g. management and workers, different trades), and often correlated with subjective measures of safety behaviour.
		Safety behaviour has been a preferred subjective indicator in safety related studies.
Objective	Sinelnikov *et al*., 2015; Grabowski *et al*., 2007; Ali *et al*., 2022; Laitinen *et al*., 2013;	Objective measures have the advantage of being straightforward to collect, monitor and maintain, consistent with the performance metrics gathered by the organisation as part of the normal conduct of business. However, objective measures may not be able to capture the quality of the systems or activities in place. For example, an objective measure for measuring

	Agumba and Haupt, 2012; Haas and Yorio, 2016; Guo *et al.*, 2017; Mashi *et al.*, 2018; Lingard *et al.*, 2011; Schwatka *et al.*, 2016.	the feedback in an organisation could be the percentage of safety reports on which feedback was provided to participants in the system. However, this metric cannot measure the quality of the feedback provided. Another difficulty is that objective measures may be manipulated and skewed to improve the appearance of the organisation. Objective indicators measure the frequency and hence are appropriate for monitoring key performance indicators of activities implemented. However, they are likely to be manipulated and distorted to improve the appearance of the organisation. Another difficulty is they are less studied, the main reason of which could be that the quality of existing systems or activities may not be measurable through objective measurements. Early researchers measured safety outcomes through objective indicators, such as number of accidents, fatalities, permanent disability, temporary disability, workers' compensation, etc. However, objective indicators are rather difficult to obtain, because of confidentiality and sensitivity issues. They are measures of ill health or objective safety and health outcomes.
Qualitative	Haas and Yorio, 2016; Xu *et al.*, 2021; Oswald, 2020; Mitchell, 1999; Reiman and Pietikainen, 2011; Salas and Hallowell, 2016; Delatour *et al.*, 2014; Barbosa *et al.*, 2019; Guo and Yiu, 2015; Teizer *et al.*, 2015; Alruqi and Hallowell, 2019; Berg *et al.*, 2014; Zwetsloot *et al.*, 2020; Hinze *et al.*, 2013.	Qualitative indicators provide an indication (and explanation) into the state of safety that can be used to help identify how to improve. Hence, it is argued that for every leading indicator that is counted, there should also be a qualitative indicator to help explain the quantitative assessment and provide a clear overall picture of state of safety within organisations. They allow explanation and open opportunity for improvement. Qualitative indicator is an indicator that would describe or assess a quality or a behaviour. For example, worker ratings of management commitment to achieving 'best practice' in OHS. Studies on indicator measurements needs to combine qualitative information and quantitative measures so that measurements can explain how and why an indicator is at the level it is quantitatively assessed and drives proactive actions. The qualitative measurement option ('Yes' or 'No') is simple and user friendly; it can be useful for any organisation, also for small organisations.
Quantitative	Costin *et al.*, 2019; Haas and Yorio, 2016; Zheng *et al.*, 2019; Oswald, 2020; Mitchell, 1999; Xu *et al.*, 2021; Reiman and Pietikainen,2011; Guo and Yiu, 2015; Hallowell *et al.*, 2020; Zwetsloot *et al.*, 2020; Delatour *et al.*, 2014; Barbosa *et al.*, 2019; Alruqi and Hallowell, 2019; Hinze *et al.*, 2013; Leveson, 2015.	Quantitative indicator can be useful for benchmarking, as they produce an output which can take the form of simple percentage or statistic that can provide an indication into the state of safety. While this can be useful, it does not mean qualitative indicators should be ignored as they can reveal rich insights that are relevant for helping to avoid future accidents. Quantitative indicators can measure management efforts to some extent, the number on its own can be interpreted in different ways. For example, an increase in near-miss reports might suggest that there are many hazards and incidents of non-compliance on site. Alternatively, it might indicate an open culture of reporting and effective communication systems. Moreover, frequent safety walks or training do not mean that these activities are effective and might lead to tick-box behaviour. Quantitative indicator is an indicator that can be counted or measured and is described numerically. For example, number of safety audits conducted. A safety indicator is any measure—quantitative or qualitative—that seeks to produce information on an issue of interest.
Implicit	Haji *et al.*, 2022; Reiman and Pietikainen, 2011; Pe˜naloza *et al.*, 2021; Grabowski *et.*, 2010; Leveson, 2015; Deepak and Mahesh, 2019	Adoption of implicit knowledge is difficult in construction projects due to their complexity and uniqueness. Experts' expertise, although it is implicit source of information, is one of the paramount sources regarding safety leading indicators. The experience that experts have accumulated over time can be exploited. In this case, their opinions should be questioned and then converted to knowledge.
Explicit	Haji *et al.*, 2022; Reiman and Pietikainen, 2011; Pe˜naloza *et al.*, 2021; Deepak and Mahesh, 2019	Implicit knowledge is stored in the individual's mind and explicit knowledge is stored in manuals, policies and databases Data gathered from previous projects and literature are considered explicit knowledge, and knowledge of construction site workers are considered implicit
Specific	Sipila *et al.*, 2014; Tomic *et al.*, 2018; Leveson, 2015; Periera *et al.*, 2020; Hassan and Khan, 2012; Thorsen and Nja, 2014; Xu *et al.*, 2021; Shwatka *et al.*, 2016; Riascos *et al.*, 2021; Greig *et al.*, 2023; Toellner, 2014.	Selection of the leading indicators needs to consider the specific features of the unique underground facility. While extant research has recognized a variety of leading indicators in construction, the specific contexts under investigation need attention because safety management is contextual and practices vary in different industries. They are functional metrics that directly measure the condition of asset. The mistake made by project teams is that quite often they continue to measure a set of specific leading indicators for much longer than needed. Once they have a success with a specific leading indicator, they need to make a reasonably quick decision as to the value of continuing to measure their efforts. Since each organisation has its strategic objectives, it needs to create specific measures appropriate for each purpose and the generic indicators is not recommended.
Generic / Abstract	Leveson, 2015; Riascos *et al.*, 2021; Greig *et al.*, 2023; Shea *et al.*, 2016; Zheng *et al.*, 2019.	Almost all of the past effort has involved finding a set of generally applicable metrics or signals that presage an accident. Examples of such identified leading indicators are quality and backlog of maintenance, inspection, and corrective action; minor incidents such as leaks or spills; equipment failure rates, and so on. Some depend on surveys about employee culture and beliefs, with the underlying assumption that all or most accidents are caused by employee misbehaviour and include as leading indicators such culture aspects as safety awareness, mutual trust, empowerment, and promotion of safety.

'*LIs' categories and characteristics*' column in the Table 8.1 describes different types of LIs that emerged as the main semantic characteristics of LIs; whereas the '*description of corresponding type and characteristics*' column provides more detail of the structural characteristics of LIs. For example, the table indicates that the common structure for ALIs (shaded with blue in the table) are frequently associated with being: continuous (i.e. occurs in the format such as frequency or scores) (Alruqi and Hallowell, 2019; Zwetsloot *et al*., 2020); dynamic (i.e. subject to change in a short period of time and hence, can readily be modified or corrected in real time) (Costin *et al*., 2019; Talebi *et al*., 2021; Haji *et al*., 2022); and both qualitative and quantitative measurement (Hinze *et al*., 2013). Whereas PLIs (also shaded in blue) are commonly associated with: being static (i.e. unalterable on operation stage or in real time) (Alruqi and Hallowell, 2019; Zwetsloot *et al*., 2020); bearing a dichotomous nature (i.e. based on binary yes/no response or feedback) (Alruqi and Hallowell, 2019; Ali *et al*., 2022); and measuring safety status in the long term and macro scale (Hinze *et al*., 2013; Chen *et al*., 2019; Costin *et al*., 2019).

Descriptions of the other two characteristics categories namely, *subjective* with *objective* (shaded with gold in the table); and *qualitative* with *quantitative* groups (shaded with grey in the table) respectively overlaps. For example, the description of *subjective* LIs overlaps with the description of *qualitative* LIs in a way that they both serve the function of measuring quality of a safety element or activity which requires interpretation, perception or opinion (Oswald, 2020). Whereas *objective* LIs and *quantitative* LIs that measure a safety element or activity numerically do not require interpretation and hence, they are easily communicated, unequivocally measured and objectively monitored (*ibid*). Similarly, the *implicit* and *explicit* LIs dichotomous group (shaded with light orange in the table) were closely associated with these two dichotomous groups (i.e. objective/subjective group and qualitative/quantitative group) respectively (Haji *et al*., 2022; Reiman and Pietikainen, 2012). Lastly, LIs are also categorised based on the characteristics such as *specific* and *generic* (shaded with green in the table). *Specific* LIs are system, organisation or project specific and hence, reflects the specificity of that entity. Conversely, *generic* LIs are those measurements of safety that are general and abstract and can be applicable to any organisation or industry (i.e. they are generalisable).

In addition to the nodes with the content about LIs structural and semantic characteristics (presented in Table 8.1), a compendium of LIs examples were collated during content analysis, to further study and identify those features of LIs existing in the pertinent literature.

8.1.1. Examples of leading indicators in pertinent literature

As another source of studying and describing LIs' distinctive characteristics in the process the constructing the analytical framework, existing LIs examples in literature were analysed. An extensive review was performed to identify a critical mass of LI examples in the first step of framework analysis , as a result of which a tabulation (in Microsoft Excel) of those LI examples containing 2,423 items has been generated. The created table consists of four columns, *viz*.: 1) article citation (i.e. authors' last name and year of publication); 2) number of LI examples identified in each article; 3) LI examples and 4) description/elaboration of each LI example (as exemplified in Appendix 1). The description column contains different content, *viz*.: some of the LIs are described and measured through an equation (cf. Peñaloza *et al*., 2021; Quaigrain and Issa, 2021); others provide descriptive instructions of how to use and measure that LI example (e.g. '*continuous improvement*' LI is described as '*simplifying incident reporting by generating incident reporting flowchart from 10+ page document*'); whereas most are indicating to elements of safety, such as *safety culture* (cf. Santos *et al*., 2019; Abubakar *et al*., 2021), *safety management* (cf. Hallowell *et al*., 2020; Ali *et al*., 2022) or *safety leadership* (cf. Reiman and Pietikäinen, 2012; Guo and Yiu, 2015). Structurally, LI examples themselves are in the form of: a word or phrase (such as, *competence*, *communication* or *senior management commitment*) (Almost *et al*., 2019); a statement that is concerned about presence or absence of certain condition, activity, situation or task, e.g.: '*supervisors undergo safety leadership training*', '*there is a substance abuse program set in place and advertised to workers*', or '*workers' observations are recorded and evaluated*' (Akroush and El-adaway, 2017).

Through revision of these LI examples, two different types of LIs emerged, *viz*., generic LI and specific LI. Generic LI (shaded in green in Appendix 1) are abstract examples that do not specify any activity or task to be followed or counted. The examples of generic LIs are '*safety auditing*' (Xu *et al*., 2021), '*workload*' (Sun *et al*., 2019), '*cramped spaces*' (Jemai *et al*., 2021) or '*employee involvement*' (Almost *et al.,* 2019). They serve the function of indicating to an aspect of safety that need to be considered, but do not provide a specific step/ task/ activity to act upon. Other main characteristic of generic LIs is that they represent LIs which are not easily quantified or perception-based qualitative type elements such as '*audit compliance'* (Erikson, 2009), '*safety behaviour*' (Jemai *et al*., 2021) '*adequate barriers are set against the identified* *hazards*' (Reiman and Pietikäinen, 2012) or '*inadequate assessment of contractor training and competency*' (Tamim *et al*., 2020). Whereas specific LIs (shaded in yellow in Appendix 1) represent a specified condition or situation need to be achieved (or avoided) or activity that need to be performed and their frequency. Examples of specific LIs are '*written safety policy signed by senior managers in place*' (Guo an Yiu, 2015), '*number of accident investigations that received attention*' (Almost *et al*., 2019) or '*entry of worker-on-foot in equipment blind spot*' (Golovina *et al*., 2016). As the name suggests, specific LIs are more detailed and descriptive in terms of the conditions or activities that are being measured, and they can be quantified in contrast to generic LIs. This novel dichotomous classification of LIs elucidate about less-known functions of LIs *viz*., to signal to the aspects of safety that should be included in safety management (refers to generic LI function) and to specify required condition, situation or activity (refers to specific LI function) to achieve certain goal (e.g. avoidance of unfavourable events or maintenance of safety status).

8.1.2. Development of new leading indicators

These different LIs categories (representing their characteristics in Table 8.1) and insights observed in the compendium of existing LI examples serve as a foundation to develop an analytical framework. The framework constitutes rows and columns (cf. Appendix 2), where rows are for LIs identified in the data and columns contains LIs types with their description of the key characteristics to aid their identification from the data and enable their classification. Using this analytical framework, analysis of 12 disparate batch of case study materials and normative documents that are relevant to each case was commenced to identify LIs. The process of LIs identification begins with familiarisation with each case by reviewing each document in that case. Areas (i.e. phrases or statements describing events, occurrences, change of circumstances, state and condition or any weak signals that are potential to change) in the text are then coded in accordance with the descriptions of LIs included in analytical framework. Consequently, a total of 484 LIs were identified from the analysis of the 12 sampled cases. Each identified LI was accordingly classified into their relevant categories by scrutinising their characteristic(s), structure, semantic and the function they serve. Le Coze (2009) states that classifying LIs is helpful to understand the conceptual characteristics of any given concept which helps to differentiate their function, structure and augments their implementation, adoption, use and efficiency. Table 8.2 showcases the classification of LIs (i.e. newly identified 484 LIs) as per the analytical framework developed and presents the quantity of identified LIs in the sampled dataset.

Table 8.2 - Number of LIs classified according to categories in the analytical framework.

Types of leading indicator	Number of leading indicators (No.)	Ratio to total number of leading indicators (%)
Active leading indicators	422	87
Passive leading indicators	184	38
Qualitative leading indicators	451	93
Quantitative leading indicators	102	21
Implicit leading indicators	269	56
Explicit leading indicators	343	71
Negative leading indicators	125	26
Positive leading indicators	307	63
Total number of leading indicators	484	100

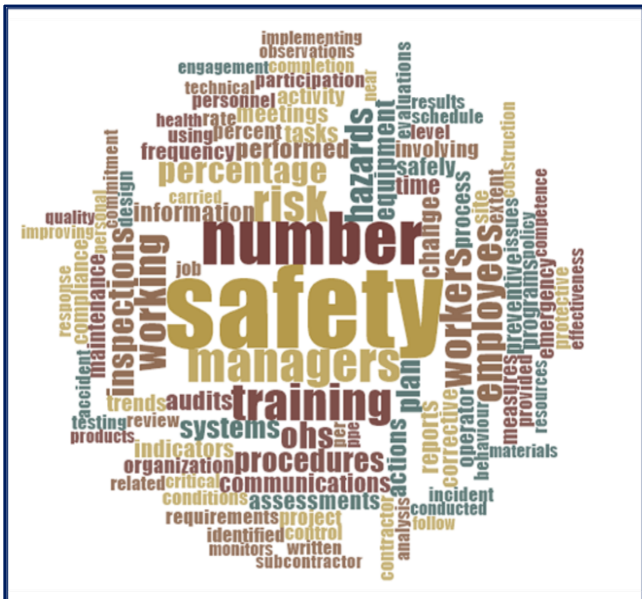
As Table 8.2 indicates, most of the LIs are qualitative LIs (frequency (f) = 451 (93% of total number of LIs identified)), followed by ALIs (f = 422 (87% of total number of LIs identified)). Quantitative LIs are the least frequently occurring LI type (f = 102 (21% of total number of LIs identified)), which can be related to the way this LI type is being measured (e.g. by counting frequency, quantifying occurrences or measuring the length of time spent). Qualitative LIs identified generally indicate the presence or absence of a certain activity, event or changes taken place, tasks performed, steps taken or procedures followed. Conversely, quantitative LIs are numerical (continuous) such as: length of time to investigate an incident or case (which is calculated using the time the incident took place to incident investigation closure); time dedicated for task completion; and/or generated from a specific job activity perspective – e.g. number of trial holes performed to detect underground utility lines.

The number of LIs in the dichotomous group of implicit and explicit LIs is closer to each other (implicit LIs f = 269 (56% of total number of LIs identified) and explicit LIs f = 343 (71% of total number of LIs identified)), compared to other dichotomous groups of LIs. Implicit LIs denote LIs that are not directly measured or objectively observed and hence, terms used to describe such LIs are *sufficiently*, *adequately*, *proper*, *regular*, *suitable*, *as safe as possible*, *competently*; these nebulous and fuzzy expressions are open to interpretation and the measurement of which might be dissimilar between different individuals. Another noteworthy point in this aggregation of LIs types (in Table 8.2) is the preponderance of positive LIs (f = 307 (63% of total number of LIs identified) over negative LIs (f = 125 (26% of total number of LIs identified). The plausible explanation of such tendency may be related to the methodological choice adopted for this present study *viz*., addition of relevant normative documents to the case study dataset, from which most of the positive LIs were developed.

8.1.3. Contrast of newly developed leading indicators with existing leading indicators in the literature

To view newly developed 484 case study LIs (CSLIs) in contrast to aggregated 2,423 literature review LIs (LRLIs), the content of both CSLIs and LRLIs was compared. Figure 8.1 illustrates the result of LRLIs and CSLIs comparison: initially, contrasting most frequently occurring keywords used in both LRLIs and CSLIs in a word cloud diagram at the top; followed by tabular contrast of the top 20 keywords used in LRLIs and CSLIs at the bottom of the figure.

Figure 8.1 – Cross comparison of leading indicators from the literature and case study data.



Leading indicators from the literature review				Leading indicators from case study analysis			
Word	**Count**	**Weighted Percentage (%)**	**Similar Words**	**Word**	**Count**	**Weighted Percentage (%)**	**Similar Words**
Safety	454	3.78	safety	**Works**	168	2.84	work, working, works
Number	264	2.20	number, numbers	**Services**	109	1.84	service, services
Managers	183	1.52	manage, managed, management, manager, managers, managers',	**Using**	105	1.77	use, used, uses, using
Training	173	1.44	train, trained, training, trains	**Cutting**	73	1.23	cut, cuts, cutting
Risk	166	1.38	risk, risks	**Equipment**	64	1.08	equipment
Workers	141	1.17	worker, workers, workers'	**Plans**	57	0.96	plan, planned, planning, plans
Working	139	1.16	work, worked, working, works	**Safe**	53	0.90	safe, safely
Employees	131	1.09	employee, employees, employees'	**Cables**	53	0.90	cable, cables
Hazards	113	0.94	hazard, hazardous, hazards	**Operator**	52	0.88	operate, operation, operations, operative, operatives, operator
Ohs	112	0.93	ohs	**Lines**	51	0.86	line, lines
Percentage	111	0.92	percentage	**Location**	51	0.86	locate, located, locating, location, locator, locators
Inspections	109	0.91	inspected, inspection, inspections	**Excavator**	50	0.84	excavate, excavated, excavating, excavation, excavations, excavator, excavators
Procedures	92	0.77	procedure, procedures	**Site**	47	0.79	site
Plan	86	0.72	plan, planned, planning, plans	**Team**	42	0.71	team, teams
Systems	81	0.67	system, systems	**Survey**	41	0.69	survey, surveying, surveys
Equipment	74	0.62	equipment	**Utility**	39	0.66	utilities, utility
Change	72	0.60	change, changed, changes	**Identify**	38	0.64	identified, identify, identifying
Performed	68	0.57	perform, performance, performed, performing, performs	**Time**	38	0.64	time, timely, times
Actions	67	0.56	action, actions	**Condition**	38	0.64	condition, conditions
Audits	67	0.56	audit, audited, auditing, audits	**Underground**	38	0.64	underground

The content of LRLIs as illustrated (on the left side of Figure 8.1) in the word cloud is predominated with the keywords such as 'number', 'percentage', 'frequency' and 'trend' which suggests that majority of LRLIs are on quantitative type LIs. Whereas the occurrence of keywords such as ‘workers’, ‘employee’, ‘training’, ‘audits’ ‘meeting’ and ‘procedures’ in LRLIs word cloud represent generic safety management activities, approaches and tools used to monitor and improve safety. Falahati *et al.* (2020) find a similar trend in the literature of LIs; the study (*ibid*) identifies that training is the most prominent PLIs.

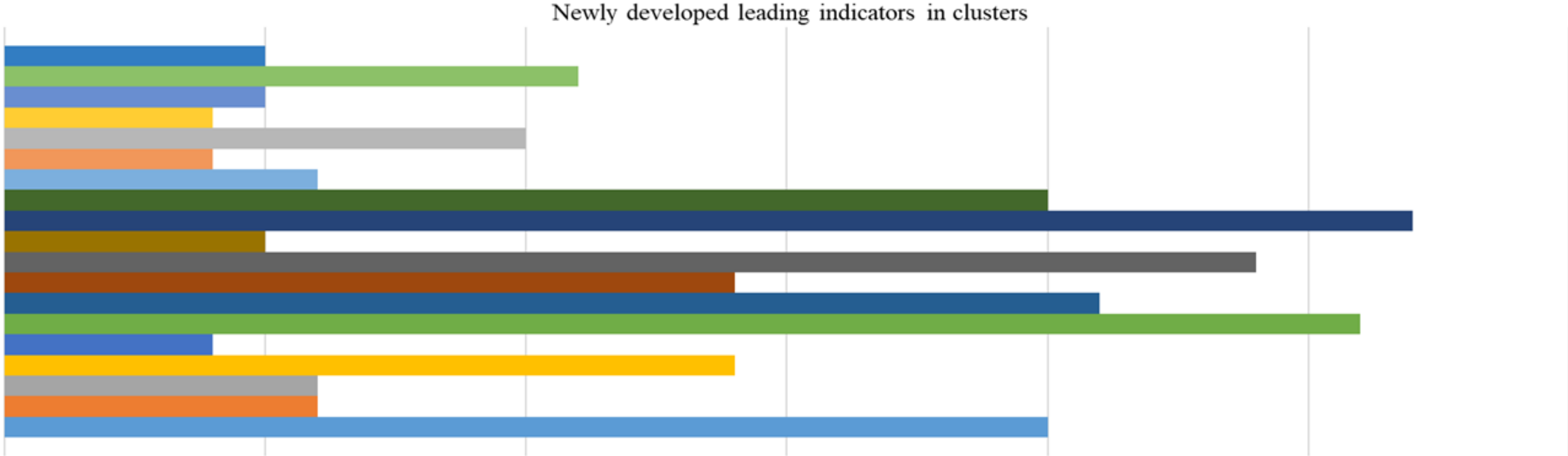
In contrast, the content of CSLIs depicted (on the right side of Figure 8.1) in the word cloud is dominated with the keywords such as ‘services’, ‘utility’, ‘lines’, ‘equipment’, ‘cables’, ‘digging’ and ‘plans’ which demonstrate the work process, activities and tasks performed, tools and machinery used in the work of horizontal construction or civil engineering (representing the mainstream work of the company the case study materials were obtained from). Frequency of occurrence of these keywords is included in the table under the corresponding word cloud depictions.

Following this macro level contrast of the content of LRLIs and CSLIs (refers to word cloud depiction), a more detailed contrast of individual CSLIs with LRLIs was performed. Through aggregation of similar (duplicate) CSLIs, the list preserved 415 distinct CSLIs. Subsequently, each of these 415 CSLIs were contrasted with the 2,423 LRLIs, to crossmatch existence of each CSLI within LRLIs. The process of matching CSLIs with LRLIs was performed by keyword search as well as a semantics search within the LRLIs dataset to identify matching LIs. The most significant difference of these two sources of LIs was that LRLIs dataset falls short of LIs that focus on utility detection, safe digging, utility map or drawing use, cable avoidance and service detection device use. Another difference is that the most extensively studied piece of safety related document in LRLIs is work permit; whereas CSLIs have more examples of safety related document on risk assessment methods statement (RAMS) and point of work risk assessment (POWRA) (e.g. absence or presence of point of work risk assessment document). These differences between LRLIs and CSLIs signify the self-referential cycle of studying generalisable LIs in the literature, rather than specifically focusing on the task, activity or behaviour specific LIs. This perhaps exemplifies inherent differences between WAP (i.e. LRLIs) versus WAD (i.e. CSLIs).

The most commonly occurring LIs in both LRLIs and CSLIs are on the topic of supplying/providing suitable and correct equipment, tool(s) or machinery. These LIs focalise on suitability levels of equipment, tool or machinery with: 1) task, work or activity type; 2) workers’ skill, competence, experience and authority to use; 3) site condition (including limitation in terms of weather conditions, space restrictions and changing hazard level). These examples are implicit and constitute a qualitative type of LIs, which are not easily detectable and are open to subjective interpretation. For example, these suitability levels in CSLIs are denoted as ‘poor’, ‘good’, ‘positive’, ‘negative’ or ‘adequate’, which are perception-based measurements (typically representing ordinal or nominal data), accuracy of which can only be tested during the activity or after the event occurrence. Therefore, for these types of implicit and qualitative LIs, organisations must devise a specific metric, procedure or threshold to gauge or to monitor the suitability of these elements which are capable of shifting safety status. However, ordinal and nominal data is infamously difficult to generate the finer nuances of granulation to establish clear boundaries between subjective categories or employ complex statistical analysis (such as multivariate statistical analysis) to develop predictive or classification models. Attempts to model such data is often stochastic (and subject to shades of grey) rather than deterministic.

Following this cross-matching process of each CSLI with any similar existing LRLIs, a total of 232 CSLIs were identified to be a unique LI (provided in Appendix 3) that has not been recognised in the pertinent literature before. Subsequently, these unique and newly developed LIs were filtered and clustered together based on the theme they represent. The resultant 19 clusters constituting CSLIs that are not present in the pertinent literature are included in Figure 8.2. Full list of LIs in each of these 19 clusters are included in Appendix 3.

Figure 8.2 - Clusters of leading indicators that are not present in extant literature.

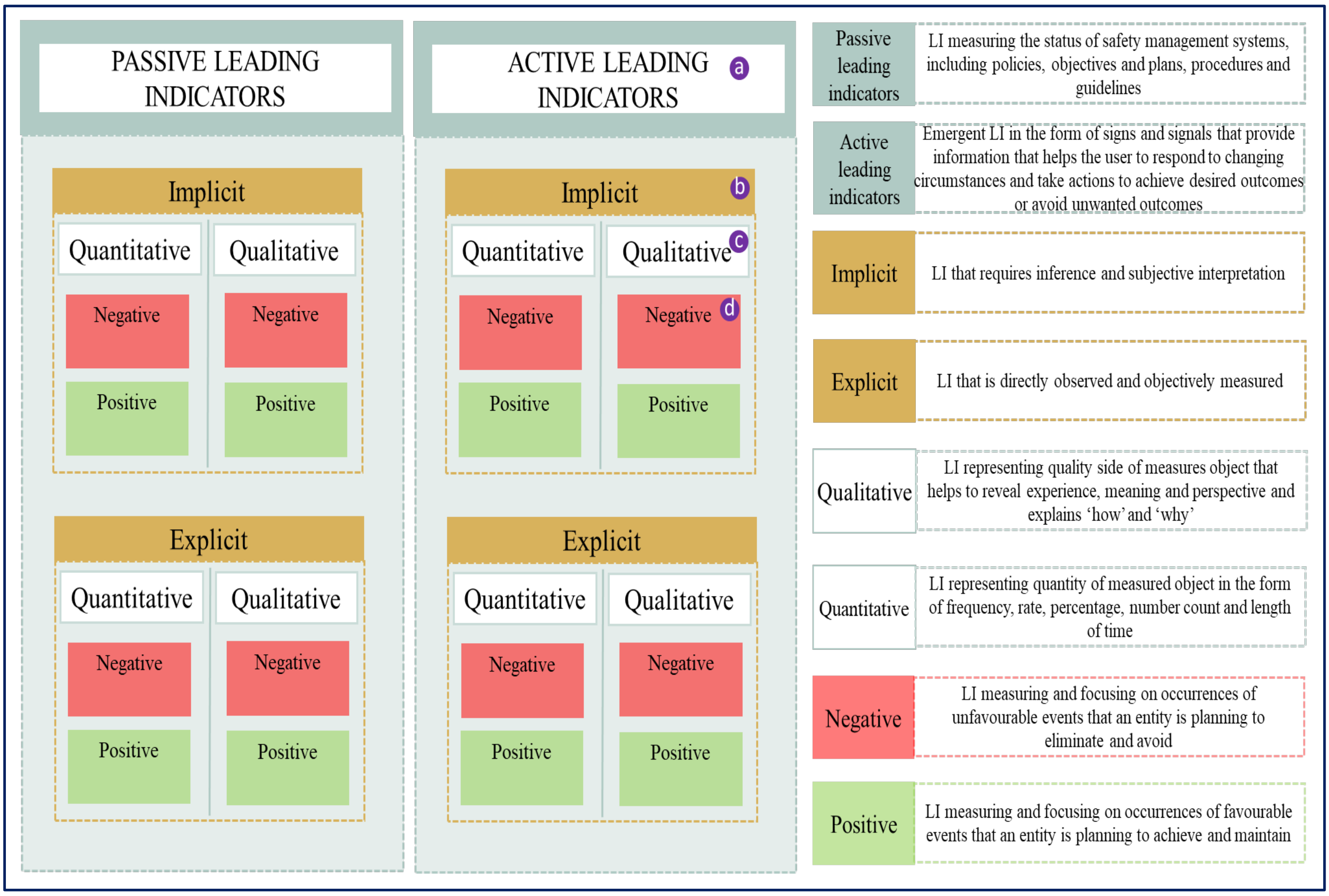


	Number of LIs in the cluster
LIs for safety learning	5
LIs of safety culture	11
Safety documentation	5
Equipment suitability and fitness	4
LIs for emergency preparedness	10
Material handling	4
Using jet guns	6
Safe use of machinery	20
LIs for proving duct/utility lines	27
Safe moling	5
Safe digging LIs: during digging	24
Safe digging LIs: prior to digging	14
LIs for underground utility lines detection: using detection equipment	21
LIs for underground utility lines detection: using utility drawing/maps	26
Ground condition LIs	4
Overhead lines avoidance LIs	14
Pre-task LIs	6
Time vs safety LIs	6
Pre-project/planning LIs	20

8.1.4. Discussion: analytical framework to develop leading indicators from qualitative data

Apart from serving as a validation of the conceptual model previously developed (cf. Bayramova *et al*., 2023), this proof-of-concept step also presents new theoretical and practical contributions to the literature of LIs development and implementation. The main emergent observations from the aforementioned findings can be recapitulated as follows: 1) developing or identifying LIs from pertinent qualitative data is feasible and generates more comprehensive and rich insights; 2) developing or identifying LIs (as a process) requires a structured approach (that follows the same definition or description of LIs) in order to maintain consistency; 3) and developing or identifying LIs must be continuously reviewed and improved to sustain their usefulness and relevance. Identification of novel LIs, their contrast with previously developed LRLIs and their classification illustrates a substantial theoretical outcome of the study. In addition, the analytical framework developed and used in current step of the study represents a practical contribution which can be adopted in future research studies or in practice. Figure 8.3 presents an infographic representation of the framework.

Figure 8.3 – Analytical framework for leading indicators' identification.

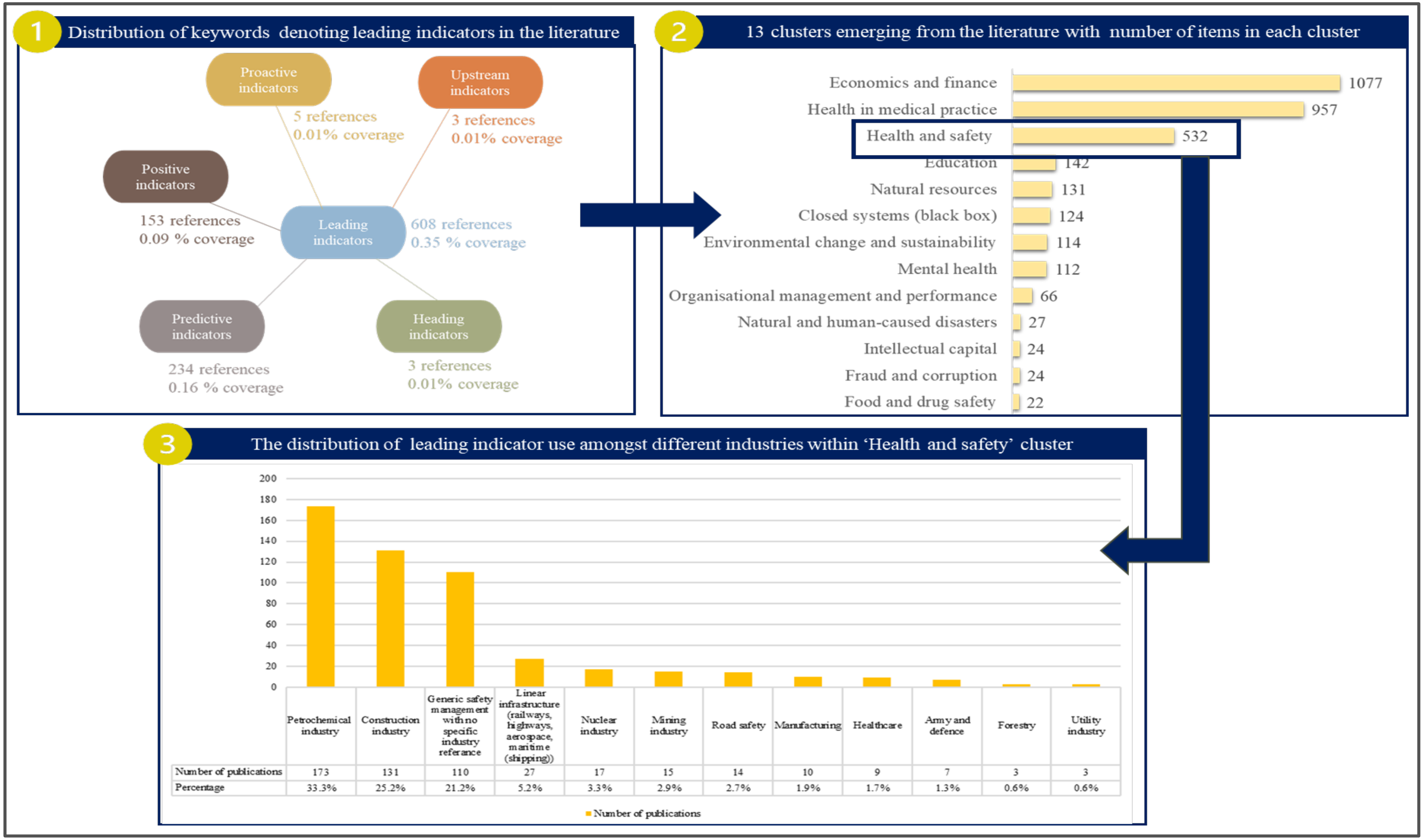


The figure illustrates that classification of LIs is not mutually exclusive across dichotomous groups. For example, one LI can be described as ‘*active’* LI (denoted as ‘a’) *‘implicitly’* (denoted as ‘b’) and *‘qualitatively’* (denoted as ‘c’) measuring/indicating a *‘negative’* event, behaviour, situation, status or condition (denoted as ‘d’). Classification groups included in the analytical framework provide useful guidance, initially in the process of identification or development of LIs, but also later at the adoption stage of LIs. For example, once adopted, the active/passive group of LIs facilitates determining an appropriate response to the observed LI in an appropriate time frame (short time or long time). Similarly, the implicit/explicit group of LIs can inform how a LI is observed (i.e. ‘spotting’ LIs directly or inferentially); qualitative/quantitative group determine how a LI is measured (i.e. whether by counting number of events and activities or by assessing quality of events and activities through inference and interpretation); whereas the negative/positive group distinguishes sentimental meaning (e.g. whether event, activity or status is safe or unsafe) of the LI that is being observed, measured and used to make decisions.

8.2. CONTEMPORARY STATE OF THE LITERATURE ON LEADING INDICATORS IN SAFETY MANAGEMENT

As selected in the search keywords (in Figure 6.2 depicted as 5), LIs have many other synonymous expressions such as proactive indicator, heading indicator, positive indicator, upstream indicator and predictive indicator (Hinze *et al*., 2013; Haas and Yorio, 2016; Robson *et al*., 2017; Xu *et al*., 2021). Figure 8.4 describes (section 1 in the figure) occurrences of each of those interchangeable phrases that are used to denote LIs with their coverage (in %) in the literature and number of references in the publications that were selected in this step.

Figure 8.4 - Coverage of keywords in the literature (1); 13 clusters emerging from the literature with their quantities (2); and the use of leading indicators in safety management distributed amongst different industries (3).



Both the coverage and number of references indicated in the figure was determined by examining the abstracts of selected publications (i.e. 3451 items as detailed in Figure 6.2) in text search query using NVivo. The most frequently used way of describing LIs is predictive indicator (with 0.16 % coverage and 234 references), followed by positive indicator (with 0.09 % coverage and 153 references). This is also related to difference in the use and application of LIs in various fields. For example, reference to LIs as proactive indicator is most common in safety management use, whereas reference as predictive indicators is prevalent in healthcare in medical practice (Alavi *et al*., 2024). However, such specific reference and use of LIs are not exclusive to the clusters described. For instance, reference to LIs in safety management context can be equally described as leading, proactive or upstream indicators.

In addition, all 13 emergent clusters that were identified through thematic analysis are illustrated in Figure 8.4 (section 2 in the figure) which represent those different applications or areas of LIs use. The most prominent use of LIs is in economics and finance as illustrated in the figure (n = 1077 articles); followed by its application in monitoring health in medical practice (n = 957 articles) and then safety management (n = 532 articles). These numbers correspond to the widespread use of LIs in those respective fields.

As numerous scholars state (cf. Haas and Yorio, 2016; Walker and Strathie, 2015; Patriarca *et al*., 2019; Oswald, 2020) the concept of LIs derives from the field of economics and later is adopted to use in safety management. However, adoption of LIs in safety management cannot be retraced to one specific industry or sector that are considered safety critical. Falahati *et al*. (2020) cite that the use of LIs in safety management was pioneered by the nuclear industry and followed by the chemical process and petroleum industry. Therefore, to identify the distribution of LI use/research amongst the safety critical industries with high-risk activities, '*health and safety*' cluster (from those 13 clusters included in section 2 of Figure 8.4) was selected for further analysis. By reviewing the bibliometric details of all 532 items that are focusing on LIs in health and safety, 13 different subclusters were generated based on the industry or sector each item is representing. 12 of them represent industry-specific studies and one describe generic use of LIs (no specific industry reference). As illustrated in section 3 of Figure 8.4, petrochemical (n = 173 items) and construction (n = 131 items) industry are respectively on top list, whereas 110 items from the total of 532 publications focus on specifically LIs' use in health and safety, rather than focusing in one industry use. For example, these studies are directed towards: validation of LI examples; application of LIs in complex systems; or classification of LIs and etc. Next on the downward trend is the group of linear infrastructure (n = 27 items) which contains LIs use in health and safety of railways, highways, aerospace and maritime.

8.2.1. Discussion: challenges in extrapolation of leading indicator use

Studies in the pertinent literature attempted to address the ambiguities and inconsistencies existing around LIs' development, selection, implementation and use, since these obscurities hinder the extrapolation of LIs and proactive safety management (Sheehan *et al*., 2016; Alruqi and Hallowell, 2019; Quaigrain and Issa, 2021; Bayramova *et al*., 2023). The emergent theoretical outcomes of current step are intended to provide sought-after clarity and to spur on extrapolation of LI adoption in practice which will instigate a more proactive approach and continuous learning culture amongst high-risk companies. Table 8.3 illustrates some of the examples of challenges associated with LI use in health and safety. The challenges are categorised into three groups representing three stages *viz*., development, implementation and adoption or use of LIs.

Table 8.3 - Challenges and considerations associated with stages of developing, implementing and using leading indicators.

Stages	Challenges and precautions	Considerations and potential solutions
Development of leading indicators	Lack of consensus on the definition, purpose and type of LIs and the indicated phenomena (i.e. safety), as well as absence of clear guidance or tool (that is coherent with the definition and purpose for which LIs are used) as to how to develop LIs (Guo and Yiu, 2015; Akroush and El-adaway, 2018; Haji *et al*., 2022).	For successful use of LIs following three solutions are required: 1) a clear conceptual framework which outlines the ways of deriving LIs and their associated set of purposes (that those LIs are intended to serve); 2) a selection process that determines which LIs are to be applied and how they are applied; 3) specification of how LIs fit into management and decision-making processes (Guo and Yiu, 2015).
	To avoid taking fragmented or single level view on LIs and their effect on safety performance (Xu *et al*., 2021).	LIs should not be randomly selected to measure existing safety practices but should be developed to describe and monitor specific safety conditions through a systematic development process where safety conditions are viewed as a dynamic phenomenon created, improved, and maintained by safety practices (Guo and Yiu, 2015).
	Removing or significantly reducing biases in the process of developing, selecting, using and measuring LIs (Leveson, 2015).	While heuristic biases can never be totally eliminated, a structured method for identifying, detecting, and managing LIs can reduce the impact of our biases (Leveson, 2015).
	A tendency to use only statistical sensible data by safety managers hinders recognition, identification or effective use of LIs (Hopkins, 2009; Haji *et al*., 2022).	While the quantitative indicator can be useful for benchmarking, the qualitative indicator allows for explanation by providing the how or why and opens opportunity for improvement by providing insights about context (Mengolini and Debarberis, 2008; Oswald, 2020).
	There is no specific set of LIs to monitor safety and safety culture (Mengolini and Debarberis, 2008).	LIs should be developed for: product/element level, system level and system of systems level, since every level requires different set of LIs (Rhodes *et al*., 2009).
	To avoid adopting and using leading indicators by directly sourcing from other projects, organisations or industries without adjustments (Xu *et al*., 2021).	Since safety management of each organisation is unique and contextual, organisation or project specific leading indicators must be considered (Xu *et al*., 2021).
	The difficulty in coming up with any theoretically well-motivated indicators that can be 'objectively' linked and shown to predict actual major process incidents prevents the generation of effective and believable LIs (Hudson, 2009).	Initially, conditions impacting on changes in safety must be studied. After which LIs should be developed based on the assumptions generated (as to how safety is changing) out of such studies (Leveson, 2015).
Implementation of leading indicators	Difficulty to convey to users in worksites the constructs of leading indicators (Costin *et al*., 2019).	To develop established, learnt and shared understanding of: what is normal, expected and desired (versus what is not normal, unexpected and undesirable); what to look out for, monitor, expect and fear when experiencing LIs in worksites (Costin *et al*., 2019).
	Due to similarity to classical metrics in the base measures collected, it may be difficult to get the management and practitioners in an organisation to buy into using LIs as they may on a superficial look be dismissed as "something we are already doing." (Rhodes *et al*., 2009; Akroush and El-adaway, 2018).	Project leadership teams should: 1) self-determine (with input from their safety professionals and the workers) the leading safety indicators that want to drive to higher levels of performance; and 2) be willing to hold themselves (and their respective teams) accountable for sustained performance improvement (Toellner, 2014).
	It is important to find effective ways to present the information in a concise and graphical form to address the specific information needs of the organisation or project in order to aid effective decisions (Rhodes *et al*., 2009; Toellner, 2014).	The data must be presented in a fashion that the message is clear (Toellner, 2014).

	The dearth of information about the validation of LIs as useful and appropriate for the activity being measured (which is due to unwillingness of companies to share such information) hinders their extrapolation (Rhodes *et al*., 2009).	In the early phases of LI use, the individual organisation still should further validate the conditions under which a leading indicator can be most useful in their organisation by observing its usefulness in various programs over time (Rhodes *et al*., 2009).
	The fact that interpretation of LIs is a blend of statistical analysis and subjective assessment based on experience (Rhodes *et al*., 2009).	A guidance to tailor to the project environment and experience is needed the interpretation guidance must be carefully developed with highly knowledgeable staff or subject matter experts (Rhodes *et al*., 2009).
	It may be difficult to get leadership support for using high level engineering talent for a "task" (for interpreting the collected data, i.e. LIs) that was previously performed by junior analysts (Rhodes *et al*., 2009).	The effective use of the leading indicators requires a systems engineering program to not only gather and analyse the indicators, but to also dedicate experienced personnel's time to the interpretation of the resulting information. The ability to use the indicators for real-time management of programs requires decision making using this information at all levels (Rhodes *et al*., 2009).
	Deciding whether to use LIs as standalone, combined or aggregated sets could become another source of challenge (Rhodes *et al*., 2009).	The selection of the subset of appropriate leading indicators in context of organisational factors is a rich area for future research. The focus of future studies must be on: understanding the relationships between the leading indicators; whether it is possible or necessary to find appropriate ways to aggregate leading indicators; and when aggregation should not be done (Rhodes *et al*., 2009).
	There is a need to develop adequate training for these indicators to obtain a wide level of infusion across industry. This includes two levels of training, one for the decision-makers and one for the measurement practitioners (Rhodes *et al*., 2009).	The course for decision-makers should be a short course focused on describing LIs, the utility of the indicators and the resources needed to implement them. The practitioner course should focus on selecting the right set of indicators, how to analyse and interpret for leading insight rather than lagging insight and detail discussion and exercise for the indicator (Rhodes *et al*., 2009).
Adoption or use of leading indicator	A critical aspect of adopting safety indicators is related to their potential manipulation in case a corporate safety culture is not firmly established. The focus on "*what can be measured*" rather than "*what should be measured*" might have a misleading impact on understanding and management of systems' states (Hudson, 2009; Patriarca *et al*., 2019).	To adopt a dynamic and agile methodology which allow to continuously identify and refine the most appropriate LIs (Patriarca *et al*., 2019).
	The difficulty in determining an accurate forecast of accidents due to the complexity and abundance of variables in the safety systems is an obstacle in LIs use (Mengolini Debarberis, 2008; Guo and Yiu, 2015; Akroush and El-adaway, 2017).	During the implementation process, LIs should be continually improving and adjusting by comparing the results with the intended effects. Such continuous assessment should demonstrate correlations to safety performance on a site-by-site basis and organisations should ensure that only indicators successfully tailored to their safety systems are the ones being developed and used further (Akroush and El-adaway, 2017).
	The fact that data collection takes time and the lack of centralised repository to build a core history overshadow potential benefits of using LIs (Rhodes *et al*., 2009; Guo and Yiu, 2015).	Collecting LIs and other contextual data in a centralised database enables establishment of safety analytics where organisations can not only identify holes in your safety systems, but also can it serve as a source of positive safety metric to be shared with employees (Pettinger, 2013).

Challenges at the *development stage* are commonly related to lack of theoretical understanding of LIs and absence of systematic guidance for developing LIs. The *implementation stage* entails difficulties in conveying the constructs of LIs to users (i.e. direct users of LI, analysts of LIs and top managers) and in achieving their buy-in. These implementation challenges necessitate both theoretical clarity (i.e. to understand LIs constructs) and empirical testing and evidence, alongside the training requirements. Challenges in the *adoption or use stage* of LIs cumulatively reflect leadership commitment and organisational safety culture maturity level. Top managers' support in terms of resources required for a full leverage of LI benefits and their commitment to progress towards proactive safety management are pivotal at this stage (Akroush and El-adaway, 2018). Similarly, superior safety culture and a continuous learning mindset shared amongst their staff lays a solid foundation for successful LIs adoption (Grecco *et al*., 2014; Deepak and Mahesh, 2019).

8.2.2. Discussion: potential for using leading indicators

Although scant, there are some examples of successful LIs adoptions (cf. Toellner, 2014; Marks *et al*., 2014) by different organisations in safety critical industries which partake high risk activities. These studies are propitious to glean not only challenges and considerations of LIs adoption but also potential benefits of using LIs can be derived from such empirical works. To fully apprehend potentials of LIs, an understanding about LIs' functions in line with their types is *sine qua non*. However, there is a glaring knowledge gap in the literature of LIs in terms of a systematic study that specifically focuses on the function of LIs; albeit some studies fleetingly refer to their function as their characteristics (cf. Guo and Yiu, 2015; Akroush and El-adaway, 2017; Almost *et al*., 2019; Santos *et al*., 2019). The functions that negative and positive LIs serve are discussed by Reiman and Pietikäinen (2012), where they are respectively referred to as the '*dirty dozen*' and '*positive bunch*'. The authors (*ibid*) emphasise that for each identified or used negative LI, a positive LI must be adopted, not only to ensure the absence of an unfavourable event and to confirm the presence of positive and favourable outcome, but also to assess whether organisations are meeting their important safety prerequisites. This function of LIs enables focusing and enhancing organisational potential for safety and supports continuous organisational learning.

Examples of LIs' functions are compiled in Table 8.4 (second column), each of which is incorporated with a specific type of LI used for a respective function (third column of the table).

The fourth column of the table accordingly describes where each LI can be sourced from or how they can be developed and how those respective functions can be achieved.

Table 8.4 - Summary of leading indicators functions with their corresponding type and source and method to achieve each function.

Function Number	Examples of leading indicator function	Type of leading indicators that are appropriate for the function	**Method and source of information used to achieve the function-**The source of material used (or method used) for the function or to develop and use the appropriate LIs
F1.	To indicate to generic points (or safety elements) in safety management that were not considered (i.e. to identify unknown unknowns).	Generic leading indicators	Generic LIs can be identified through review of relevant normative documents and research publications at early phase of LI adoption. Generic LIs can be identified through review of dataset contained within centralised database of LIs at later phase of LI adoption.
F2.	To identify unknown practices or factors for achieving safety or preventing unfavourable occurrences.	Specific leading indicators	Organisations can develop specific LIs through review of relevant normative documents and publications with best practices at early phase of LI adoption. Organisations can identify specific LIs through review of dataset contained within centralised database of LIs at later phase of LI adoption.
F3.	To continuously monitor safety	Active leading indicators	At early phase of LIs adoption, active LIs can be collected through frequently arranged safety observations, safety inspections and safety monitoring at operation stage At later phase of LIs adoption, active LIs are continuously collected in real time at operation stage by training staff to recognise them.
F4.	To prevent occurrences of unfavourable events/outcomes	Active leading indicators + Passive leading indicators	At early phase of LIs adoption, through training staff who are conducting safety observations, safety inspections and safety monitoring at operation stage: 1) to apply timely corrective measures through recognising active LIs and 2) to eliminate unfavourable and timely uncorrectable events, conditions or activities through recognising passive LIs. At later phase of LIs adoption, through training staff who are continuously involved in operation stage (to continuously monitor) to actively recognise emerging active LIs and accordingly apply corrective measures (then later report the event in order to gather in centralised database of LIs). At later phase of LIs adoption, through proactive assessment (e.g. testing emergency preparedness or assessing efficiency or effectiveness of safety efforts i.e. efficiency of safety management systems) and simulation (i.e. running worse case scenarios) at design stage by using passive LIs.
F5.	To mitigate the impact of unfavourable occurrences.	Active leading indicators + Passive leading indicators	Through adoption of active and passive LIs as a form of feedback mechanism (weak signals informing about current or timely status of safety or listening to weak signals whether they are negative or positive and react accordingly) and corrective tool/guidance (by reacting accordingly (whether it is correcting in response to negative signals or reinforcing in response to positive signals) and timely to the weak signals received).
F6.	To measure impact and efficiency of safety performance, safety efforts or safety policy (i.e. efficiency of safety management systems)	Passive leading indicators + Active leading indicators	Through assessment (e.g. testing emergency preparedness or assessing efficiency or effectiveness of safety efforts i.e. efficiency of safety management systems) and simulation (i.e. running worse case scenarios) at design stage using passive LIs and continuously monitoring at operation stage using active LIs.
F7.	To predict future safety performance	Qualitative passive leading indicators + Quantitative passive leading indicators	- Through qualitative and quantitative assessment and analysis of safety efforts put by organisation. - Through quantitative and qualitative assessment of safety performance and safety efforts during safety audits, safety observations, safety inspections and safety monitoring.
F8.	To predict near future or in time safety performance	Qualitative active leading indicators + Quantitative active leading indicators	Through continuous monitoring of emerging events by assessing them quantitively and qualitatively. Through qualitative and quantitative assessment and analysis of current status/condition, ongoing events and emerging factors.

F9.	To assess current/ ongoing safety performance	Negative active leading indicator + Positive active leading indicators + Negative passive leading indicator + Positive passive leading indicators	By contrasting negative and positive active LIs collected through continuous safety observation, safety inspection and safety monitoring at operation stage. By contrasting negative and positive passive LIs collected through continuous safety observation, safety inspection and safety monitoring at operation stage.
			By contrasting negative and positive active LIs recorded in the database of LIs. By contrasting negative and positive passive LIs in the database of LIs.
F10.	To assess earlier put safety efforts	Negative passive leading indicators + Positive passive leading indicators	By contrasting negative passive LIs (which inform about shortcomings in the safety efforts) and positive passive LIs (which inform about strength in the safety efforts) based on the data collected through continuous safety observation, safety inspection and safety monitoring at operation stage.
			By contrasting negative passive LIs (which inform about shortcomings in the safety efforts) and positive passive LIs (which inform about strength in the safety efforts) based on the data in the database of LIs.
F11.	To serve as feedback of previous and ongoing safety efforts	Negative passive leading indicators + Positive passive leading indicators	By studying negative passive LIs (which inform about shortcomings in the safety efforts) and positive passive LIs (which inform about strength in the safety efforts) based on the data collected through continuous safety observation, safety inspection and safety monitoring at operation stage.
			By studying negative passive LIs (which inform about shortcomings in the safety efforts) and positive passive LIs (which inform about strength in the safety efforts) based on the data in the database of LIs.
F12.	To identify areas for improvement (For companies to proactively learn or to adopt safety learning approach)	Negative leading indicators	By studying negative LIs (which inform about shortcomings in the safety efforts) based on the data collected through continuous safety observation, safety inspection and safety monitoring at operation stage.
			By studying negative LIs (which inform about shortcomings in the safety efforts) based on the data in the database of LIs.
F13.	To identify opportunities to learn and positive impact of earlier and ongoing safety effort (For companies to proactively learn or to adopt safety learning approach)	Positive leading indicators	By studying positive LIs (which inform about strength in the safety efforts) based on the data collected through continuous safety observation, safety inspection and safety monitoring at operation stage.
			By studying positive LIs (which inform about strength in the safety efforts) based on the data in the database of LIs.
F14.	To indicate to activities/tasks that need to be performed to maintain safety	Specific leading indicators	By developing specific LIs through the review of normative documents, organisations current safety activities and publications with best practices at early phase of LI adoption.
			By developing and continuously revising specific LIs through the review of data contained within database of LIs.
F15.	To assess the quality of safety efforts in safety management systems	Qualitative active leading indicators + Qualitative passive leading indicators	By studying qualitative data collected and obtained from administrative records of organisation (relevant to their safety activities, safety policies and documents of their research development on safety) and by keeping up to date with emerging changes and trends from industry, other organisations and government.
F16.	To benchmark the state of safety and tap on trends	Quantitative active leading indicators + Quantitative passive leading indicators	By studying quantitative and quantified qualitative data from administrative records of organisation (relevant to their safety activities, safety policies and documents of their research development on safety) and by keeping up to date with emerging changes and trends from industry, other organisations and government.

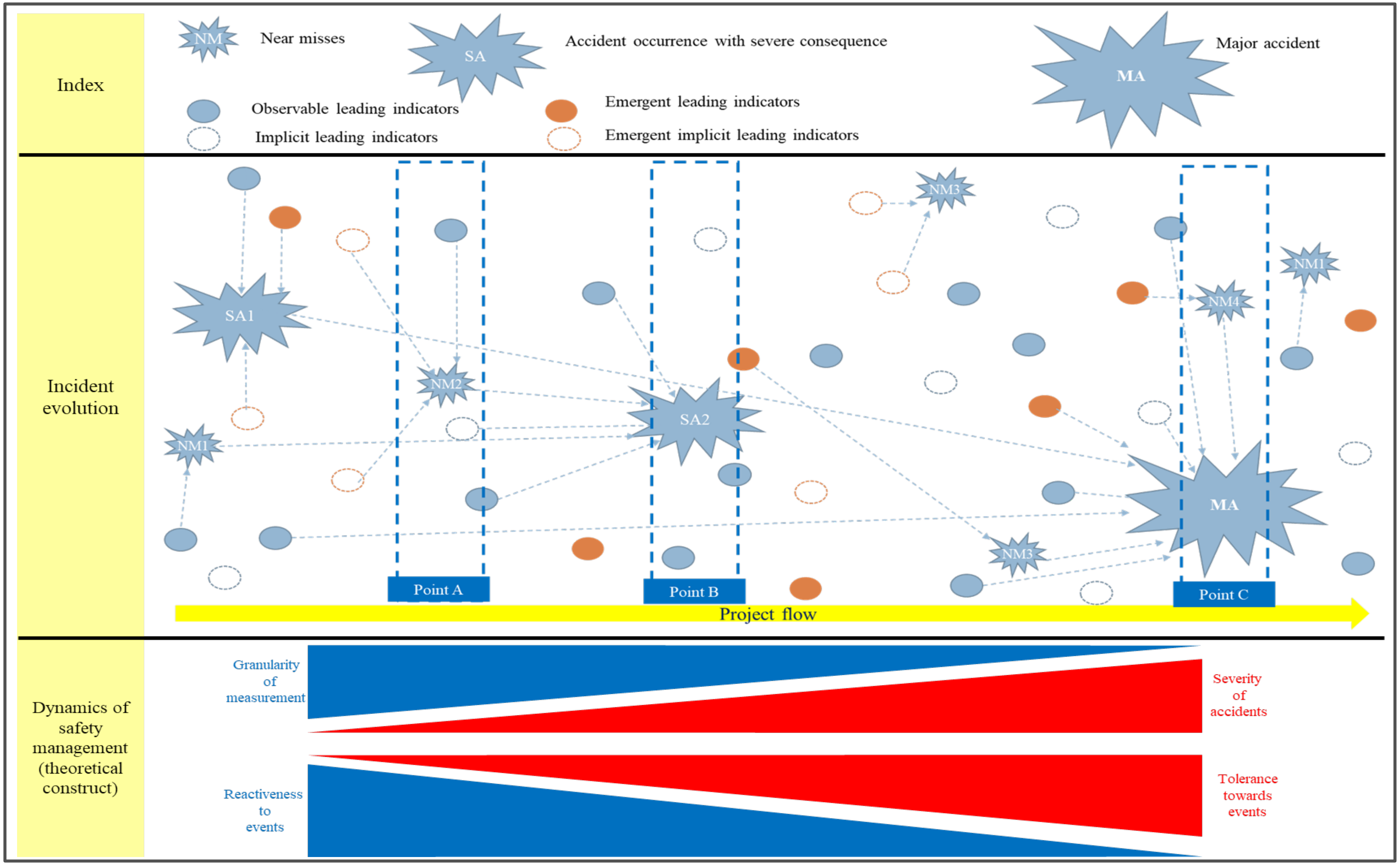
Additionally, the table provides guidance as to what stage of LIs adoption each function can become relevant and feasible. There are two stages differentiated, *viz*., early stage (highlighted in grey shading in Table 8.4) and later stage (highlighted in gold shading in Table 8.4). Early stage here denotes a first ever introduction of LIs in safety management of a company, whereas the later stage implies the stage where an organisation is continuously using LIs and has collected historical data of LI use.

The process of selecting a specific LI function (from Table 8.4) will depend on an organisation's: purpose or plan in terms of their safety management improvement and priorities; existing safety performance history and data; and safety maturity level (which represents their safety capacity, commitment and capability). For example, if the organisation is at the outset of introducing LI use into their safety management, they would greatly benefit from the first function (F1 in Table 8.4) of LIs. Namely, to use the function of '*to indicate to points in safety that were not considered (to identify unknown unknowns)*', the company would explore generic LIs through a review of relevant normative documents and scientific publications. Whereas at a later stage of LIs adoption, the company can benefit (from the same F1 function) to identify their unknown unknowns through using generic LIs that are identified from a centralised database of LIs (i.e. the repository that was generated via their continuous use, collection and analysis of LIs). However, some of the functions described in Table 8.4 are exclusive to only the later LIs adoption stage. For instance, functions F5, F6, F7, F8, F15 and F16 in the table are only applicable to the later stage of LIs adoption, where functions can be achieved in the presence of an LIs data repository which enables establishment of safety analytics. This in turn generates safety intelligence specific to the company where they can: proactively evaluate and improve their safety process; learn from their past and current safety performance; and continuously assess and review their LIs and safety models.

8.2.3. Discussion: evolution of events

The ambiguity around which indicator is leading or lagging has drawn attention of many scholars (cf. Knijff *et al*., 2013; Sheehan *et al*., 2016). For example, Hopkins (2009) reviews the distinction of lagging and LIs by referring to: 1) an investigative report by Baker panel (Baker *et al*., 2007) which focuses on the BP Texas city explosion; and a guidance report by the UK Health and Safety Executive (HSE, 2006) about developing process safety indicators. Hopkins (2009) persuasively discusses the difficulties and inconsistency around the description and examples of leading and lagging indicators in those reports. As a result, this publication sparked significant interest amongst scholars and became a theoretical debate which culminated in (amongst other things) a special issue in the Safety Science journal dedicated to this topic (Patriarca *et al*., 2019; Santos *et al.,* 2019). In this special issue contributing authors express their agreement and disagreement alike with the points Hopkins (2009) is making, but also contribute their own perspectives about the complexity of measuring safety as well as characteristics, functions and contributions of leading and lagging indicators (Patriarca *et al*., 2019). Following the review of this theoretical debate, the relationship existing between leading and lagging indicators can be described in the form of pictorial representation as illustrated in Figure 8.5. In the index section of Figure 8.5, explosion shapes, small, medium and large, respectively describe near miss (e.g. slip and trip), severe consequence occurrence (e.g. caught-in between, fall from height or loss of life type accidents) and major catastrophic accident occurrences (e.g. accidents with major impact to number of lives and severe environmental damage and facility destructions). Whereas oval shapes in the figure represent LIs that are observable, implicit and emergent observable and emergent implicit (or not easily observable and discernible).

Figure 8.5 - Pictorial representation of lagging and leading indicators in 'Dynamic theory of incident evolution'.



All the elements depicted at the incident evolution section in Figure 8.5 can be described as a signal (or feedback or 'communication means' of complex systems) coming from the system that are occurring in the lifecycle of any project or complex system depicted as a yellow right-pointing 'project flow' arrow in the figure. Assigning elements as leading or lagging indicators depends on two factors *viz.*: 1) on which point of the timeline the event occurs (e.g., after or before one of the events); and 2) which event is the priority and where the focus is being concentrated, so to avoid the occurrence of that event (Hudson, 2009; Murray, 2015). As stated in Bowtie Diagram, occurrences of event can be classified as leading if they represent efficiency of control measures which occurs prior to an accident and is represented as a lagging indicator if they appear after the incident and describe the consequence of an accident (Samuel and Das, 2015; Abdelmalek and Soares, 2021; Schmitz *et al*., 2021). Therefore, it is a matter of which event occurrence a company wants to avoid and after which accident occurrence the company begins to react with corrective measures. In other words, which events are deemed 'tolerable' within company's safety culture and safety management practice. For example, if a company's ambition is to avoid major accident occurrence (depicted as an explosion shape with 'MA' in Figure 8.5) then all the occurrences depicted in the figure, (namely, observable or explicit LIs, implicit LIs, emergent LIs, emergent implicit LIs) including near misses (depicted as an explosion shape with 'NM' in Figure 8.5) and accidents with severe consequences (depicted an as explosion shape with 'SA' in Figure 8.5) will be accounted as LIs. Hence, the focus of that company will be to apply corrective measures towards prevention of major accident occurrences. In this first scenario depicted as point C in Figure 8.5, events that are generally considered to be a lagging indicator (i.e. near misses and accidents with severe consequences) serve as LIs by prompting or signalling to the occurrence of major accidents. Such an approach illustrates an example of safety management that is far from proactivity where: safety is managed through less granular measurements; corrective measures are initiated reactively after the occurrence of severe accidents; company's tolerability to accidents are higher and early signals (i.e. near misses and any type of LIs) which could prevent occurrences of severe accidents are dismissed or ignored. These descriptions are illustrated at the bottom of Figure 8.5 as a spectrum of: *granularity of measurement*; *severity of accidents*; *tolerance towards events*; and *reactiveness to events*. All these four scales are theoretical constructs that represent dynamics of safety management.

However, on the second scenario (point B in Figure 8.5), if company's ambition is to avoid the occurrences of severe accidents (SA in the figure), then all the 'minor' occurrences prior to that serious accidents will serve as LIs including all types of LIs and near miss occurrence. In such circumstances, a company's effort towards safety management becomes more granular and proactive, because it starts to react to near misses (that are occurrences with a minor consequence) and apply corrective measures.

For a third scenario (point A in Figure 8.5), if the company's safety maturity level is on higher level and the company aims to tackle near miss occurrences, then the company's safety effort and control countermeasures will be driven by LIs (most likely by active LIs that are emergent in the live project). These three scenarios also represent three different safety maturity levels of companies ; where what a company measures can serve as LIs of their safety maturity level. That is, the more granular the safety measurement and initiator of corrective action become, the more proactive and preventative their safety efforts and the higher their safety maturity level become (Glendon, 2009). This also denotes that the earlier company reacts to a weak signal, the less tolerant the company becomes to negative events. On the contrary, as more acceptable and non-reactive a company becomes to occurrences of less severe negative events, the more susceptible they become to the occurrences of more severe events' occurrences.

8.3. SUMMARY OF CHAPTER 8

These two steps in the phase 2 respectively present proof-of-concept of the main outcome of the doctoral work and proffers the recapitulation of the research findings. The proof-of-concept step tests the validity of development of LIs from the stated data sources in the conceptual model by identifying 484 LIs in total and by additionally offering the analytical framework as a tool to develop/identify LIs and later use in application of LIs. The second step recapitulates research findings by collating challenges of using LIs (and by classifying them into stages of developing, implementing and using LIs) along with potential considerations to address these challenges accordingly (Table 8.3). This chapter also presents guidance for LIs adopters (that can be at early or later adoption stage) that incorporates: 16 different LIs functions that represent LIs' potential benefits; LIs types corresponding to each LIs function; and direction as to how to achieve the corresponding function and what source of data to use to develop each LIs type at different (early and later) stages of LIs adoption. As a final outcome, the study offers a new theory on 'evolution of incidents' which are explicated through dynamics of safety management that are: 1) granularity of measurement; 2) severity of accidents; 3) reactiveness to events and 4) tolerance towards events. Testing such new theory is beyond the scope of this doctoral work and hence, this is clarion call for future researchers or future extension of this work to perform the testing through further empirical studies.

CHAPTER NINE – VALIDATION OF RESEARCH FINDINGS

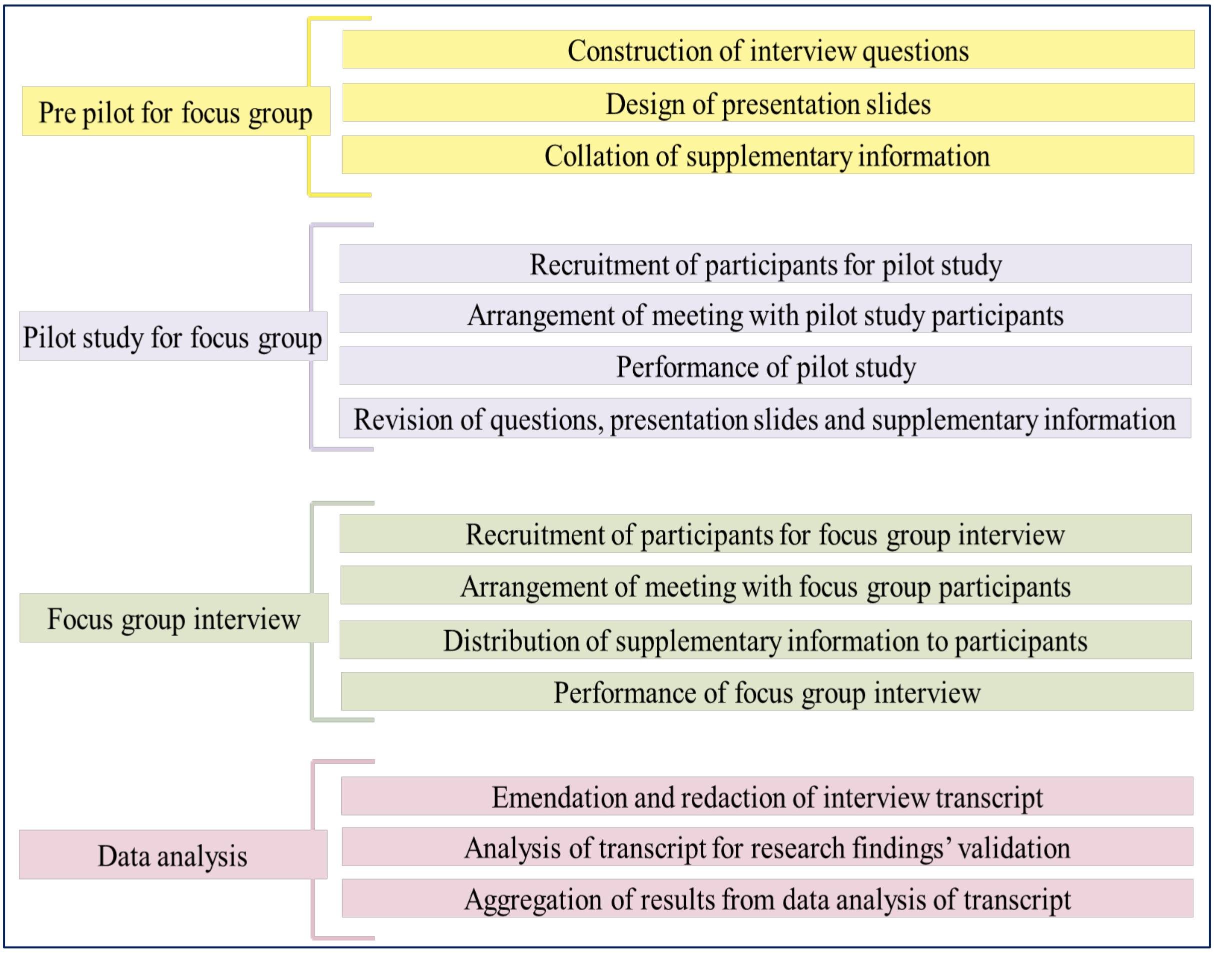
9.0. INTRODUCTION

Any outcome of a research endeavour is a result of academic rigour, systematic approach and careful consideration in the selection of data collection (inclusion and exclusion criteria) and data analysis method (Robson and McCartan, 2016; Saunders *et al*., 2019; Fellows and Liu, 2022). However, to enhance the quality of achieved research outcomes, further validation or testing of these findings is *sine qua non*. Validation is described as the process of establishing: scientific soundness of the steps adopted to develop the research outcome (i.e. whether methodological procedure fits scientific standards); and adequacy of the developed outcome for a specific purpose (i.e. whether tested object achieves overall objective or produces the intended effects) (Bockstaller and Girardin, 2003). Therefore, validating research findings not only allows accomplishment of credibility and academic soundness but also this process enables improvement of the research outcome's applicability in practice (Clark *et al*., 2021). However, different research developments might require different approach for testing or validation. Bockstaller and Girardin (2003) differentiate three types of validation, *viz.*: 1) design validation; 2) outcome validation; and 3) end user validation. Design validation refers to the scientific quality of the design or tool used to generate the research outcome, whereas outcome and end-use validations are concerned around the outcome itself, i.e. soundness of the outcome and usefulness for users (Bockstaller and Girardin, 2003; Walter *et al*., 2007). Design validation of current study's findings has been tested through a peer-review process (cf. Bayramova *et al*., 2024 in addition to Bayramova *et al*., 2021; Bayramova *et al*., 2023; Bayramova *et al*., 2023a; Bayramova *et al*., 2024a), as per the description by Bockstaller and Girardin (2003). Peer-review process enables the establishment of scientific soundness of both the research outcomes and the process adopted to develop such research outcome (*ibid*). However, next step is to test the research findings based on outcome validation. Outcome validation involves determining whether the research findings are fit for purpose or useful for overall objective (Guo and Yiu, 2015). Such outcome validation can be achieved either through comparison with existing similar outcomes or through expert validation (Hallowell *et al*., 2013; Santos *et al*., 2019).

9.1. PROCESS FOR RESEARCH FINDINGS' VALIDATION

Current study adopts a focus group interview to validate the research outcomes by testing them with experts' opinion and feedback. A focus group was selected for validation (instead of comparing with similar research outcomes existing in the literature) in order to establish user-friendliness and practicality of the research outcomes that current doctoral study proffers in an objective way. The research outcomes being validated (i.e. the model for LIs development and implementation, analytical framework for LIs identification and examples of new LIs identified) have already been tested for scientific quality. In addition, an alternative method of outcome validation (i.e. comparison with existing similar outcomes in the literature) has already been performed when newly developed LIs (i.e. CSLIs) from the current work was contrasted with LIs (LRLIs) existing in the literature of LIs in safety management (in Figure 8.1 and 8.2). Figure 9.1 describes the process adopted in organising the focus group validation interview and analysing the discussion of experts.

Figure 9.1- Process for validating research findings.



As illustrated in the figure, four stages *viz*. *pre pilot*, *pilot study*, *focus group* and *data analysis* stages are consecutively followed to test the study's research outcome and obtain pertinent experts' perspective and feedback. The *pre pilot* stage involves the steps of generating:

interview questions, presentation slides and supplementary information pack. In addition to data collection tool generation (i.e. interview questions in Appendix 4), prefatory items such as presentation slides and supplementary information pack were developed at this stage to familiarise interview participants with the research topic anterior to the topic discussion session. Subsequently, all these three items were tested in a *pilot study* prior to actual focus group interview. A pilot study was conducted by recruiting five academic experts in order to test the scientific soundness of the tools and supplementary items to be used in a focus group interview. Selected academic experts for the pilot study are practicing scholars with professional background in academia and experience in higher education. Accordingly, based on the feedback and comments from pilot study participants, interview questions, presentation slides and information pack were refined to reduce any potential systematic bias.

Next, at the *focus group* stage: participants for actual validation focus group (i.e. group constituting experts from industry and academia were recruited; a meeting day and time was agreed to arrange online meeting; and supplementary information (presented in Appendix 5) was sent for their revision prior to focus group interview. During the *focus group* performance step, the following order of sessions were followed: welcome and introductory session to secure informed consent; PowerPoint slides presentation session to present the research findings to participants; question and answer (or discussion) session on the findings presented; and a conclusion session where participants could add any further comment, they felt relevant. In addition, during the PowerPoint slides presentation session, participants were offered to partake an interactive task of using the analytical framework to foster their engagement in subsequent discussion session.

Final *data analysis* stage in Figure 9.1 involves data cleansing (i.e. editing text for mistranscription, grammatical error and identifiable detail of participants), data analysis and summary of the result from focus group validation.

9.1.1. Questions of the focus group validation

The area of interest to be validated in this focus group interview of experts constitutes the research outcomes, *viz.*: proof-of-concept model for LIs development and application (Figure 7.9 in Chapter 7); analytical framework adopted to identify LIs from case study materials (Figure 8.3 in Chapter 8); and some examples of LIs developed (Table 1 in Appendix 5). As described in Appendix 4, question-1 in the interview (i.e. *Does the conceptual model (or* *process illustrated on Figure1 on page 1 in your document) make logical sense?*) sought to elicit perceptional views about the conceptual model. This question also incorporates a number of prompts to obtain full, comprehensive and rich insights and/or responses from each participant from the question posed.

The following two questions (i.e. *How easy or difficult the framework is to use to identify LIs?* and *Would you be prepared to apply this research in your organisation's safety management?*) are intended to inquire about usefulness or applicability of the analytical framework. Consequently, next two questions (i.e. question-4 and question-5 in Appendix 4) sought to explore: 1) usefulness of LIs; and 2) important features of LIs. Whereas the final question-6 (i.e. *What are the good practices that you may have encountered in terms of LIs development and implementation?*) sought to explore participants' experience of best practices in LIs' development and implementation. At the end of the focus group interview all participants were asked a final concluding question (i.e. *Of everything discussed in today's interview session, what is the most important point for you or have we missed anything to include today that you would like to add?*) in order to obtain their general feedback on the focus group interview process and allow them to contribute their additional thoughts or comments.

9.1.2. Mode of the focus group validation

A focus group validation was performed in the form of a group interview and was conducted online using Microsoft Teams (MS Teams). A total of seven participants attended the focus group interview, five of which were experts from industry and two of the participants were academic experts. These industry experts were selected for focus group validation due to their extensive and lengthy experience managing safety and working as and with site workers. Two academic experts were chosen due to their extended academic experience, one of whom had experience in both industry and academia. Their participation in focus group ensures not only the processual rigour of the focus group, but also their comments and perspective (on the research outcomes being tested) in the discussion provides invaluable insights about the theoretical rigour of the items being tested.

The duration of the focus group interview was 1 hour and 30 minutes – at which point saturation of comments was obtained and no further new information transpired. The transcript of the focus group interview was obtained via the use of transcription function embedded in MS

Teams. Participants' permissions were obtained prior to recording and transcribing the discussion of the focus group interview in conformance with BCU's ethical process.

9.2. FOCUS GROUP DISCUSSION

The transcript of focus group interview was downloaded from MS Teams and securely saved in BCU's OneDrive. The transcript underwent through following steps of edits *viz.*: the transcript and the video recording of the meeting were contrasted for consistency (i.e. to eliminate mistranscriptions); grammatical errors were corrected; filler words or sounds (particularly expressed by the interviewer such as 'yes', 'right' or 'okay' to ensure the speaker is being listened) were reduced to eliminate 'white noise'; and the names of the participants or any other identifiable details mentioned in the discussion were redacted. Consequently, the transcript was changed to tabular format (consisting of: *number* of rows column; *questions and prompts* column; *speaker* column; and *discussion* column) as illustrated in Appendix 6.

9.2.1. Group dynamics in focus group discussion

In the deidentification step, the participants' identity details were changed to *industry expert* (IE) and *academic expert* (AE) adding chronological number (as appeared in the transcript). Prior to these edits, the transcript of the focus group discussion was scrutinised to identify participants' engagement in the discussion. As a result, the details described in the Table 9.1 were established.

Table 9.1 - Group level participation of experts.

Participants	**Frequency of contribution to the discussion (number of interaction)**		**Interaction with (or reference to) other participants**	**Posing questions to interviewer**
	Overall discussion	**Topic discussion**		
IE-1	66	64	35	-
IE-2	61	58	11	3
IE-3	62	55	11	-
IE-4	98	88	8	2
IE-5	57	49	11	1
AE-1	21	15	4	-
AE-2	38	33	17	-

The table illustrates group level participation and engagement of participants through measurement of their interaction frequency: in overall discussion (on the second column), in the topic discussion (on the third column), with other participants (on the fourth column); and in addition to the frequency of initiating questions around the topic area (on the fifth column). Level of experts' participation enables identification of richness of discussion and fosters elucidation of any potential dominance or reticence in the discussion (Jones *et al*., 2011; Åker *et al*., 2023). Such detailed examination of discussion transcript aids to establish the distribution of group and power dynamic in overall discussion (Dijkers, 2010; Jones *et al*., 2011) and tests the moderator's management of discussion for equal and balanced contribution by participants (Robson and McCartan, 2016; Denscombe, 2021).

Overall interaction of each participant collectively includes: their response in introductory or greeting session; their response to the question posed and addressed by moderator in the discussion session; their interaction with other participants; and their reverse interaction (i.e. participants asking a question to the interviewer) with moderator or active inquiry about the discussed topic. Next, the third column describes participants engagement in the topic discussion only (excluding their interaction in greeting and concluding sessions). Fourth column of the table exclusively focuses on interaction of experts with each other or group level relationships of participants which incorporates/counts their initiation of comments to other participant's response or their reference to other participants responses. Whereas, last fifth column of the table demonstrates each participant's initiation of question to the moderator or their expression of interest in the discussed topic area. These different ways of measuring the frequency of participant's interaction reveals intricacies of group dynamics. For instance, the top active participant in overall discussion (i.e. IE-4) appears sixth in the list where their interaction with other participants is measured (i.e. eight interactions with other participants). Another example is, the fourth only active participant in the overall discussion (IE-2) appears to be the most active participant in terms of initiating/posing questions to the moderator and showing their interest in the topic discussed.

9.2.2. Participants' engagement in each question of focus group discussion

Subsequently, a further analysis was conducted to define the interest level (i.e. participation or engagement) of all participants in each question. Table 9.2 provides the details of this examination.

Table 9.2 - Experts' participation in each question.

Questions	Volume of discussion in each question (in frequency of words)	Ratio of discussion volume in each question to overall volume of discussion (in %)
1.Does the conceptual model (or process illustrated on Figure1 on page 1 in your document) make logical sense?	4,276	28
2.How easy or difficult the framework is to use to identify LIs?	2,149	14.1
3.Would you be prepared to apply this research in your organisation's safety management?	840	5.5
4.Referring to your Table 1 on page 1, what are your initial thoughts when you read these LIs?	3,609	23.6
5.Leading on from previous question, which of the following LI feature is the most important than others: 1) measurable; 2) preventative; or 3) relevant?	1,022	6.7
6.What are the good practices that you may have encountered in terms of LIs development and implementation?	3,384	22.1

The most lengthily and extensively discussed question is question-1 of discussion which asks about the proof-of-concept model for LI's development and implementation. This measurement is expressed in word counts in the second column of Table 9.2 (i.e. 4,276 words in the discussion of question - 1) which equates to 28% of the entire discussion (as illustrated in the third column of Table 9.2). This research outcome was the main interest of participants, to the extent that participants reversed the roles in the interview process by asking the moderator questions about the item (e.g. rows 20 and 48 in Appendix 6). Such moments of role reversals are noted as '*additional question from participant*' in the second column of Appendix 6, where, in total, six instances of such occurrences were identified in entire transcript of discussion (as detailed in Table 9.1). However, to maintain/preserve consistency, to remain within the time limit allocated for the discussion and to adhere to focus group objective (validation of research outcome), only a brief explanation/answer was provided and the pre-planned research topic discussion was resumed.

9.3. VALIDATION OF RESEARCH FINDINGS BY FOCUS GROUP EXPERTS

Active participation and dynamic engagement of participants in each presented topic area have produced invaluable insights for considerations towards the research outcomes being validated. Their comments, suggestions and recommendations reflected from their expertise and experience in industry and academia revealed a number of opportunities and possibilities for future work and potentials for applications of study's research findings in practice.

9.3.1. Validation of proof-of-concept model for leading indicators' development and implementation

As per Appendix 4, there was only one question (i.e. question-1) allocated for the discussion of this research outcome, in addition to five prompts representing different details that moderator was looking to determine in participants' responses. Regardless of incorporating only one question to be discussed in this topic area, this research outcome (or individual question) attracted the greatest level of interest within the ensuing discussion (as illustrated in Table 9.2). More specifically, participants favourably commented on the continuous loop element of the model where newly developed LIs are adopted and later revised in knowledge repository based on the insights obtained through their implementation. For instance, IE-2 mentioned about the importance of the continuous loop and significance of LIs to be revised and reviewed as follows:

"*I like the knowledge repository piece, where you spoke about earlier, in terms of it's [being] updated and there's the continuing loop go feeding back information into that…*
…So it's good that when you spoke about, [that] *we feed into it, we keep reviewing it, we keep updating it. That's to me is very important part of this model that you've built.*"

Overall consensus or views about the proof-of-concept model expressed amongst interviewees are positive where IE-3 described the model as "*totally logical*" and IE-4 characterised the model as "*perfectly operational*". Additionally, participants' interest in the question and in this particular research outcome (i.e. proof-of-concept model for LI's development and implementation) is reflected by (two instances of) their reversal of roles in the focus group interview process, where participants inquired about the model (refer to row 20 and 48 in Appendix 6). Specifically, they were willing to learn more about the model and how they could use it in practice.

9.3.2. Validation of analytical framework used to identify leading indicators

Two questions (i.e. question-2 and question-3) sought to inquire about the analytical framework (i.e. research outcome described in Figure 8.3 in Chapter 8). This research outcome was used to identify LIs from qualitative data that comprised combination of documents on accident records and normative documents. As per the volume of discussion described in Table 9.2, this topic area is the third extensively discussed area (cumulatively 2,989 words were used in the discussion of two questions related to this topic/research outcome).

Overall semantics of the discussion around this research outcome was incongruous and with multiple connotations. Question-2 in this topic area explored the user-friendliness of the analytical framework (given that participants had interactive task of classifying an example of LIs using the analytical framework in the preceding PowerPoint presentation session). Prevalently, the participants described their involvement in this interactive task and using the framework in LIs classification to be difficult. For instance, IE-2 responded:

"*I'll be absolutely honest. I didn't find it easy at all. It's quite a busy infographic… As a practitioner, you just have leading indicators, full stop… I didn't find it overly easy to use, personally…*"

Similarly, IE-4 commented:

"*In all honesty, I think it's very confusing. And that's probably because of the nature of the terminology… I suggest they are probably more academic terms than commercial terms… I think it needs that level of explanation* [refers to AB- interviewers' explanation in presentation session]."

Subsequently, IE-5 added:

"*I think, IE-4, I agree with you. I picked up and looked at it* [the analytical framework] *and when actually* [if you] *try and break this down without being taken through it, you wouldn't. Your* [AB-interviewer's] *explanation was absolutely bang on, but it needed that verbal piece to layer up on top of it to make it make sense.*"

These comments were predominantly the views of industry experts, where they recommended to simplify (i.e. to make less academic) the terminology for describing LIs to make the framework more accessible for end users such as workers at project sites. In these comments, experts also highlighted the importance of the explanation presented by the moderator. However, another industry expert IE-3 replied:

"*I think within the constructions industry, we tend to try and keep away with a page, that's for the words. You haven't done that; you've got lots of colours in here and you can map across the colours, there's no problem. But I suppose if you hadn't explained it in the beginning, some people may have struggled with reading it and mapping it across, maybe. But for me it was fine, because I understood what you were trying to do.*"

In addition to the industry practitioners' dominant view on the complexity of the analytical framework, perspectives from academic experts on the usability of the analytical framework expressed future opportunities. For instance, AE-2 commented:

"*…this really is the back end. This is the key thinking, difficult bit if you like. But it's how we now get that* [the analytical framework] *and transform it into something, that's far more user friendly… So what you've all said today actually supports that idea that we need to simplify this and develop into something more usable.*"

Overall, experts' view on the user-friendliness of the analytical framework indicates that this research outcome conveys knowledge or information which will be more beneficial for safety analysts. It was universally agreed that software developers must now turn this framework into an application or piece of software to assist workers at sites in their decision making and safety monitoring.

9.3.3. Validation of newly developed leading indicators' examples

The focus of the third topic area is on the newly identified LIs. To avoid information overload during the focus group discussion, only 19 randomly selected examples (one example from each 19 thematical clusters) of these newly developed LIs were presented to participants for their review before the focus group discussion. As demonstrated in Table 9.2, this topic area is at the top (cumulatively 4,631 words were used in the discussion of two questions related to this topic, i.e. question-4 and question-5) in terms of volume of discussion. This metric representing the volume of discussion is equivalent to 30% of the discussion out of the overall focus group discussion.

Apart from these quantitative measurements of the discussion richness, qualitatively, experts were readily sharing their views on LIs usability and their experiences of using LIs. Three instances of role reversal by participants (out of total six) occurred in the process of responding to the questions of the topic area (refer to rows 152, 156 and 160 in Appendix 6).

In general, participants' view on LIs examples (i.e. responses to question-4) were positive; where IE-2 described LI examples as "*…It's good list and I'm sure they're all valued leading indicators…*" and IE-3 characterised the list of LIs as "*…what you've written in* [here and] *the description of it is right…*".

To the question-5 around the most important features of LIs (to be selected from presented three LIs features *viz. measurable*, *preventative* or *relevant*) responses of experts differed. Five participants selected the *preventative* feature of LIs to be more important than other two features. Whereas one participant selected *relevant* feature and another participant chose all three features to be equally important. The *measurable* LI feature was the least favoured selection amongst participants, whereas two participants 'struggled' choosing between *relevant* and *preventative* features and consequently preferred the *preventative* feature over *relevant* LIs feature. AE-1 commenced:

"*…They're all very important. I think it has to be relevant. If it's not relevant, why are you doing it? It has to be measurable so that you can take some sort of action afterwards. However… there's this whole thing about reactive maintenance versus proactive maintenance. And actually, to me, preventing it* [from] *happening is king here. So, I'm on the same page as everybody else.*"

Similarly, IE-3 added:

"*I was going to say it was a score draw between preventative and relevant. But given that I accepted that all that leading indicator we're going to be talking about at any particular project are all relevant. Because you wouldn't be talking about them if they weren't relevant. That's where I was, my brain was at…You need all three, honestly. But preventative for me, is where you're trying to reduce harm…So preventative for me is the top one…*"

As a result, the discussion around examples of LIs and their important features generated rich conversation amongst participants from which myriads of suggestions, recommendations and inquiry emerged. Examples of additional observations shared by participants are: 1) participants (IE-2, IE-3, IE-5 and IE-4) rightly noticed some examples of LIs to be specific whereas others to be general; 2) IE-2 noted that presented 19 LI examples do not contain LIs around human aspect and directed to the need of focus on human behaviour, leadership and competence (e.g. rows 126 and 127 in Appendix 6); 3) IE-1 extensively discussed the importance of one of the LIs examples (i.e. sixth LI in Table 1 of Appendix 5) (row 127 in Appendix 6). They also described the challenges in their experience that stem from data abundance which causes: loss of opportunities in terms of leveraging safety data for continuous improvement (rows 202 and 219 in Appendix 6) on an organisational level; and potential cognitive overprocessing for end users or workers at site on an individual level (row 69 in Appendix 6) due to data management difficulties.

9.4. SUMMARY OF CHAPTER 9

Experts' discussion about the research outcomes presented for their validation was informative and abundant in relevant suggestions and valuable feedback. Participants' interest in the topic was apparent from their interaction with each other, the way they were engaged in conversation and their enquiry about the research outcomes during the focus group interview. Overall, experts participating in this focus group validation are in consensus about the usefulness of the model, framework and LI examples presented in the discussion. Moreover, they unanimously highlighted the importance of transforming these research outcomes into a user-oriented, accessible solutions and products. This point was highlighted by the sponsor of this research as an area for future development and next stage for this on-going programme of research.

Apart from the validation of study's research findings, this focus group discussion highlighted number of challenges experienced in safety management. One of the examples of such challenges was data or information abundance around safety management which leads to difficulty of harnessing the opportunity to learn from safety activities. Whereas with the use of knowledge repository where safety data is timely and continuously collected, analysed and transformed into decision making tool using apposite and effective techniques can address these challenges. Overall, this discussion by experts uncovered numerous future opportunities for the application of current study's research outcomes in industry practice.

CHAPTER TEN - CONCLUSION

10.0. INTRODUCTION

Construction accidents and injuries continue unabated across the globe despite the historic and considerable investment in research, training, technological and legislative developments. To reverse the direction of this well-trod chartered path, a new *modus operandi* is needed to breath fresh insight and generate wider polemic debate. The contributions presented in this doctoral research act as a catalyst for that change and signposts much-needed new direction for future research. The long-term goal of this current multi-step research is to facilitate the generation of a knowledge repository constituting LIs and their associated insights which will aid their continuous development and revision. This knowledge repository will serve as a foundation for organisations (as well as industries) on their journey to become continuous learning entities.

In such a centralised database or platform of safety intelligence, both leading and lagging indicators are crucial elements or signals emanating from complex systems from which more insights can be deduced whether timely or after-the-fact. Therefore, new theory built in the form proof-of-concept model in current study becomes critical to ensuring the next step change leap in safety science, whereas the polemic debate presented seeks to challenge conventional thinking and intends to instigate a new line of scientific enquiry.

10.1. SUMMARY OF THE STUDY AND ITS IMPLICATIONS

Cumulatively this doctoral work sought to integrate the fragmented nature of construction projects through holistic or systems thinking approach. Therefore, the use of LIs for proactive safety management was selected as a research focus, in an attempt to study the interrelationships of WMS elements rather than focusing on one specific element. The research outcomes (including theoretical models, a framework and a proof of concept) are generated based on the foundation of all-inclusiveness, comprehensiveness and holistic approach. All these stated theoretical contributions purvey a new perspective and opportunities for researchers to develop a blueprint model for knowledge management systems that will finetune existing understanding about accident occurrences. Likewise, the study's outcomes serve as a guidance and elucidation for safety practitioners, experts and early adopters of LIs in safety critical industries and for continuous learning organisations with higher safety maturity level.

10.1.1. The role of human aspect and training programmes

The practical contribution of the first step in phase 1 developed a conceptual model which incorporates key elements for safety training design. This research outcome is generated in the early phase of research focus identification as a result of preliminary literature review. The model integrates features of both Safety-I and Safety-II to ensure organisational introspection upon past mistakes but also to enable reflection upon good practices observed to better train operatives on site. Seven constituent elements of effective training programmes identified are arranged in accordance with the relevant design and development stages. This practical implication serves as a guidance for industry leaders in selecting impactful training programmes with favourable outcomes in safety management. Furthermore, developers of training programmes will benefit from this step of the study to generate cost and time-effective training with multifarious courses addressed to the different needs of participants. Moreover, as a theoretical contribution, this step explored the role of competency in training interventions. Based upon the findings of analysis, it can be concluded that competency is driven by higher engagement and participation of trainees in the process of training. In addition, competence can be reinforced by providing complementary contents and communication post completion of training programmes. Examples of high-engagement and active participation training interventions include methods such as work-together groups, role-playing, using physical models for vivid demonstrations, and utilising simulated virtual environments. Ultimately, this outcome of research intends to stimulate wider polemic debate and discourse to engender much needed investment to test the model developed in practice which will foster higher knowledge retention of trainees and maintenance of competence of workers after the training concluded.

10.1.2. Safety-in-cohesion

Driven by the Safety-II concept, the STS approach to safety management provides a comprehensive and holistic view for generating solutions to tackle systemic failures. This step sets a starting point which aims to launch a further expansion of STS adoption in safety management research and practice. According to the Safety-II concept, accidents happen due to co-occurrence of multiple factors (each necessary and jointly sufficient) and hence, solutions to such complex occurrence must be wide-ranging, multilevel and comprehensive. Moreover, complex and elusive phenomenon such as safety requires multilevel and congruent approach which encompasses all elements' interaction with their intricacies and weaker signals. Therefore, this step introduces a novel theoretical conceptual model (entitled 'Safety-in-cohesion') which adopts STS thinking by combining pertinent Safety-I and Safety-II principles as an optimised hybrid that combines the best facets of both concepts in one integral concept. This theoretical contribution will augment cohesion of: concepts (Safety-I and Safety-II); goals (PQS); data (leading and lagging indicators); safety measurement (negative and positive); project stages (design and construction stage); people involved (designers, constructors, owners, managers, frontline workers and members of the public who may be impacted by the works); and project components (WMS) in research and practice accordingly. For more specific quantitative or qualitative enhancements (that can potentially be obtained through proposed Safety-in-cohesion concept and conceptual model) however, an empirical study with application and implementation must be followed. Such validation work will establish potential future improvements and amendments of the model to enhance its user-friendliness, feasibility and practicality and to define cost and time efficiency of the item for organisational use.

10.1.3. Constructs of leading indicators

The conceptual model developed (in Figure 7.1) serves as a practical contribution for LI adopting organisations. Moreover, compilation and deduction of LIs constructs (i.e. definition, types and development methods) from extant literature adds a valuable theoretical contribution to developing the wider body of knowledge on LI. This step concludes that variance in LIs definitions and functions are related to different types of LIs, namely PLIs and ALIs. PLIs measure and assess the elements of organisational safety management systems (such as the efficiency of training programmes or contractor selection methods, impact of adopted preventative steps or designed work process). Whereas ALIs measures or unravels granular and dynamic elements of safety such as preventable and correctable early signs of possible negative or positive events. However, ALIs studies remain strikingly scant - only four out of 93 publications (reviewed in the step of literature analysis on LIs in safety management) focus on ALIs. Given the capacity of ALIs to generate knowledge and immediate feedback from the action being performed in the operation stage (which allows close to real-time monitoring of safety (or unsafety)), more studies on their theoretical and practical applications are required. In terms of application of the conceptual model offered at this step of the study, there are number of considerations that organisations must include to effectively adopt LIs as their safety performance measurement. Although an organisation's lagging indicators and industry white papers are important sources (and constitute the starting point to develop LIs), a pivotal step prior to that is to comprehensively understand the main features of LIs by their definition, function, focus and types. Without this knowledge, efficiency of developed LIs will remain questionable (regardless of the source of materials used to develop them) and hence, understanding the constructs of LIs is a first priority for adopting organisations. Therefore, the proffered model intends to facilitate such understanding and explicate the main constructs of LIs by providing guidance on the role, difference and function with addition of processes for adoption and continual revision of LIs.

10.1.4. Proof-of-concept

The initial step in phase 2 has developed the conceptual level model (in Figure 7.1) into a proof-of-concept model by adopting and testing the LIs development process offered in the model. Therefore, this step of current study used lagging indicators and normative documents relevant to each case to identify or develop LIs. Consequently, a total of 484 LIs were identified and 232 of these were distinguished as unique to this study (i.e. LIs that could not be found or matched with LIs previously published in the pertinent literature). Additionally, this step of LIs identification and development was performed using a novel analytical framework as another product of the research. Consequently, this study has led to a new theoretical contribution to the body of knowledge in LIs' use which explains the challenges towards LIs expansion in practice, despite the abundance of research present in academia. WAP (or *work-as-imagined)* in the scholarly world is predominated with generic type of LIs, whereas WAD in case study materials are more specific, task and activity oriented. While generic LIs are beneficial to identify pivotal elements of safety management systems (i.e. safety communication, safety climate, leadership and commitment), more specific LIs must be developed which will provide actionable insights for users at site. Therefore, to augment the propagation of LIs adoption, both generic LIs (to identify gaps and shortcomings in organisations' safety management systems) and specific LIs (to identify specified conditions to be met and detailed activities/tasks to be performed to maintain safety) must be developed at the outset and revised/updated and proactively used later on.

10.1.5. Concluding step

There are differences in attributes of lagging and LIs. Lagging indicators: are associated with unfavourable outcome, adverse consequence; have the power to halt the system; and are more discernible than LIs. Whereas LIs are: weaker and not easily detectable unless sought after; indistinct and blended in *status quo* (i.e. the time period when there is no accidents); and dynamic and time dependent, hence require continuous monitoring. Nevertheless, collectively both leading and lagging indicators are feedback or response emanating from the interrelationship of elements (WMS) in complex STS. Accordingly, it is incumbent upon organisations' choice on which signal (weaker, stronger or combination of both) they are willing and able to base their safety management. However, due to the manoeuvrability of both leading and lagging indicators, regardless of the metric chosen to adopt, their accuracy will be threatened with poor safety culture in organisation and this will lead to management of metrics rather than management of safety. Therefore, one of the main hurdles, organisations need to address from the outset is their preparedness, priorities and safety culture maturity level. These and many other challenges and nuances (in Table 8.3) along with potential benefits (in Table 8.4) embedded in LIs functions are extensively discussed throughout this work. However, for efficient LIs adoption and sustainable proactive safety management approach, LIs must be adopted with a systems thinking approach. Moreover, LIs should be developed and used for each and every element of STS rather than merely focusing on human behaviour or identifying LIs for machinery or plant. In addition, such an approach must be applied through the use of active LIs (alongside other LI types) which will: enable constant monitoring of emergent features of STS; and facilitate early detection of changes in safety status.

10.2. RESEARCH AIM, OBJECTIVES AND QUESTIONS

As a research aim, this doctoral study sought to generate a novel theoretical base in the form of conceptual model for dissemination of holistic and proactive safety management which is derived from pertinent literature and tested with real life case study data. To achieve this research aim, the following three research questions were posed [*as a recap*]:

1. Why do current attempts to reduce accident occurrences fail and what approach will facilitate desired efficiency?
2. What are the main constructs of LIs that enable elucidation of such concept and facilitate their wider adoption for proactive safety management? and
3. What is the relationship or contrast between leading and lagging indicators and what is their role in safety management?

Accordingly, research objectives reflect these research questions and specify steps of achieving the research aim set, *viz*. [*as a recap*]:

1. To identify apposite methodology or approach for proactive and holistic safety management through the systematic review of pertinent literature.

2. To generate a conceptual model (through systematic literature review) which allows design/development of systemic countermeasures and preventative steps for a continuous safety improvement and maintenance.
3. To develop an analytical framework (via framework analysis of pertinent literature) to systematically identify LIs from qualitative dataset.
4. To test the proposed conceptual model with real life case study data (in combination with relevant normative documents) to determine its potential impact and identify further considerations and recommendations for future work.

10.2.1. First research objective and first research question

A systematic review of the safety management literature at the outset of the study enabled fulfilment of the first research objective and answered the first research question. This study identifies that main challenges or shortcoming of current safety management is the lack of holistic and proactive approach. To address the shortcoming of holism, practices of managing safety requires a systems thinking or STS perspective. Whereas to resolve the challenges of proactivity, safety management process must be developed based on early signals, *viz*., using LIs. Therefore, the conceptual model 'Safety-in-cohesion' presented in Figure 7.7 in Chapter 7 was generated to: fulfil these identified gaps in the practice and research of managing safety; and set the theoretical foundation for holistic safety management. Subsequently, the research focus was directed towards in-depth analysis of the literature on LIs and their adoption in safety management.

10.2.2. Second and third research objectives and second research question

However, as the second research question indicates, there are hindrances around successfully implementing LIs. Therefore, the second research question sought to identify main LI constructs that would foster their wider adoption and based on which the second research objective focused on generating a conceptual model. As discussed in Chapter 7, the main LIs constructs are their definition (which differ according to their typology), typology, development method and as the final concluding step of the study reveals their function is another construct. Therefore, the conceptual model (in Figure 7.9) which incorporates these LIs constructs was developed to fulfil the second research objective and second research question. The model was designed to foster development, implementation and continuous revision of LIs as a systemic, proactive countermeasure and preventative step. In addition, the third research objective of the study sought to develop an analytical tool that enables systematic identification of LIs from the qualitative dataset. Therefore, a research outcome in the form of analytical framework presented in Figure 8.3 of Chapter 8 represents the achievement of the third research objective.

10.2.3. Fourth research objective and third research question

Next the newly developed conceptual model required testing for its feasibility and practicality. Hence, the last and fourth research objective were directed towards testing the model developed. Therefore, phase 2 of the study began with the proof-of-concept step by: adopting the development process in the conceptual model; and identifying the LIs from qualitative data of case study data and normative documents. Furthermore, the resultant analytical framework and examples of newly developed LIs from this step, along with the proof-of-concept model itself were validated in focus group with industry and academic experts. Details of the findings and the discussion of these research outcomes are presented in Chapter 8 which summarises: challenges of LI development, implementation and adoption along with their corresponding potential solutions (in Table 8.3); and future potentials for LI adopters in the form of collation of different LIs functions that can be achieved with different types of LIs and with different steps (Tabe 8.4). In addition, Chapter 8 presents a new explanation (Figure 8.5) of the abstruseness between leading and lagging indicators by adding dynamics of safety management representing different safety maturity level of organisations. Accordingly, this final research outcome (Figure 8.5 in Chapter 8) answered the third research question of this study.

10.3. LIMITATIONS OF THE STUDY AND POTENTIALS FOR FUTURE WORK

Alongside these research findings alluded to as well as its potential theoretical and practical contributions, the study's limitations must also be noted. For example, the selection of search keywords in the steps of both phase 1 and phase 2 and the choice of a single journal database (i.e. Scopus in phase 1 mainly) used to source those bibliometric data can be argued to be overly restricted, specific or narrow. The studies identified in the literature through such criteria form the basis of the theoretical conceptual model and informs the research findings. While broader search criteria in terms of keywords or databases (e.g. Google scholar or Web of Science) could return larger amounts of data for analysis and present further perspectives into research contributions, the abundance of such scale of publications would be overwhelmingly restrictive to handle, given that bibliometric details in every step of both phases went through manual scanning. Additionally, such an approach to data sourcing could diffuse the research outputs of the study. However, to enhance the comprehensiveness and exhaustiveness of the research outcome, in the steps of phase 2, secondary data were sourced from Web of Science journal database in addition to Scopus journal database. Furthermore, in two instances or steps of the current study (on the third step of phase 1 and on the second step of phase 2), additionally relevant items were added through snowballing technique to expand the reach and inclusion of relevant-to-the-topic items from the pertinent literature.

10.3.1. Examples of specific limitations and prospects for future work

Apart from these generic limitations mentioned, there are some specific limitations relevant to study outcome apiece. For example, the 'Safety-in-cohesion' model presented in Figure 7.7 is largely limited to the immediate project environment and it is acknowledged that other external factors (such as legislative developments, macroeconomic or black swan events and disruptive technologies) could impact upon the safe system of working adopted. These factors will require further elucidation and delineation to ensure that their exact impact can be measured quantitatively in future research. Therefore, whilst the development of new theory (using inductive reasoning) constitutes a notable contribution to knowledge, such work must now be tested deductively in practice to monitor, measure and assess the performance and validity of the model theory proposed. In turn, this will require further elaboration on the finer nuances of bespoke project characteristics such as client knowledge of the construction process and the chosen procurement path adopted. Most likely, the theory presented in the model will retain common elements that are applicable to all projects (such as the design and construction phases) and more specific detail (e.g. prevailing financial arrangements) that are unique to a particular project. Such work will require case studies of practice to achieve this objective of accurately reflecting the myriads of project arrangements in the sector. It is envisaged that advanced intelligent modelling approaches (such as machine learning algorithms (cf. Jian *et al.,* 2012)) present useful opportunities to accurately predict big data required from case studies into complex STS as are apparent in construction projects.

Another example of limitation or consideration specific to a study outcome that is important to highlight appertains to newly developed LIs (in Appendix 3). These LIs are resultant of current work which was developed by adopting the steps in the conceptual model (Figure 7.9 in Chapter 7) and using the analytical framework (Figure 8.3 in Chapter 8) to detect those LIs in qualitative data selected. All these three research outcomes, *viz*., model for LIs development and implementation, analytical framework and some examples of LIs were validated through design validation (where research outcomes are validated via peer-review process) and outcome validation (where research outcomes are validated by feedback and discussion of focus group experts) (Bockstaller and Girardin, 2003). Next step of validation for these three research outcomes, which is end user validation (where validation process focuses on whether research outcomes provide useful information and practical benefit), must be followed in the future work. Therefore, all these 484 LIs examples that are newly developed in current study must be acknowledged as only alpha version of LIs which will be tested in the future with end users themselves to determine their fitness for purposes (Rhodes *et al*., 2009). Additional shortcoming in this study could be related to inherent systemic error, associated with case study data. Since the study's outcome is based on retrospective analysis of existing data (i.e. data that is neither designed nor collected for research purposes), this potential inherent weakness could be reflected in the findings. That said, case study data does represent WAD rather than WAP or *work-as-envisaged* (Hallowell *et al*., 2013; Karakhan *et al*., 2018) – and in this respect, case study data is arguably more insightful. Nevertheless, the research indicates that quality of lagging indicators (i.e. accuracy, legibility, format and structure of data being recorded) is an important element for developing more relevant, useful and efficient LIs that can improve an organisation's safety performance in the long-run and monitor safety immediately.

Another such example of specific limitation applies to the research outcome in Figure 8.5. The events illustrated in Figure 8.5 should not be assumed as a cogent link, but rather they are illustrated arbitrarily to describe the relationship of leading and lagging indicators and to reflect the emphasis existing in pertinent literature around the use of LIs (i.e. weak but early signals and feedback from complex systems) and benefits of applying corrective measures at early stage to maintain safety (rather than waiting for severe or major accident occurrences). For instance, factors leading to occurrence of different severe accidents (SA1 and SA2 in Figure 8.5) are dissimilar. LIs for SA1 severe accident occurrence are combination of emergent LI, observable LI and emergent implicit LI. Whereas LIs of SA2 occurrence are due to observable LIs, implicit LI as well as near miss event occurrences. In addition, the relationship between safety management dynamics stated in the model requires an empirical testing across organisations in safety critical industries. Such explanatory study could either be: cross sectional, which cross compares these dynamics across number of organisations; or longitudinal, which tracks or traces changes in safety management dynamics of one organisation in longer time period.

10.4. RECOMMENDATIONS AND FUTURE DIRECTIONS

As observed in the study about training programmes, the main source of influence and frequently used control tool in the industry is based on regulations and technology adoption. Yet the success of new technology adoption or introduction of new rules and regulations are incumbent upon people's acceptance of such deployments. Therefore, to incorporate the social aspect in developments of new solutions (whether it is a new technology, processes improvement or new approach to safety management), workers' perspectives must be considered. Therefore, all proposed theoretical and practical contributions of this doctoral research should be introduced to users and conveyed through easily perceivable, cognoscible and intelligible way. Such perspicuous conveyance of newly introduced solutions will increase acceptance of users and most importantly will ensure achievement of intended outcome and success of new developments.

10.4.1. Humans as enablers of solutions for safety improvement and maintenance

The human aspect must be leveraged as a source of resilience, rather than a problem to be controlled. Workers must be encouraged and trained for: autonomous and informed decision-making; anticipating, monitoring and responding to small changes; and adapting to changing working conditions. This requires the development of: training programmes that are targeted for competency, adaptation and resilience building; and systems that are designed and developed for humans' limitations and strength; whilst new technological developments must be considered as a complementary tool to facilitate their work. These are examples of changes that can be instigated on an individual or organisation level. However, some other changes required for individual organisations are contingent upon industry level practices, *viz.,* changes refined and guided through industry standards and regulations will alter expectations and the cultural norms within organisations in the construction industry. Therefore, new guidance or incentivisation is required to endorse safety innovation and encourage adaptation capability of organisations, whilst statistics on accidents occurrences must serve as a guidance for safety performance improvement within organisations only, rather than reputational indicators of organisations' success or failure within industry. An important note about laws and regulations is that although a punishment is needed to discourage bad behaviour, it is reactive to the event rather than being proactive. If laws and regulations alone are relied upon, the root cause of accidents and incidents continue to manifest unabated – hence, the need for proactive LIs.

Aside from designing the most impactful training experience and additional implementation resources to use post-training, other factors such as peer support and encouragement, management commitment and expectation have equally important roles for the successful implementation of learning into practice. All these conditions can create a smooth transition from basic training to on-the-job worksite training with better knowledge transfer and competence development. However, building other safety critical attributes such as resilience cannot be achieved in temporary training programmes. To generate workers' resilience in a dynamic and intractable construction workplace(s), other controls for risk elimination need to be implemented as a reinforcement rather than relying on training programmes alone (e.g. engineering controls by isolating people from the hazard where possible, administrative controls by changing the way people work and streamlining the processes; or personal protective equipment (PPE), i.e. protecting workers with personal protective equipment).

10.4.2. Proactive and holistic safety management through leading indicators

The main priority for companies adopting LIs must be to improve recordings of lagging indicators. Since lagging indicators are a crucial source of knowledge for the development of organisation specific LIs, the efficiency and accuracy of these is determined by the accuracy and quality of lagging indicators' recordings. Furthermore, development of LIs must encompass different elements of complex STS (*viz.* WMS) on different levels (organisational and procedural level), since accident(s) occurrences are the results of multiple sources of factors that are unpredictable and emergent.

On structural level, elements that LIs are indicating should be structured in a nested or multi-tiered way. For example, if a company adopts safety culture as LIs of safety, then LIs for measuring safety culture must be adopted. Similarly, if the company adopts safety inspection or safety observation to monitor safety culture of the company, then a LI to measure and monitor the efficiency of those methods (e.g. safety observation and safety inspection) must be developed and recorded. In other words, even the process of adopting the proactive safety management approach must have certain measurements or LIs to continuously monitor the efficiency of the approach.

Another caveat for efficient adoption of LIs is to measure them qualitatively as well as quantitatively to capture the breadth and depth of information on occurrences. Instead of measuring frequency of positive or negative occurrences, the focus must be on observed elements themselves and based on continuous monitoring and anticipation by frontline workers. To achieve that, the knowledge about LIs constructs must be efficiently conveyed to frontline workers (through hands-on trainings and practices) because they are important and the only stakeholders who are exposed to real challenges of changing work environment. Therefore, only frontline workers can observe the changing signs and 'read' those LIs in the work environment and act timely to correct unsafe observations or to acknowledge positive occurrences. Knowledge can be introduced on routine check sessions, by involving frontline workers in the process of detecting LIs.

10.4.3. Continuous learning organisations through safety intelligence and safety analytics

Adoption of LIs is an early impetus towards development of proactive safety management. However, this must not be limited to a single organisation, since the design and construct of countermeasures and barriers generated through continuous LI use will be limited to the knowledge of that organisation and their past experience only. Therefore, to improve the quality and extent of data collected through LIs, organisations are recommended to: create a centralised safety analytics platform; and to incorporate knowledge and insights about LIs and safety challenges from practices of other relevant organisations and industries. Such undertaking, in its turn, will provide an exhaustive and more comprehensive safety intelligence and will enable organisations to learn from their own shortcomings as well as from mistakes occurring in other organisations' projects (by uncovering unknown unknowns). However, such voluminous data can become problematic in the adoption or implementation of LIs in practice and hence, the data collated must have standardised format and automated process in order to facilitate data processing and expediate turning the data into safety intelligence and practical insights.

10.4.4. Human-technology synergy/symbiosis

The sheer volume of LIs (484 LIs) developed through the sample of only 12 cases illustrates the richness of qualitative type data for identifying LIs and showcases the feasibility of such LIs development process. However, for full leverage of the benefits and efficacy of LI adoption, alongside the generation of knowledge repository for compilation of LIs, the process of data or LIs gathering, analysing and using that insight in managing and monitoring safety becomes the upmost important. Therefore, the process of developing and identifying LIs (from safety related documents and activities) should be automated using the innate capabilities of the latest technologies (e.g. support vector machines (SVM) to identify LIs from the volume of qualitative data) combined with the knowledge of subject matter experts (i.e. scholars and practitioners alike). Similarly, to gather new LIs from ongoing projects, workers can use technology (e.g. internet of things (IoT) devices such as hands-free technologies with voice to text capability) to capture emerging new LIs (i.e. ALIs) or to report the incident or near miss faster and without distraction or interruption to their core task. This will save administration time while simultaneously, reducing human introduced error or bias in reporting and augmenting the process of systematic record-keeping. Furthermore, once implemented, these newly developed and collated (in a knowledge repository) LIs will be continuously revised, updated and new LIs will be added from ongoing projects. This will generate big data in safety, which similarly requires symbiosis of human and technology in order to put LIs into use *viz*., to select pertinent LIs from the repository in order to improve decision making in safety management. For example, combining artificial intelligence (AI) powered language model solution such as Chat Generative Pre-Trained Transformer (Chat GPT) with human expertise and knowledge (i.e. safety managers' and construction operators' knowledge from practice and research findings from academia). A generative AI based software could constitute the final product of such human-technology synergy. Such software can efficiently assist workers at the site to select relevant LIs that proactively inform users of the risks or hazards that are associated with their task, use of equipment, site condition or proximity. Utilisation of software can be performed through hands-free, voice-enabled search rather than reading through an extensive list of risk assessment and avoidance documents.

10.5. SUMMARY OF CHAPTER 10

This doctoral study can be described as: an exploratory work through the systematic synthesis of the pertinent literature step and descriptive work in an in-depth study of LIs constructs in the phase 1; and explanatory work towards the phase 2 of the study. Exploratory part of the study is related to the steps of exploration of the phenomenon (i.e. occurrence or maintenance of safety or unsafety) in the existing literature and involves identification of the research focus upon which research contribution is derived. Descriptive step involves elucidation of LIs constructs and specification of LIs development and implementation steps. Whereas explanatory side of the study entails going beyond mere description of the phenomenon or exploration of the topic. Exploratory step of the work has led to a number of research outcomes that are in the form of theoretical developments, new explanations and concepts, descriptive step proffers conceptual model for LIs development, implementation and revision; while explanatory step has generated several practical contributions in the form of proof-of-concept model, analytical framework and guidance for adopters. Towards the end of this doctoral work, the process of testing all these practical contributions of the work has been performed by obtaining experts' opinion in focus group interview validation. However, moving forwards further tests that validate the usability, practicality and benefits of these research developments must be followed.

Ultimately, the research presented has broken new ground in the scientific domain of safety and publications produced provide evidence of the various contributions to new knowledge made. However, safety represents a Gordian knot and the more research focuses on this complex topic, the more it is realised that further and more detailed work must be undertaken. This thesis provides a strong theoretical basis for such future work and in many ways challenges contemporary thinking in the field. As such further polemic debate is needed to advance safety science further in the construction and civil engineering industry.

REFERENCES

Abas, N., Jalani, A. and Affandi, H. (2020). Stakeholders' Perceptions of Occupational Safety and Health Risks in Malaysia. *International Journal of Sustainable Construction Engineering and Technology*, 11 (1). pp. 300–311. DOI: https://publisher.uthm.edu.my/ojs/index.php/IJSCET/article/view/6273

Abbas, M., Mneymneh, B.E. and Khoury, H. (2018). Assessing on-site construction personnel hazard perception in a Middle Eastern developing country: An interactive graphical approach. *Safety Science*, 103. pp. 183–196. DOI: https://doi.org/10.1016/j.ssci.2017.10.026

Abdelmalek, G. and Soares, M. (2021). Performance-based leading risk indicators of safety barriers on liquefied natural gas carriers. In: *Maritime Technology and Engineering* CRC Press 5 (1). 1st edn. DOI: https://doi.org/10.1201/9781003216582-23.

Abdullah, A.H., Yaman, S.K., Mohammad, H. and Hassan, P.F. (2018). Construction manager's technical competencies in Malaysian construction projects. *Engineering, Construction and Architectural Management*, 25 (2). pp. 153–177. DOI: http://dx.doi.org/10.1108/ECAM-07-2016-0176

Abubakar, M., Zailani, B.M., Abdullahi, M. and Auwal, A.M. (2021). Potential of adopting a resilient safety culture toward improving the safety performance of construction organizations in Nigeria. *Journal of Engineering, Design and Technology,* 20. pp.1236–1256. DOI: https://doi.org/10.1108/JEDT-09-2020-0354

Acar, E., Wall, J., McNamee, F., Carney, M. and Öney-Yazici, E. (2008). Innovative Safety Management Training Through e-Learning. *Architectural Engineering and Design Management*, 4 (3–4). pp. 239–250. DOI: http://dx.doi.org/10.3763/aedm.2008.0085

Agnew, J. (2018). Is human and organizational performance (HOP) a new approach to safety? Available from: www.aubreydaniels.com/media-center/ human-and-organizational-performance-hop-new-approach-safety.

Agumba, J.N. and Haupt, T.C. (2012). Identification of Health and Safety Performance Improvement Indicators for Small and Medium Construction Enterprises: A Delphi Consensus Study. *Mediterranean Journal of Social Sciences,* 3(3). pp. 545-557. DOI: http://dx.doi.org/10.5901/mjss.2012.v3n3p545

Ajayi, V.O. (2017). Primary sources of data and secondary sources of data. *Benue State University*, 1. pp.1–6.

Åker, T.H., Risan, P. and Milne, R. (2023). Responding to reticence in investigative interviews of alleged victims with a mental illness: Maintaining rapport. *Nordic Journal of Studies in Policing,*10. pp. 1–11. DOI: https://doi.org/10.18261/njsp.10.1.2

Akroush, N.S. and El-adaway, I.H. (2017). Utilizing Construction Leading Safety Indicators: Case Study of Tennessee. *Journal of Management in Engineering*, 33, 06017002. DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000546

Akroush, N.S. and El-Adaway, I.H. (2018). Penetration of Leading Safety Indicators in the Construction Industry: The Case of Tennessee, *Construction Research Congress 2018: Safety and Disaster Management - Selected Papers from the Construction Research Congress 2018.* pp. 334–344. DOI: https://doi.org/10.1061/9780784481288.033

Alavi, H., Gordo-Gregorio, P., Forcada, N., Bayramova, A. and Edwards, D.J. (2024). AI-Driven BIM Integration for Optimizing Healthcare Facility Design. Buildings 14, 2354. DOI: https://doi.org/10.3390/buildings14082354

AlBahnassi, H. and Hammad, A. (2012). Near Real-Time Motion Planning and Simulation of Cranes in Construction: Framework and System Architecture. *Journal of Computing in Civil Engineering*, 26 (1). pp. 54–63. DOI: http://dx.doi.org/10.1061/(ASCE)CP.1943-5487.0000123

Albert, A. and Hallowel, M.R. (2013). Revamping occupational safety and health training: Integrating andragogical principles for the adult learner. *Construction Economics and Building*, 13(3). pp. 128–140. DOI: 10.5130/AJCEB.v13i3.3178.

Albert, A., Hallowell, M.R. and Kleiner, B.M. (2014). Experimental field testing of a real-time construction hazard identification and transmission technique. *Construction Management and Economics*, 32 (10). pp. 1000–1016. DOI: http://dx.doi.org/10.1080/01446193.2014.929721

Albert, A., Hallowell, M.R., Kleiner, B., Chen, A. and Golparvar-Fard, M. (2014). Enhancing construction hazard recognition with high-fidelity augmented virtuality. *Journal of Construction Engineering and Management,* 140 (7) 04014024. DOI: 10.1061/(ASCE)CO.1943-7862.0000860.

Albert, A., Pandit, B. and Patil, Y. (2020). Focus on the fatal-four: Implications for construction hazard recognition. *Safety Science*, 128. 104774. DOI: 10.1016/j.ssci.2020.104774.

Albert, L. and Routh, C. (2021). Designing Impactful Construction Safety Training Interventions. *Safety*, 7(2). 42. DOI: 10.3390/safety7020042.

Ale, B. (2009). More thinking about process safety indicators. *Safety Science*, SRAE 2006 47, pp. 470–471. DOI: https://doi.org/10.1016/j.ssci.2008.07.012

Alexander, D., Hallowell, M. and Gambatese J. (2017). Precursors of Construction Fatalities. II: Predictive Modelling and Empirical Validation. *American Society of Civil Engineers,* 143 (7). DOI: https://ascelibrary.org/doi/epdf/10.1061/%28ASCE%29CO.19437862.0001297

Ali, M.X.M., Arifin, K., Abas, A., Ahmad, M.A., Khairil, M., Cyio, M.B., Samad, M.A., Lampe, I., Mahfudz, M. and Ali, M.N. (2022). Systematic Literature Review on Indicators Use in Safety Management Practices among Utility Industries. *International Journal of Environmental Research and Public Health* 19, 6198. DOI: https://doi.org/10.3390/ijerph19106198

Almost, J., Caicco Tett, L., VanDenKerkhof, E., Paré, G., Strahlendorf, P., Noonan, J., Hayes, T., Van hulle, H., Holden, J., Silva e Silva, V. and Rochon, A. (2019). Leading Indicators in Occupational Health and Safety Management Systems in Healthcare: A Quasi-Experimental Longitudinal Study. *Journal of Occupational & Environmental Medicine,* 61. pp. e486–e496. DOI: https://doi.org/10.1097/JOM.0000000000001738

Alruqi, W.M. and Hallowell, M.R. (2019). Critical Success Factors for Construction Safety: Review and Meta-Analysis of Safety Leading Indicators. *Journal of Construction Engineering and Management* 145, 04019005. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0001626

Alsamadani, R., Hallowell, M. and Javernick-Will, A.N. (2013). Measuring and modelling safety communication in small work crews in the US using social network analysis. *Construction Management and Economics*, 31 (6). pp. 568–579. DOI: http://dx.doi.org/10.1080/01446193.2012.685486

Andersen, L.P., Karlsen, I.L., Kines, P., Joensson, T. and Nielsen, K.J. (2015). Social identity in the construction industry: implications for safety perception and behaviour. *Construction Management and Economics*, 33 (8), pp. 640–652. DOI: http://dx.doi.org/10.1080/01446193.2015.1087645

Andersen, L.P.S. and Grytnes, R. (2021). Different ways of perceiving risk and safety on construction sites and implications for safety cooperation. *Construction Management and Economics*, 39 (5). pp. 419–431. DOI: http://dx.doi.org/10.1080/01446193.2021.1904516

Anger, W.K., Kyler-Yano, J., Vaughn, K., Wipfli, B., Olson, R. and Blanco, M. (2018). Total Worker Health® Intervention for Construction Workers Alters Safety, Health, Well-Being Measures. *Journal of Occupational & Environmental Medicine*, 60 (8). pp. 700–709. DOI: http://dx.doi.org/10.1097/JOM.0000000000001290

Antonio, R.S., Isabel, O.-M., Gabriel, P.S.J. and Angel, U.C. (2013). A proposal for improving safety in construction projects by strengthening coordinators' competencies in health and safety issues. *Safety Science,* 54. pp. 92–103. DOI: 10.1016/j.ssci.2012.12.004.

Anuar, N.I.P., Aziz, H.A. and Ahmad, R. (2019). Integrated chemical, technology and equipment process knowledge management system based on risk-based process safety. In: *IOP Conference Series: Materials Science and Engineering, 702. 1st ProSES Symposium*, Kuantan, Pahang, Malaysia. DOI: https://doi.org/10.1088/1757899X/702/1/012052

Arnold, P. (2015). Evidence and leading indicators of change success. *Strategic Direction*, 31. pp. 1–5. DOI: https://doi.org/10.1108/SD-08-2015-0128

Arslan, M., Cruz, C. and Ginhac, D. (2019). Semantic enrichment of spatio-temporal trajectories for worker safety on construction sites. *Personal and Ubiquitous Computing,* 23 (5–6). pp. 749–764. DOI: http://dx.doi.org/10.1016/j.procs.2018.04.039

Assiri, G.A., Alanazi, B.M. and AlRuthia, Y. (2022). The Prevalence of High-Risk Prescribing of Oral Non-Steroidal Anti-Inflammatory Drugs in Primary Healthcare: A Single-Centre Retrospective Chart Review Study. *Healthcare*, 10, 867. DOI: https://doi.org/10.3390/healthcare10050867

Atkinson, A.R. and Westall, R. (2010). The relationship between integrated design and construction and safety on construction projects, *Construction Management and Economics*, 28(9). pp. 1007–1017. DOI:10.1080/01446193.2010.504214.

Atkinson, P.A., Coffey, A.J. and Delamont, S. (2003). *Key themes in qualitative research: continuities and changes*. AltaMira Press, Walnut Creek, CA, USA. URL: https://orca.cardiff.ac.uk/id/eprint/3085

Azar, E.R. and Kamat, V.R. (2017). Earthmoving Equipment Automation: A Review of Technical Advances and Future Outlook. *Journal of Information Technology in Construction*, 22. pp. 247-265. DOI: https://www.itcon.org/2017/13

Azarian, A., Siadat, A. and Martin, P. (2011). A new strategy for automotive off-board diagnosis based on a meta-heuristic engine. *Engineering Applications of Artificial Intelligence*, 24 (5). pp. 733–747. DOI: http://dx.doi.org/10.1016/j.engappai.2011.03.008

Badham, R., Clegg, C. and Wall, T. (2000). *Socio-technical theory. In: Karwowski, W. (Ed.), Handbook of Ergonomics*. John Wiley, New York, NY.

Bahn, S. (2013). Transformational leaders? The pivotal role that supervisors play in safety culture. *International Journal of Training Research*, 11 (1). pp. 17–26. DOI: http://dx.doi.org/10.5172/ijtr.2013.11.1.17

Bahn, S. and Barratt-Pugh, L. (2012). Evaluation of the mandatory construction induction training program in Western Australia: Unanticipated consequences. *Evaluation and Program Planning,* 35 (3). pp. 337–343. DOI: http://dx.doi.org/10.1016/j.evalprogplan.2011.11.006

Bahn, S. and Barratt-Pugh, L. (2013a). Getting reticent young male participants to talk: Using artefact-mediated interviews to promote discursive interaction. *Qualitative Social Work*, 12. pp. 186–199. DOI: https://doi.org/10.1177/1473325011420501

Bahn, S.T. and Barratt-Pugh, L.G. (2013). Improving safety culture: The impact of the construction induction training on the construction industry in Western Australia. Available from: https://ro.ecu.edu.au/ecuworks2013/389

Baker, J., Leveson, N., Bowman, F. and Priest, S. (2007). The Report of the BP US Refineries Independent Safety Review Panel. *Rapp Tech*. Available from: https://www.documentcloud.org/documents/25773-the-bp-u-s-refineries-independent-safety-review-panel-report [Accessed 02.05.2023].

Ball, D.R. and Frerk, C. (2015). A new view of safety: Safety 2. *British Journal of Anaesthesia*, 115. pp. 645–647. DOI: https://doi.org/10.1093/bja/aev216

Barbosa, C., Azevedo, R. and Rodrigues, M.A. (2019). Occupational safety and health performance indicators in SMEs: A literature review. *Work*, 64. pp. 217–227. DOI: https://doi.org/10.3233/WOR-192988

Başağa, H.B., Temel, B.A., Atasoy, M. and Yıldırım, İ. (2018). A study on the effectiveness of occupational health and safety trainings of construction workers in Turkey. *Safety Science,*110. pp. 344–354. DOI: 10.1016/j.ssci.2018.09.002.

Basahel, A.M. (2021). Safety Leadership, Safety Attitudes, Safety Knowledge and Motivation toward Safety-Related Behaviors in Electrical Substation Construction Projects. *International Journal of Environmental Research and Public Health,* 18 (8). p. 4196. DOI: http://dx.doi.org/10.3390/ijerph18084196

Baxter, G. and Sommerville, I. (2011). Socio-technical systems: From design methods to systems engineering. *Interacting with Computers*, 23 (1). pp. 4–17. DOI: https://doi.org/10.1016/j.intcom.2010.07.003

Bayramova, A., Edwards, D.J. and Roberts, C. (2021). The role of blockchain technology in augmenting supply chain resilience to cybercrime. *Buildings.* 11(7). DOI: https://doi.org/10.3390/buildings11070283

Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2021a). Embedding training and competence within an organisation's safety culture: a systematic literature review. In: *Quantity Surveying Research Conference*, Nelson Mandela University, 10th November.

Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2023). Constructs of leading indicators: A synthesis of safety literature. *Journal of Safety Research*, 85. pp. 469–484. DOI: https://doi.org/10.1016/j.jsr.2023.04.015

Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2023a). Enhanced safety in complex socio-technical systems via safety-in-cohesion. *Safety Science* 164, 106176. DOI: https://doi.org/10.1016/j.ssci.2023.106176

Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2024a). Unravelling the Gordian Knot of Leading Indicators. *Safety Science*, 177, 106603. DOI: https://doi.org/10.1016/j.ssci.2024.106603

Bayramova, A., Edwards, D.J., Roberts, C. and Rillie, I. (2024). Uncovering the Genome of Leading Indicators from Lagging Indicators and Normative Documents: A Proof-Of-Concept Study. *Journal of Safety Research*, 91. pp. 230–244. DOI: https://doi.org/10.1016/j.jsr.2024.08.015

Beck-Krala, E. and Klimkiewicz, K. (2016). Occupational safety and health as an element of a complex compensation system evaluation within an organisation. *International Journal of Occupational Safety and Ergonomics,* 22. pp. 523–531. DOI: https://doi.org/10.1080/10803548.2016.1183338

Behie, S.W., Halim, S.Z., Efaw, B., O'Connor, T.M. and Quddus, N. (2020). Guidance to improve the effectiveness of process safety management systems in operating facilities. *Journal of Loss Prevention in the Process Industries,* 68, 104257. DOI: https://doi.org/10.1016/j.jlp.2020.104257

Bell, J. (1993). *Doing your Research Project*. 2nd edn. Buckingham: Open University Press.

Bengtson, V.L., Elder Jr, G.H. and Putney, N.M. (2012). The life course perspective on ageing: Linked lives, timing, and history. *Adult lives: A life course perspective*. pp. 9-17.

Bergh, L.I.V., Ringstad, A.J., Leka, S. and Zwetsloot, G.I.J.M. (2014). Psychosocial risks and hydrocarbon leaks: an exploration of their relationship in the Norwegian oil and gas industry. *Journal of Cleaner Production*, 84, pp. 824–830. DOI: https://doi.org/10.1016/j.jclepro.2013.09.040

Bhandari, S. and Hallowell, M.R. (2017). Emotional engagement in safety training: impact of naturalistic injury simulations on the emotional state of construction workers. *Journal of Construction Engineering and Management,* 143(12). 04017090. DOI: 10.1061/(ASCE)CO.1943-7862.0001405.

Bhandari, S., Hallowell, M.R. and Correll, J. (2019). Making construction safety training interesting: a field-based quasi-experiment to test the relationship between emotional arousal and situational interest among adult learners. *Safety Science*, 117. pp. 58–70. DOI: 10.1016/j.ssci.2019.03.028.

Bhoir, S. and Esmaeili, B. (2015). State-of-the-Art Review of Virtual Reality Environment *Applications in Construction Safety*. (March,17). pp. 457–468. DOI: 10.1061/9780784479070.040.

Biggs, H.C. and Biggs, S.E. (2013). Interlocked projects in safety competency and safety effectiveness indicators in the construction sector. *Safety Science*, 52. pp. 37–42. DOI: http://dx.doi.org/10.1016/j.ssci.2012.03.014

Blokland, P. and Reniers, G. (2019). Measuring (un)safety. A broad understanding and definition of safety, allowing for instant measuring of unsafety. *Chemical Engineering Transactions,* 77. pp. 253–258. DOI: https://doi.org/10.3303/CET1977043

Boadu, E.F., Wang, C.C. and Sunindijo, R.Y. (2020). Characteristics of the Construction Industry in Developing Countries and Its Implications for Health and Safety: An Exploratory Study in Ghana. *International Journal of Environmental Research and Public Health*, 17(11). p. 4110. DOI:10.3390/ijerph17114110.

Bockstaller, C. and Girardin, P. (2003). How to validate environmental indicators. *Agricultural Systems*, 76. pp. 639–653. DOI: https://doi.org/10.1016/S0308-521X(02)00053-7

Boje, C., Guerriero, A., Kubicki, S. and Rezgui, Y. (2020). Towards a semantic Construction Digital Twin: Directions for future research, *Automation in Construction*, 114. DOI: https://doi.org/10.1016/j.autcon.2020.103179

Bortey, L., Edwards, D.J., Roberts, C. and Rillie, I. (2022). A Review of Safety Risk Theories and Models and the Development of a Digital Highway Construction Safety Risk Model. *Digital*, 2. pp. 206–223. DOI: https://doi.org/10.3390/digital2020013

Bortey, L., Edwards, D.J., Shelbourn, M. and Rillie, I. (2021). Development of a proof-of-concept risk model for accident prevention on highways construction, *Quantity Surveying Research Conference*, Nelson Mandela University, 10th November.

Borys, D. (2012). The role of safe work method statements in the Australian construction industry. *Safety Science*, 50 (2). pp. 210–220. DOI: http://dx.doi.org/10.1016/j.ssci.2011.08.010

Brooks, J., McCluskey, S., Turley, E. and King, N. (2015). The Utility of Template Analysis in Qualitative Psychology Research. *Qualitative Research in Psychology*, 12. pp. 202–222. DOI: https://doi.org/10.1080/14780887.2014.955224

Bryman, A. (2012). *Social research methods*. 4th edn. Oxford ; New York, Oxford University Press.

Budzynski, M., Jamroz, K., Kustra, W., Michalski, L. and Gaca, S. (2017). Road Infrastructure Safety Management in Poland. *IOP Conference Series: Materials Science and Engineering* 245. 042066. DOI: https://doi.org/10.1088/1757-899X/245/4/042066.

Busch, C. (2019). Brave new world: can positive developments in safety science and practice also have negative sides? *MATEC Web of Conferences*. 273. 01003. DOI: 10.1051/matecconf/201927301003.

Bust, P., Gibb, A. and Pink, S. (2008). Managing construction health and safety: migrant workers and communicating safety messages. Available from: https://repository.lboro.ac.uk/articles/journal_contribution/Managing_construction_health_and_safety_migrant_workers_and_communicating_safety_messages/9442109/1. [Accessed 16th November 2021].

Cambon, J., Guarnieri, F. and Groeneweg, J. (2006). Towards a new tool for measuring Safety Management Systems performance. In: *2nd Symposium on Resilience Engineering*. Nov, 2006, Juan-les-Pins, France. p. 10. Available from: https://minesparis-psl.hal.science/hal-00637874

Carr, J.A., D'Odorico, P., McGlathery, K.J. and Wiberg, P.L. (2012). Modelling the effects of climate change on eelgrass stability and resilience: future scenarios and leading indicators of collapse. *Marine Ecology Progress Series,* 448. pp. 289–301. DOI: https://doi.org/10.3354/meps09556

Carriço, A., Gomes, A. and Gonçalves, A. (2015). Quantitative Analysis of the Construction Industry Workers' Perception of Risk in Municipalities Surrounding Salvador. *Procedia Manufacturing*, 3. pp. 1846–1853. DOI: http://dx.doi.org/10.1016/j.promfg.2015.07.225

Carrillo-Castrillo, J.A., Trillo-Cabello, A.F. and Rubio-Romero, J.C. (2017). Construction accidents: identification of the main associations between causes, mechanisms and stages of the construction process. *International Journal of Occupational Safety and*

Ergonomics, 23 (2). pp. 240–250. DOI: http://dx.doi.org/10.1080/10803548.2016.1245507

Chan, A.H.S. and Ng, A.W.Y. (2010). Effects of sign characteristics and training methods on safety sign training effectiveness. *Ergonomics,* 53 (11). pp. 1325–1346. DOI: http://dx.doi.org/10.1080/00140139.2010.524251

Chan, A.H.S. and Ng, A.W.Y. (2010a). Investigation of guessability of industrial safety signs: Effects of prospective-user factors and cognitive sign features. *International Journal of Industrial Ergonomics,* 40 (6). pp. 689–697. DOI: http://dx.doi.org/10.1016/j.ergon.2010.05.002

Chan, A.P.C., Javed, A.A., Lyu, S., Hon, C.K.H. and Wong, F.K.W. (2016). Strategies for Improving Safety and Health of Ethnic Minority Construction Workers. *Journal of Construction Engineering and Management*, 142 (9). p. 05016007. DOI: http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001148

Chan, K., Louis, J. and Albert, A. (2020). Incorporating Worker Awareness in the Generation of Hazard Proximity Warnings. *Sensors,* 20 (3). p. 806. DOI: https://doi.org/10.3390/s20030806

Chan, K.L. and Chan, A.H.S. (2011). Understanding industrial safety signs: implications for occupational safety management. *Industrial Management and Data Systems*, 111 (9). pp. 1481–1510. DOI: http://dx.doi.org/10.1108/02635571111182809

Chatzimichailidou, M. and Ma, Y. (2022). Using BIM in the safety risk management of modular construction, *Safety Science*, 154. DOI: https://doi.org/10.1016/j.ssci.2022.105852

Chen, H. and Luo, X. (2019). Exploring the Quantitative Impact of Localization Accuracy on Localization-Based Safety Monitoring's Performance on a Construction Jobsite. *Journal of Computing in Civil Engineering*, 33 (6), p. 04019035. DOI: http://dx.doi.org/10.1061/(ASCE)CP.1943-5487.0000852

Chen, M., Zhang, Y. and Chen, Y. (2019). Development of risk assessment model for civil aviation service providers. In: *2019 5th International Conference on Transportation Information and Safety (ICTIS).* Liverpool, UK. pp. 678–683. DOI: https://doi.org/10.1109/ICTIS.2019.8883728

Chen, Y., McCabe, B. and Hyatt, D. (2017.) Impact of individual resilience and safety climate on safety performance and psychological stress of construction workers: A case study of the Ontario construction industry. *Journal of Safety Research*, 61. pp. 167–176. DOI: http://dx.doi.org/10.1016/j.jsr.2017.02.014

Cheng, Y.-H. (2019). Railway safety climate: a study on organisational development. *International Journal of Occupational Safety and Ergonomics* 25, pp. 200–216. DOI: https://doi.org/10.1080/10803548.2017.1361591

Cherrett, T., Wills, G., Price, J., Maynard, S. and Dror, I.E. (2009). Making training more cognitively effective: making videos interactive. *British Journal of Educational Technology*, 40(6). pp. 1124–1134. DOI: 10.1111/j.1467-8535.2009.00985.x.

Choe, S. and Leite, F. (2020). Transforming inherent safety risk in the construction Industry: A safety risk generation and control model. *Safety Science* 124:104594. DOI: https://doi.org/10.1016/j.ssci.2019.104594.

Choi, B., Ahn, S. and Lee, S. (2017). Role of Social Norms and Social Identifications in Safety Behavior of Construction Workers. I: Theoretical Model of Safety Behaviour under Social Influence. *Journal of Construction Engineering and Management*, 143 (5), p. 04016124. DOI: http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001254

Choi, T.N.Y., Chan, D.W.M. and Chan, A.P.C. (2011). Perceived benefits of applying Pay for Safety Scheme (PFSS) in construction – A factor analysis approach. *Safety Science*, 49 (6). pp. 813–823. DOI: http://dx.doi.org/10.1016/j.ssci.2010.10.004

Choudhry, R.M. (2014). Behaviour-based safety on construction sites: a case study. *Accident Analysis and Prevention*, 70. pp. 14–23. DOI: 10.1016/j.aap.2014.03.007.

Choudhry, R.M. (2015). Achieving Safety and Productivity in Construction Projects. *Journal of Civil Engineering and Management,* 23 (2). pp. 311–318. DOI:10.3846/13923730.2015.1068842.

Chuang, S. and Wears, R.L. (2015). *Strategies to get resilience into everyday clinical work*. In Resilient health care. 2nd edn. CRC Press.

CII (Construction Industry Institute) (2012). Measuring safety performance with active safety leading indicators. 284-1. University of Texas at Austin, Austin, TX.

Clark, T., Foster, L., Bryman, A. and Sloan, L. (2021). *Bryman's Social Research Methods*. 6th edn. Oxford University Press.

Coggins, M.A., Van lente, E., Mccallig, M., Paddan, G. and Moore, K. (2010). Evaluation of Hand-Arm and Whole-Body Vibrations in Construction and Property Management. *The Annals of Occupational Hygiene*, 54 (8), pp. 904–914. DOI: http://dx.doi.org/10.1093/annhyg/meq064

Collis, J. and Hussey, R. (2021). *Business Research: A Practical Guide for Students.* 5th edn. London, United Kingdom, Bloomsbury Publishing Plc.

Conklin, T. (2012). *Pre-accident investigations: an introduction to organizational safety*. Ashgate Publishing

Cooper, M.D. (2020). Temporary removal: the emperor has no clothes: a critique of safety-II. *Safety Science*, (October). 105047. DOI: 10.1016/j.ssci.2020.105047.

Costantino, F., Gravio, G.D., Falegnami, A., Patriarca, R., Tronci, M., Nicola, A.D., Vicoli, G. and Villani, M.L. (2020). Crowd Sensitive Indicators for Proactive Safety Management: A Theoretical Framework. In: *Proceedings of the 30th European Safety and Reliability Conference and 15th Probabilistic Safety Assessment and Management Conference.* Rome, Italy. pp. 1453–1458. DOI: https://doi.org/10.3850/978981148593-0_3928-cd

Costella, M.F., Stanisci, R.B., Martins, J.B., Lantelme, E.M.V. and Pilz, S.E. (2021). Exploring Safety-II in Practice: a Case Study of the Construction Industry. 12 (2), p. 11. DOI: http://dx.doi.org/10.15866/irece.v12i2.19385

Costin, A., Wehle, A. and Adibfar, A. (2019). Leading Indicators-A Conceptual IoT-Based Framework to Produce Active Leading Indicators for Construction Safety. *Safety,* 5 (86). pp. 1-26. DOI: https://doi.org/10.3390/safety5040086

CPCS (2024). Construction Plant Competence Scheme - NOCN Job Cards. Available from: https://www.nocnjobcards.org/CPCS/ [Accessed 07.03.24].

Cuerden, R., Pittman, M., Dodson, E. and Hill, J. (2008). The UK On the Spot Accident Data Collection Study – Phase II Report. Available from: http://worldcat.org/isbn/1904763715

Dai, F., Olorunfemi, A., Peng, W., Cao, D. and Luo, X. (2021). Can mixed reality enhance safety communication on construction sites? An industry perspective. *Safety Science*, 133, p. 105009. DOI: http://dx.doi.org/10.1016/j.ssci.2020.105009

Davahli, M.R., Karwowski, W., Gutierrez, E., Fiok, K., Wróbel, G., Taiar, R. and Ahram, T. (2020). Identification and prediction of human behavior through mining of unstructured textual data. *Symmetry* 12, 1902. DOI: http://dx.doi.org/10.3390/sym12111902

Davies, R., Coole, T. and Smith, A. (2017). Review of Socio-technical Considerations to Ensure Successful Implementation of Industry 4.0. *Procedia Manufacturing*, 11, pp. 1288–1295. DOI: http://dx.doi.org/10.1016/j.promfg.2017.07.256

Davis, M.C., Challenger, R., Jayewardene, D.N.W. and Clegg, C.W. (2014). Advancing socio-technical systems thinking: A call for bravery. *Applied Ergonomics*, 45 (2), pp. 171–180. DOI: http://dx.doi.org/10.1016/j.apergo.2013.02.009

Dekker, S. (2015). *Safety differently: human factors for a new era*. 2nd edn. Boca Raton, FL: CRC Press.

Dekker, S. (2019). *Foundations of Safety Science: A Century of Understanding Accidents and Disasters*. 1st edn. Routledge. DOI: https://doi.org/10.4324/9781351059794

Delatour, G., Laclemence, P., Calcei, D. and Mazri, C. (2014). Safety Performance Indicators: a Questioning Diversity. *Chemical Engineering Transactions*, 36. pp. 55–60. DOI: https://doi.org/10.3303/CET1436010

Demirkesen, S. and Arditi, D. (2015). Construction safety personnel's perceptions of safety training practices. *International Journal of Project Management*, 33 (5). pp. 1160–1169. DOI: http://dx.doi.org/10.1016/j.ijproman.2015.01.007

Denscombe, M. (2021). *The good research guide: research methods for small-scale social research projects*. 7th edn. Open UP study skills. London, England, McGraw Hill.

Dijkers, M.P. (2010). Issues in the Conceptualization and Measurement of Participation: An Overview. *Archives of Physical Medicine and Rehabilitation, Measurement of Participation in Rehabilitation Research*, 91. pp. S5–S16. DOI: https://doi.org/10.1016/j.apmr.2009.10.036

Dingsdag, D.P., Biggs, H.C. and Sheahan, V.L. (2008). Understanding and defining OH&S competency for construction site positions: Worker perceptions. *Safety Science*, 46 (4), pp. 619–633. DOI: http://dx.doi.org/10.1016/j.ssci.2007.06.008

Dixon-Woods, M., (2011). Using framework-based synthesis for conducting reviews of qualitative studies. *BMC Medicine,* 9 (39). DOI: https://doi.org/10.1186/1741-7015939

Duryan, M., Smyth, H., Roberts, A., Rowlinson, S. and Sherratt, F. (2020). Knowledge transfer for occupational health and safety: Cultivating health and safety learning culture in construction firms. *Accident Analysis and Prevention*, 139. p. 105496. DOI: https://doi.org/10.1016/j.aap.2020.105496

Dyreborg, J. (2009). The causal relation between lead and lag indicators. *Safety Science*, 47 (4). pp. 474–475. DOI: http://dx.doi.org/10.1016/j.ssci.2008.07.015

Eaton, G., Song, L. and Eldin, N. (2013). Safety Perception and its Effects on Safety Climate in Industrial Construction. In: *2013 proceedings of the 30th International Symposium on Automation and Robotics in Construction and Mining*; Held in conjunction with the 23rd World Mining Congress. Montreal, Canada. ISBN 978-1-62993-294-1, ISSN 2413-5844, pp. 812-820

Ebrahimi, H., Sattari, F., Lefsrud, L. and Macciotta, R. (2021). Analysis of train derailments and collisions to identify leading causes of loss incidents in rail transport of dangerous goods in Canada. *Journal of Loss Prevention in the Process Industries*,72. 104517. DOI: https://doi.org/10.1016/j.jlp.2021.104517

Edirisinghe, R. and Lingard, H. (2016). Exploring the potential for the use of video to communicate safety information to construction workers: case studies of organizational use. *Construction Management and Economics*, 34 (6). pp. 366–376. DOI: http://dx.doi.org/10.1080/01446193.2016.1200736

Edwards, D. J., Harris, F. C. and McCaffer, R. (2003). Management of off-highway plant and equipment. London: Spon. ISBN 0-415-25127-3 DOI: https://doi.org/10.1201/9781482289152

Edwards, D. J., Pärn, E. A., Sing, C. P. and Thwala, W.D. (2019). Risk of excavators overturning: determining horizontal centrifugal force when slewing freely suspended loads. *Engineering, Construction and Architectural Management*, 26 (3). pp. 479-498. DOI: https://doi.org/10.1108/ECAM-03-2018-0125

Edwards, D.J. and Holt, G.D. (2007). Perceptions of workplace vibration hazards among a small sample of UK construction professionals. *Engineering, Construction and Architectural Management*, 14 (3). pp. 261–276. DOI: http://dx.doi.org/10.1108/09699980710744908

Edwards, D.J. and Holt, G.D. (2008). Construction workers' health and safety knowledge: initial observations on some test-result data. *Journal of Engineering, Design and Technology*, 6 (1). pp. 65–80. DOI: 10.1108/17260530810863343.

Edwards, D.J. and Holt, G.D. (2008). Health and safety issues relating to construction excavators and their attachments. *Engineering, Construction and Architectural Management,* 15 (4). pp. 321–335. DOI: http://dx.doi.org/10.1108/09699980810886838

Edwards, D.J. and Holt, G.D. (2009). Construction plant and equipment management research: thematic review. *Journal of Engineering, Design and Technology*, 7 (2). pp. 186–206. DOI: http://dx.doi.org/10.1108/17260530910974989

Edwards, D.J. and Nicholas, J. (2002). The state of health and safety in the UK construction industry with a focus on plant operators. *Structural Survey*, 20 (2). pp.78–87. DOI: 10.1108/02630800210433855.

Edwards, D.J., Holt, G.D. and Robinson, B. (2002). An artificial intelligence approach for improving plant operator maintenance proficiency. *Journal of Quality in Maintenance Engineering,* 8 (3). pp. 239–252. DOI: http://dx.doi.org/10.1108/13552510210439810

Edwards, D.J., Rillie, I., Chileshe, N., Lai, J., Hosseini, M.R. and Thwala, W.D. (2020). A field survey of hand–arm vibration exposure in the UK utilities sector. *Engineering, Construction and Architectural Management*, 27. pp. 2179–2198 DOI: https://doi.org/10.1108/ECAM-09-2019-0518

Eggerth, D.E., Keller, B.M., Cunningham, T.R. and Flynn, M.A. (2018). Evaluation of toolbox safety training in construction: The impact of narratives. *American Journal of Industrial Medicine*, 61(12). pp. 997–1004. DOI: 10.1002/ajim.22919.

Elbeltagi, E., Hegazy, T. and Eldosouky, A. (2004). Dynamic Layout of Construction Temporary Facilities Considering Safety. *Journal of Construction Engineering and Management,* 130 (4). pp. 534–541. DOI: http://dx.doi.org/10.1061/(ASCE)0733-9364(2004)130:4(534)

El-Rayes, K. and Khalafallah, A. (2005). Trade-off between Safety and Cost in Planning Construction Site Layouts. *Journal of Construction Engineering and Management*, 131 (11). pp. 1186–1195. DOI: http://dx.doi.org/10.1061/(ASCE)07339364(2005)131:11(1186)

Elsebaei, M., Elnawawy, O., Othman, A. and Badawy, M. (2020). Elements of Safety Management System in the Construction Industry and Measuring Safety Performance – A Brief. *IOP Conference Series: Materials Science and Engineering*, Cairo, Egypt. 974 (1). pp. 1-12. DOI:10.1088/1757-899X/974/1/012013

Emery, F.E. and Trist, E.L. (1960). Socio-technical systems. In: Churchman, C.W., Verhulst, M. (Eds.) *Management Science Models and Techniques*, 2. Pergamon, Oxford, UK, pp. 83–97.

Erikson, S.G. (2009). Performance indicators. *Safety Science*, Process Safety Indicators / SRAE 2006 47, 468. DOI: https://doi.org/10.1016/j.ssci.2008.07.024

Erkal, O.E.D., Hallowell, M.R. and Bhandari, S. (2021). Practical Assessment of Potential Predictors of Serious Injuries and Fatalities in Construction. *Journal of Construction Engineering and Management*, 147 (10). p. 04021129. DOI: http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0002146

Esmaeili, B. and Hallowell, M. (2013). Integration of safety risk data with highway construction schedules. *Construction Management and Economics*, 31 (6). pp. 528–541. DOI: http://dx.doi.org/10.1080/01446193.2012.739288

Falahati, M., Karimi, A., Mohammadfam, I., Mazloumi, A., Reza Khanteymoori, A. and Yaseri, M. (2020). Multi-dimensional model for determining the leading performance indicators of safety management systems. *Work*, 67 (4). pp. 959–969. DOI: https://doi.org/10.3233/wor-203346

Falahati, M., Mohammadfam, I., Mazloumi, A., Khanteymoori, A. and Karimi, A. (2017). Development of safety and health leading performance indicators in the phase of construction of a gas refinery plant using Bayesian network and AHP1. *International Journal of Advanced Biotechnology and Research*, 8 (2). pp. 1440–1453. DOI: http://www.bipublication.com/

Fargnoli, M., Minicis, M.D. and Gravio, G.D. (2011). Knowledge Management integration in Occupational Health and Safety systems in the construction industry. *International Journal of Product Development*, 14 (1/2/3/4). p. 165. DOI: http://dx.doi.org/10.1504/IJPD.2011.042298

Fellows, R. and Liu, A. (2022). *Research methods for construction*. 5th edn. Hoboken, NJ, USA: Wiley Blackwell.

Fereday, J. and Muir-Cochrane, E. (2006). Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development. *International Journal of Qualitative Methods*, 5. pp. 80–92. DOI: https://doi.org/10.1177/160940690600500107

Flannery, J., Ajayi, S.O. and Oyegoke, A.S. (2021). Alcohol and substance misuse in the construction industry. *International Journal of Occupational Safety and Ergonomics*, 27 (2). pp. 472–487. DOI: https://doi.org/10.1080/10803548.2019.1601376

Floyd, H.L. (2021). A Balanced Scorecard of Leading and Lagging Indicators for Your Electrical Safety Program. In: *2021 IEEE IAS Electrical Safety Workshop (ESW)*. pp. 1–4. DOI: https://doi.org/10.1109/ESW45993.2021.9461566

Forteza, F.J., Carretero-Gómez, J.M., Sesé, A., Forteza, F.J., Carretero-Gómez, J.M. and Sesé, A. (2020). Safety in the construction industry: accidents and precursors. *Revista de la construcción*, 19. pp. 271–281. DOI: https://doi.org/10.7764/rdlc.19.2.271

Fox, N.J. (2008). Post-positivism. In: Given, L.M. (ed.) *The SAGE Encyclopaedia of Qualitative Research Methods*. London: Sage.

Gale, N.K., Heath, G., Cameron, E., Rashid, S. and Redwood, S. (2013). Using the framework method for the analysis of qualitative data in multi-disciplinary health research. *BMC Medical Research Methodology* 13, 117. DOI: https://doi.org/10.1186/1471228813117

Gantt, R. (2017). Safety Differently: A New View of Safety Excellence. *ASSE Professional Development Conference and Exposition*. p. ASSE-17-590. Denver, Colorado, USA, June 2017.

Gao, Y., Gonzalez, V.A. and Yiu, T.W. (2019). The effectiveness of traditional tools and computer-aided technologies for health and safety training in the construction sector: a systematic review. *Computers and Education,* 138. pp. 101–115. DOI: 10.1016/j.compedu.2019.05.003.

Gardiner, E. (2022). Evaluating the quality of WHS disclosures by ASX100 companies: Is mandatory WHS reporting necessary? *Safety Science* 153, 105798. DOI: https://doi.org/10.1016/j.ssci.2022.105798

Ghasemi, F., Mohammadfam, I., Soltanian, A.R., Mahmoudi, S. and Zarei, E. (2015). Surprising Incentive: An Instrument for Promoting Safety Performance of Construction Employees. *Safety and Health at Work*, 6 (3), pp. 227–232. DOI: http://dx.doi.org/10.1016/j.shaw.2015.02.006

Gillham, B. (2000). *Case study research methods*. Real world research. London, Continuum.

Givehchi, S., Hemmativaghef, E. and Hoveidi, H. (2017). Association between safety leading indicators and safety climate levels. *Journal of Safety Research*, 62. pp. 23–32. DOI: https://doi.org/10.1016/j.jsr.2017.05.003

Glendon, A.I. (2009). Process hazards and analogies: Response to Andrew Hopkins. *Safety Science*, Process Safety Indicators / SRAE 2006 47, pp. 476–477. DOI: http://dx.doi.org/10.1016/j.ssci.2008.07.025

Goh, Y.M. and Askar Ali, M.J. (2016). A hybrid simulation approach for integrating safety behaviour into construction planning: An earthmoving case study. *Accident Analysis and Prevention*, 93. pp. 310–318. DOI: http://dx.doi.org/10.1016/j.aap.2015.09.015

Goldenhar, L.M., Schwatka, N. and Johnson, S.K. (2019). Leadership skills for strengthening jobsite safety climate. *Journal of Safety Research*, 70. pp. 263–271. DOI: 10.1016/j.jsr.2019.04.011.

Golovina, O., Teizer, J. and Pradhananga, N. (2016). Heat map generation for predictive safety planning: Preventing struck-by and near miss interactions between workers-on-foot and construction equipment. *Automation in Construction*, 71. pp. 99–115. DOI: http://dx.doi.org/10.1016/j.autcon.2016.03.008

Golzad, H., Teimoory, T., Mousavi, J. Bayramova, A. and Edwards, D.J. (2023). Mental Health Causation in the Construction Industry: A Systematic Review Employing Psychological Safety Climate Model, Buildings, 13 (10). DOI: https://doi.org/10.3390/buildings13102442

Gong, S., Gao, X., Li, Z. and Chen, L. (2021). Developing a Dynamic Supervision Mechanism to Improve Construction Safety Investment Supervision Efficiency in China:

Theoretical Simulation of Evolutionary Game Process. *International Journal of Environmental Research and Public Health*, 18 (7), p. 3594. DOI: http://dx.doi.org/10.3390/ijerph18073594

Goodbrand, P.T., Deng, C., Turner, N., Uggerslev, K.L., Gordon, J., Martin, K. and McClelland, C.R. (2021). Exploring safety knowledge sharing among experienced and novice workers. *Journal of Safety Research*, p. S0022437521001110. DOI: http://dx.doi.org/10.1016/j.jsr.2021.08.013

Goulding, J., Nadim, W., Petridis, P. and Alshawi, M. (2012). Construction industry offsite production: A virtual reality interactive training environment prototype. *Advanced Engineering Informatics*, 26 (1). pp. 103–116. DOI: http://dx.doi.org/10.1016/j.aei.2011.09.004

Grabowski, M., Ayyalasomayajula, P., Merrick, J. and McCafferty, D. (2007a). Accident precursors and safety nets: leading indicators of tanker operations safety. *Maritime Policy & Management,* 34. pp. 405–425. DOI: https://doi.org/10.1080/03088830701585084

Grabowski, M., Ayyalasomayajula, P., Merrick, J., Harrald, J.R. and Roberts, K. (2007). Leading indicators of safety in virtual organisations. *Safety Science*, 45. pp. 1013–1043. DOI: https://doi.org/10.1016/j.ssci.2006.09.007

Grabowski, M., You, Z., Song, H., Wang, H. and Merrick, J.R.W. (2010). Sailing on Friday: Developing the Link Between Safety Culture and Performance in Safety-Critical Systems. In: *IEEE Transactions on Systems, Man and Cybernetics - Part A: Systems and Humans,* 40. pp. 263–284. DOI: https://doi.org/10.1109/TSMCA.2009.2035300

Grecco, C.H. dos-S, Vidal, M.C.R., Cosenza, C.A.N., dos Santos, I.J.A.L. and de Carvalho, P.V.R. (2014). Safety culture assessment: A fuzzy model for improving safety performance in a radioactive installation. *Progress in Nuclear Energy,* 70. pp. 71–83. DOI: https://doi.org/10.1016/j.pnucene.2013.08.001

Greig, M.A., Village, J., Salustri, F.A. and Neumann, W.P. (2023). Examining human factors and ergonomics aspects in a manufacturing organisation's metrics system: measuring up to stakeholder needs. *Ergonomics.* pp. 1–16. DOI: https://doi.org/10.1080/00140139.2023.2168065

Grenn, M.W., Sarkani, S. and Mazzuchi, T. (2014). The Requirements Entropy Framework in Systems Engineering. *Systems Engineering*, 17. pp. 462–478. DOI: https://doi.org/10.1111/sys.21283

Greuter, S., Wakefield, R., Tepe, S., Peterson, J.F., Boukamp, F., d'Amazing, K., Quigley, K., van der Waerden, R., Harris, T. and Goschnick, T. (2012). Designing a game for occupational health and safety in the construction industry. In: *Proceedings of the 8th Australasian Conference on Interactive Entertainment Playing the System - IE '12*. The 8th Australasian Conference. Auckland, New Zealand, ACM Press, pp. 1–8. DOI: http://dx.doi.org/10.1145/2336727.2336740

Guo, B. H. W. and Yiu, T. W. (2016). Developing leading indicators to monitor the safety conditions of construction projects. *Journal of Management in Engineering*, 32 (1). pp.1–14. DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000376.

Guo, B.H.W., Goh, Y.M. and Le Xin Wong, K. (2018). A system dynamics view of a behaviour-based safety program in the construction industry. *Safety Science*, 104. pp. 202–215. DOI: http://dx.doi.org/10.1016/j.ssci.2018.01.014

Guo, B.H.W., Yiu, T.W. and González, V.A. (2015). Identifying behaviour patterns of construction safety using system archetypes. *Accident Analysis and Prevention*, 80. pp. 125–141. DOI: org/10.1016/j.aap.2015.04.008.

Guo, B.H.W., Yiu, T.W., González, V.A. and Goh, Y.M. (2017). Using a Pressure-State-Practice Model to Develop Safety Leading Indicators for Construction Projects. *Journal of Construction Engineering and Management* 143, 04016092. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0001218

Guo, H., Li, H., Chan, G. and Skitmore, M. (2012). Using game technologies to improve the safety of construction plant operations. *Accident Analysis and Prevention*, 48. pp. 204–213. DOI: 10.1016/j.aap.2011.06.002.

Haas, E.J. and Yorio, P. (2016). Exploring the state of health and safety management system performance measurement in mining organizations. *Safety Science*, 83. pp. 48–58. DOI: https://doi.org/10.1016/j.ssci.2015.11.009

Haavik, T.K., Antonsen, S., Rosness, R. and Hale, A. (2019). HRO and RE: A pragmatic perspective. *Safety Science*, 117. pp. 479–489. DOI: https://doi.org/10.1016/j.ssci.2016.08.010

Haghani, M., Bliemer, M.C.J., Goerlandt, F. and Li, J. (2020). The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review. *Safety Science*, 129. DOI: https://doi.org/10.1016/j.ssci.2020.104806

Haji, M. and Behnam, B. (2023). An automated BIM and system dynamics tool for assessing safety leading indicators in construction projects. *International Journal of Building Pathology and Adaptation.* DOI: https://doi.org/10.1108/IJBPA-05-2022-0072

Haji, M., Behnam, B., Sebt, M.H., Ardeshir, A. and Katooziani, A. (2022). BIM-Based Safety Leading Indicators Measurement Tool for Construction Sites. *International Journal of Civil Engineering*, 21. pp. 265–282. DOI:https://doi.org/10.1007/s40999-022-00754-9

Hallowell, M.R., Bhandari, S. and Alruqi, W. (2020). Methods of safety prediction: analysis and integration of risk assessment, leading indicators, precursor analysis, and safety climate. *Construction Management and Economics*, 38. pp. 308–321. DOI: https://doi.org/10.1080/01446193.2019.1598566

Hallowell, M.R., Hinze, J.W., Baud, K.C. and Wehle, A. (2013). Proactive Construction Safety Control: Measuring, Monitoring, and Responding to Safety Leading Indicators. *Journal of Construction Engineering and Management*, 139 (10). p. 04013010. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000730

Ham, D.-H. and Park, J. (2020). Use of a big data analysis technique for extracting HRA data from event investigation reports based on the Safety-II concept. *Reliability Engineering & System Safety*, 194. p. 106232. DOI: http://dx.doi.org/10.1016/j.ress.2018.07.033

Han, Y., Feng, Z., Zhang, J., Jin, R. and Aboagye-Nimo, E. (2019). Employees' Safety Perceptions of Site Hazard and Accident Scenes. *Journal of Construction Engineering and Management*, 145(1). 04018117. DOI: https://doi.org/10.1061/(ASCE)CO.19437862.0001590.

Härmä, M., Kompier, M.A. and Vahtera, J. (2006). Work-related stress and health risks, mechanisms and countermeasures. *Scandinavian Journal of Work, Environment and Health*, 32. pp. 413–419. DOI: https://doi.org/10.5271/sjweh.1047

Harms-Ringdahl, L. (2009). Dimensions in safety indicators. *Safety Science*, Process Safety Indicators/SRAE 2006 (47), pp. 481–482. DOI: https://doi.org/10.1016/j.ssci.2008.07.019

Harvey, E.J., Pinder, J.A., Haslam, R.A., Dainty, A.R.J. and Gibb, A.G. (2020). The use of actor-based immersive health and safety inductions: Lessons from the Thames Tideway Tunnel megaproject. *Applied Ergonomics*, 82. 102955. DOI: 10.1016/j.apergo.2019.102955.

Hasanzadeh, S., Esmaeili, B. and Dodd, M.D. (2017). Impact of Construction Workers' Hazard Identification Skills on Their Visual Attention. *Journal of Construction Engineering* *and Management*, 143. 04017070. DOI: https://doi.org/10.1061/(ASCE)CO.19437862.0001373

Hasanzadeh, S., Polys, N.F. and de la Garza, J.M. (2020). Presence, Mixed Reality, and Risk-Taking Behaviour: A Study in Safety Interventions. *IEEE Transactions on Visualization and Computer Graphics,* 26(5). pp. 2115–2125. DOI: 10.1109/TVCG.2020.2973055.

Hassan, J. and Khan, F. (2012). Risk-based asset integrity indicators. *Journal of Loss Prevention in the Process Industries*, 25. pp. 544–554. DOI: https://doi.org/10.1016/j.jlp .2011.12.011

He, C., Jia, G., McCabe, B., Chen, Y. and Sun, J. (2019). Impact of psychological capital on construction worker safety behaviour: communication competence as a mediator. *Journal of Safety Research*, 71. pp. 231–241. DOI: 10.1016/j.jsr.2019.09.007

Health and Safety Executive (2006). *Developing process safety indicators: a step-by-step guide for chemical and major hazard industries*, UK Health and Safety Executive.

Health and Safety Executive (2013). Reporting Accidents and Incidents at Work: A Brief Guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 (RIDDOR) (pack of 10). *Industry Guidance Leaflet Series*. HSE Books.

Hewa Alankarage, S.M., Chileshe, N., Samaraweera, A., Rameezdeen, R. and Edwards, D.J. (2022). Organisational BIM maturity models and their applications: A Systematic Literature Review, *International Journal of Architectural Engineering and Design Management*. DOI: https://doi.org/10.1080/17452007.2022.2068496

Hinze, J. and Hallowell, M. (2013). Going beyond zero using safety leading indicators. *Construction Industry Institute*, 284-11, based at The University of Texas at Austin, Austin, TX.

Hinze, J., Thurman, S. and Wehle, A. (2013). Leading indicators of construction safety performance. *Safety Science* 51, pp. 23–28. DOI: https://doi.org/10.1016/j.ssci.2012.05.016

Hobson, P., Emery, D., Brown, L., Bashford, R. and Gill, J. (2014). People–plant interface training: targeting an industry fatal risk. *Proceedings of the Institution of Civil Engineers - Civil Engineering*, 167 (3). pp. 138–144. DOI: https://doi.org/10.1680/cien.14.00010

Hollnagel, E., Wears, R.L. and Braithwaite, J. (2015). From Safety-I to Safety-II: A White Paper. *The Resilient Health Care Net*: Published simultaneously by the University of Southern Denmark, University of Florida, USA and Macquarie University, Australia.

Hollnagel, E., Woods, D.D. and Leveson, N. (2017). *Resilience Engineering: Concepts and Precepts*. London, CRC Press.

Holt, G.D. and Edwards, D.J. (2013). Inter-organizational interactions among a sample of plant-reliant construction sub-contractors. *Engineering Project Organization Journal*, 3(2). pp. 100–115. DOI: 10.1080/21573727.2012.760156.

Hopkins, A. (2009). Thinking About Process Safety Indicators. *Safety Science,* 47. DOI: https://doi.org/10.1016/j.ssci.2007.12.006

Hovden, J., Albrechtsen, E. and Herrera, I.A. (2010). Is there a need for new theories, models and approaches to occupational accident prevention? *Safety Science*, 48 (8). pp. 950–956. DOI: http://dx.doi.org/10.1016/j.ssci.2009.06.002

Hoz-Torres, M.L., Aguilar, A.J., Ruiz, D.P. and Martínez-Aires, M.D. (2021). GIS-based framework to manage Whole-Body Vibration exposure. *Automation in Construction*, 131. p. 103885. DOI: http://dx.doi.org/10.1016/j.autcon.2021.103885

HSE (2009). *Health and Safety at Work etc Act 1974 – legislation explained*. Available from: https://www.hse.gov.uk/legislation/hswa.htm. [Accessed 28th April 2022].

HSE (2023a). Health and Safety Executive- Statistics - Index of tables. Available from: https://www.hse.gov.uk/statistics/tables/index.htm#riddor [Accessed 07.03.24].

HSE (2023). Health and Safety Executive- Statistics - Work-related fatal injuries in Great Britain. Available from: https://www.hse.gov.uk/statistics/fatals.htm [Accessed 07.03.24].

Huang, Y.-H., Sung, C.-Y., Chen, W.T. and Liu, S.-S. (2021). Relationships between Social Support, Social Status Perception, Social Identity, Work Stress, and Safety Behaviour of Construction Site Management Personnel. *Sustainability*, 13 (6). p. 3184. DOI: http://dx.doi.org/10.3390/su13063184

Hudson, P.T.W. (2009). Process indicators: Managing safety by the numbers. *Safety Science*, Process Safety Indicators / SRAE 2006 47. pp. 483–485. DOI: https://doi.org/10.1016/j.ssci.2008.07.037

Hughes, P. and Ferrett, E. (2020). *Introduction to Health and Safety at Work: for the NEBOSH National General Certificate in Occupational Health and Safety*. 7th edn. London: Routledge. DOI:10.4324/9781003039075.

Hussain, R., Pedro, A., Lee, D.Y., Pham, H.C. and Park, C.S. (2020). Impact of safety training and interventions on training-transfer: targeting migrant construction workers. *International Journal of Occupational Safety and Ergonomics*, 26 (2). pp. 272–284. DOI: http://dx.doi.org/10.1080/10803548.2018.1465671

Irfan, M., Thaheem, M.J., Gabriel, H.F., Malik, M.S.A. and Nasir, A.R. (2019). Effect of stakeholder's conflicts on project constraints: a tale of the construction industry. *International Journal of Conflict Management*, 30 (4). pp. 538–565. DOI: http://dx.doi.org/10.1108/IJCMA-04-2019-0074

Ismail, S., Che Ibrahim, C.K.I., Belayutham, S. and Mohammad, M.Z. (2021). Analysis of attributes critical to the designer's prevention through design competence in construction: the case of Malaysia. *Architectural Engineering and Design Management*, (April,7). pp. 1–19. DOI: 10.1080/17452007.2021.1910926.

Ismail, Z.-A. (2019). Optimising the safety of road transport workers on IBS building construction projects: a review. *Social Responsibility Journal,* 15 (6). pp. 837–851. DOI: 10.1108/SRJ-09-2018-0240

Jabareen, Y. (2009). Building a Conceptual Framework: Philosophy, Definitions, and Procedure. *International Journal of Qualitative Methods*, 8 (4). pp. 49–62. DOI: http://dx.doi.org/10.1177/160940690900800406

Jackson, J.E., Sanquist, T., Campbell, J., Lee, E.-B. and Van Dongen, H.P.A. (2013). Fatigue in Highway Construction Workers: Risks and Countermeasures in Rapid Renewal Project Schedules. *Transportation Research Record*, 2347 (1). pp. 11–18. DOI: https://doi.org/10.3141/2347-02.

Jafari, P., Mohamed, E., Pereira, E., Kang, S.-C. and Abourizk, S. (2019). Leading Safety Indicators: Application of Machine Learning for Safety Performance Measurement. In: *36th International Symposium on Automation and Robotics in Construction*, Banff, AB, Canada. DOI: https://doi.org/10.22260/ISARC2019/0067

Jazayeri, E. and Dadi, G.B. (2017). Construction Safety Management Systems and Methods of Safety Performance Measurement: A Review. *Journal of Safety Engineering*, 6 (2). pp. 15–28. DOI: 10.5923/j.safety.20170602.01

Jeelani, I., Albert, A. and Gambatese, J.A. (2017) a. Why Do Construction Hazards Remain Unrecognized at the Work Interface? *Journal of Construction Engineering and Management,* 143 (5), p. 04016128. DOI: http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001274

Jeelani, I., Albert, A., Azevedo, R. and Jaselskis, E.J. (2017). Development and testing of a personalized hazard-recognition training intervention. *Journal of Construction Engineering and Management*, 143(5). 04016120. DOI:10.1061/(ASCE)CO.1943-7862.0001256.

Jeelani, I., Albert, A., Han, K. and Azevedo, R. (2019). Are Visual Search Patterns Predictive of Hazard Recognition Performance? Empirical Investigation Using Eye-Tracking Technology. *Journal of Construction Engineering and Management*, 145 (1). p. 04018115. DOI: http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001589

Jeelani, I., Han, K. and Albert, A. (2020). Development of virtual reality and stereo-panoramic environments for construction safety training. *Engineering, Construction and Architectural Management*, 27(8). pp.1853–1876. DOI: 10.1108/ECAM-07-20190391.

Jemai, H., Badri, A. and Ben Fredj, N. (2021). State of the Art and Challenges for Occupational Health and Safety Performance Evaluation Tools. *Safety,* 7. 64. DOI: https://doi.org/10.3390/safety7030064

Jeschke, K.C., Kines, P., Rasmussen, L., Andersen, L.P.S., Dyreborg, J., Ajslev, J., Kabel, A. and Jensen, E. (2017). Process evaluation of a toolbox-training program for construction foremen in Denmark. *Safety Science*, 94. pp. 152–160. DOI: 10.1016/j.ssci.2017.01.010.

Jin, R., Zou, P.X.W., Piroozfar, P., Wood, H., Yang, Y., Yan, L. and Han, Y. (2019). A science mapping approach-based review of construction safety research, *Safety Science*, 113. pp. 285-297. DOI: https://doi.org/10.1016/j.ssci.2018.12.006

Jitwasinkul, B. and Hadikusumo, B.H.W. (2011). Identification of important organisational factors influencing safety work behaviours in construction projects. *Journal of Civil Engineering and Management,* 17 (4). pp. 520–528. DOI: http://dx.doi.org/10.3846/13923730.2011.604538

Joe, J.C. (2011). Comparing Safe Vs. At-Risk Behavioural Data to Predict Accidents. *7th International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human Machine Interface Technology*. Las Vegas, NV,11/07/2010,11/11/2010. DOI: https://digital.library.unt.edu/ark:/67531/metadc831953/.

Johnsen, S.O.O., Okstad, E., Aas, A.L. and Skramstad, T. (2012). Proactive Indicators to Control Risks in Operations of Oil and Gas Fields. *SPE Economics & Management*, 4. pp. 90–105. DOI: https://doi.org/10.2118/126560-PA

Jones, C.E.L., Phipps, D.L. and Ashcroft, D.M. (2018). Understanding procedural violations using Safety-I and Safety-II: the case of community pharmacies. *Safety Science*, 105. pp.114–120. DOI: 10.1016/j.ssci.2018.02.002.

Jones, P., Comfort, D. and Hillier, D. (2006). Corporate social responsibility and the UK construction industry. *Journal of Corporate Real Estate*, 8 (3). pp. 134–150. DOI: http://dx.doi.org/10.1108/14630010610711757

Jones, R., Sharkey, S., Smithson, J., Ford, T., Emmens, T., Hewis, E., Sheaves, B. and Owens, C. (2011). Using Metrics to Describe the Participative Stances of Members Within Discussion Forums. *Journal of Medical Internet Research*, 13. e1591. DOI: https://doi.org/10.2196/jmir.1591

Kanchana, S., Sivaprakash, P. and Joseph, S. (2015). Studies on Labour Safety in Construction Sites. *The Scientific World Journal*, 2015, pp. 1–6. DOI: http://dx.doi.org/10.1155/2015/590810

Karakhan, A.A., Rajendran, S., Gambatese, J. and Nnaji, C. (2018). Measuring and Evaluating Safety Maturity of Construction Contractors: Multicriteria Decision-Making Approach. *Journal of Construction Engineering and Management*, 144. 04018054. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0001503

Karimi, A., Abbasi, M., Zokaei, M. and Falahati, M. (2021). Development of leading indicators for the assessment of occupational health performance using Reason's Swiss cheese model. *Journal of Education and Health Promotion* 10, 158. DOI: https://doi.org/10.4103/jehp.jehp_1326_20

Kava, C.M., Parker, E.A., Baquero, B., Curry, S.J., Gilbert, P.A., Sauder, M. and Sewell, D.K. (2019). Associations Between Organizational Culture, Workplace Health Climate, and Employee Smoking at Smaller Workplaces. *Tobacco Use Insights*, 12. 1179173X19835842. DOI: https://doi.org/10.1177/1179173X19835842

Kazan, E., Usmen, M., Desruisseaux, B., Kaya, S. and Seyoum, M. (2019). Training Effectiveness Analysis of OSHA Silica and Excavation Standards for Construction. *Ancona*, Italy. pp. 33–42. DOI: 10.2495/SAFE190041.

Kenan, S. and Kadri, S. (2014). Process safety leading indicators survey–February 2013: Centre for chemical process safety–white paper. *Process Safety Progress* 33 (3). pp. 247–258. DOI: https://doi.org/10.1002/prs.11654

Kent, C., Laslo, E. and Rafaeli, S. (2016). Interactivity in online discussions and learning outcomes. *Computers & Education*, 97. pp. 116–128. DOI: https://doi.org/10.1016/j.compedu.2016.03.002

Kerur, B.R., Rajeshwari, T., Siddanna, R. and Kumar, A.S. (2013). Implication and hazard of radiation level in the building materials. *Acta Geophysica*, 61. pp. 1046–1056. DOI: https://doi.org/10.2478/s11600-013-0109-1

Khan, F., Abunada, H., John, D. and Benmosbah, T. (2009). Development of risk-based process safety indicators. *Process Safety Progress*, 29. pp. 133–143. DOI: https://doi.org/10.1002/prs.10354

Kim, J.Y., Lee, D.S., Kim, J.D. and Kim, G.H. (2021). Priority of Accident Cause Based on Tower Crane Type for the Realization of Sustainable Management at Korean Construction Sites. *Sustainability,* 13 (1). p. 242. DOI: http://dx.doi.org/10.3390/su13010242

Kincl, L.D., Hess, J.A., Weeks, D.L., Vaughan, A. and Anton, D. (2020). Efficacy of text messaging apprentices to reinforce ergonomics and safety voice training. *Journal of Safety Research*, 74. pp. 35–43. DOI: 10.1016/j.jsr.2020.04.007.

Kiwan, M. and Berezkin, D.V. (2021). Disaster Recognition System for Risk Management in Socio-Technical Systems. In: *2021 International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT)*. Bhilai, India, pp. 1–7. Available from: https://ieeexplore.ieee.org/document/9392625/. [Accessed 14th December 2021].

Knijff, P., Allford, L. and Schmelzer, P. (2013). Process safety leading indicators—a perspective from Europe. *Process Safety Progress,* 32, pp. 332–336. DOI: https://doi.org/10.1002/prs.11641

Kongsvik, T., Almklov, P. and Fenstad, J. (2010). Organisational safety indicators: Some conceptual considerations and a supplementary qualitative approach. *Safety Science*, 48 (10). pp. 1402–1411. DOI: http://dx.doi.org/10.1016/j.ssci.2010.05.016

Kraft, K. (2019). Language policies and linguistic competence: new speakers in the Norwegian construction industry. *Language Policy*, 18 (4). pp. 573–591. DOI: https://doi.org/10.1007/s10993-018-9502-6

Kumar, C.N., Ramaswamy, K., Sakthivel, M. and Arularasu, M. (2013). Implementation of safety education program for material handling equipment in construction sites and its effectiveness analysis using T-test. *International Journal of Applied Environmental Sciences*, 8. pp. 1961–1969. DOI: http://www.ripublication.com/ijaes.htm

Kumar, C.N., Sakthivel, M., Elangovan, R.K. and Arularasu, M. (2015). Analysis of Material Handling Safety in Construction Sites and Countermeasures for Effective Enhancement. *The Scientific World Journal*, 2015. pp. 1–7. DOI: http://dx.doi.org/10.1155/2015/742084

Kwon, Y.-T., Son, S., Kim, S., Ha, S.-G. and Son, K. (2019). Worker safety perception analysis of South Korean construction sites. *International Journal of Occupational Safety and Ergonomics*, 27 (2). pp. 488–496. DOI: http://dx.doi.org/10.1080/10803548.2019.1603709

Laitinen, H., Vuorinen, M., Simola, A. and Yrjänheikki, E. (2013). Observation-based proactive OHS outcome indicators – Validity of the Elmeri+ method. *Safety Science*, 54. pp. 69–79. DOI: https://doi.org/10.1016/j.ssci.2012.11.005

LANTRA (2014). Leading awarding body for land-based and environmental training. Available from: https://www.lantra.co.uk/ [Accessed 07.03.24].

Lauková, A., Focková, V. and Pogány Simonová, M. (2020). Enterococcus mundtii Isolated from Slovak Raw Goat Milk and Its Bacteriocinogenic Potential. *International Journal of Environmental Research and Public Health*, 17, 9504. DOI: https://doi.org/10.3390/ijerph17249504

Le Coze, J. (2009). A taxonomy issue. *Safety Science*, Process Safety Indicators / SRAE 2006 47, 490. DOI: https://doi.org/10.1016/j.ssci.2008.07.027

Le Grange, L. and Mika, C. (2018). What Is Indigenous Philosophy and What Are Its Implications for Education, In: Smeyers, P. (Ed.). *International Handbook of Philosophy of Education*, Springer International Handbooks of Education. Springer International Publishing, Cham, pp. 499–515. DOI: https://doi.org/10.1007/978331972761-5_41

Lee, H.-S., Kim, H., Park, M., Ai Lin Teo, E. and Lee, K.-P. (2012). Construction Risk Assessment Using Site Influence Factors. *Journal of Computing in Civil Engineering*, 26 (3). pp. 319–330. DOI: http://dx.doi.org/10.1061/(ASCE)CP.1943-5487.0000146

Lee, K.-P., Lee, H.-S., Park, M., Kim, H. and Han, S. (2014). A Real-Time Location-Based Construction Labour Safety Management System. *Journal of Civil Engineering and Management,* 20 (5). pp. 724–736. DOI: http://dx.doi.org/10.3846/13923730.2013.802728

Lee, S.S., Park, S. and Seo, J. (2018). Utilization analysis methodology for fleet telematics of heavy earthwork equipment. *Automation in Construction*, 92. pp. 59–67. DOI: http://dx.doi.org/10.1016/j.autcon.2018.02.035

Levers, M.-J.D. (2013). Philosophical Paradigms, Grounded Theory, and Perspectives on Emergence. *SAGE Open*, 3 (4). pp. 1-6. DOI: http://dx.doi.org/10.1177/2158244013517243

Leveson, N.G. (2015). A systems approach to risk management through leading safety indicators. *Reliability Engineering and System Safety*, 136. pp. 17–34. DOI: https://doi.org/10.1016/j.ress.2014.10.008

Leveson, N.G. (2020). Safety III: A Systems Approach to Safety and Resilience. *MIT Partnership for Systems Approaches to Safety and Security (PSASS).* Available from: https://psas.scripts.mit.edu/home/nancys-white-papers/ [Accessed 01.03.23].

Leveson, N.G. (2014). Using STAMP to develop leading indicators. *Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft fur Informatik* (GI). pp. 597–600.

Leveson, N.G. (2020) a. A more powerful approach to process safety. Department of Aeronautics and Astronautics Massachusetts Institute of Technology. Nancy's White Papers | *MIT Partnership for Systems Approaches to Safety and Security (PSASS*), Available from: https://psas.scripts.mit.edu/home/nancys-white-papers/ [Accessed 07.03.24].

Li, H., Chan, G. and Skitmore, M. (2013). Integrating real time positioning systems to improve blind lifting and loading crane operations. *Construction Management and Economics*, 31 (6). pp. 596–605. DOI: http://dx.doi.org/10.1080/01446193.2012.756144

Li, H., Chan, G., Huang, T., Skitmore, M., Tao, T.Y.E., Luo, E., Chung, J., Chan, X.S. and Li, Y.F. (2015). Chirp-spread-spectrum-based real time location system for construction safety management: A case study. *Automation in Construction*, 55. pp. 58–65. DOI: http://dx.doi.org/10.1016/j.autcon.2015.03.024

Li, H., Yang, X., Skitmore, M., Wang, F. and Forsythe, P. (2017). Automated classification of construction site hazard zones by crowd-sourced integrated density maps. *Automation in Construction,* 81. pp. 328–339. DOI: http://dx.doi.org/10.1016/j.autcon.2017.04.007

Li, J., Pang, M., Smith, J., Pawliuk, C. and Pike, I. (2020). In Search of Concrete Outcomes—A Systematic Review on the Effectiveness of Educational Interventions on Reducing Acute Occupational Injuries. *International Journal of Environmental Research and Public Health*, 17 (18), p. 6874. DOI: http://dx.doi.org/10.3390/ijerph17186874

Li, X., Song, Z., Wang, T., Zheng, Y. and Ning, X. (2016). Health impacts of construction noise on workers: A quantitative assessment model based on exposure measurement. *Journal of Cleaner Production*, 135. pp. 721–731. DOI: https://doi.org/10.1016/j.jclepro.2016.06.100

Li, Y. and Liu, C. (2012). Integrating field data and 3D simulation for tower crane activity monitoring and alarming. *Automation in Construction*, 27. pp. 111–119. DOI: http://dx.doi.org/10.1016/j.autcon.2012.05.003

Lingard, H. (2001). The effect of first aid training on objective safety behaviour in Australian small business construction firms. *Construction Management and Economics*, 19 (6). pp. 611–618. DOI: http://dx.doi.org/10.1080/01446190110049820

Lingard, H. and Wakefield, R. (2011). The development and testing of a hierarchical measure of project OHS performance. *Engineering, Construction and Architectural Management*, 18 (1). pp. 30-49. DOI: http://dx.doi.org/10.1108/09699981111098676

Lingard, H., Hallowell, M., Salas, R. and Pirzadeh, P. (2017). Leading or lagging? Temporal analysis of safety indicators on a large infrastructure construction project. *Safety Science,* 91, pp. 206–220. DOI: https://doi.org/10.1016/j.ssci.2016.08.020

Lingard, Wakefield, R. and Cashin, P. (2011). The development and testing of a hierarchical measure of project OHS performance. *Engineering, Construction and Architectural Management*, 18(1). pp. 30–49. DOI: https://doi.org/10.1108/09699981111098676

Liu, K.-H., Tessler, J., Murphy, L.A., Chang, C.-C. and Dennerlein, J.T. (2018). The Gap Between Tools and Best Practice: An Analysis of Safety Prequalification Surveys in the Construction Industry. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, 28 (4). pp. 683–703. DOI: http://dx.doi.org/10.1177/1048291118813583

Liu, Y., Yi, T.-H. and Xu, Z.-J. (2013). Safety Early Warning Research for Highway Construction Based on Case-Based Reasoning and Variable Fuzzy Sets. *The Scientific World Journal*, 2013, pp. 1–10. DOI: http://dx.doi.org/10.1155/2013/178954

Lofquist, E.A. (2010). The art of measuring nothing: The paradox of measuring safety in a changing civil aviation industry using traditional safety metrics. *Safety Science*, 48. pp. 1520–1529. DOI: https://doi.org/10.1016/j.ssci.2010.05.006

Loosemore, M. and Cheung, E. (2015). Implementing systems thinking to manage risk in public private partnership projects. *International Journal of Project Management*, 33. pp. 1325–1334. DOI: https://doi.org/10.1016/j.ijproman.2015.02.005

Loudoun, R. and Markwell, K. (2017). Energy Drink Consumption in the Australian Construction Industry: A Risky New Trend? *Journal of Construction Engineering and Management*, 143 (8). p. 04017039. DOI: http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001339

Lu, M. and Hasan, M. (2018). Developing a Cost-Effective and Adaptive Training Program to Enhance Construction Safety in Tunnelling Construction. In: Construction Research Congress 2018. New Orleans, Louisiana: *American Society of Civil Engineers*. pp. 635–644. DOI: 10.1061/9780784481288.062.

Lu, M., Cheung, C.M., Li, H. and Hsu, S. C. (2016). Understanding the relationship between safety investment and safety performance of construction projects through agent-based modeling. *Accident Analysis and Prevention*, 94. pp. 8–17. DOI: http://dx.doi.org/10.1016/j.aap.2016.05.014

Lyu, S., Hon, C.K.H., Chan, A.P.C., Javed, A.A., Zhang, R.P. and Wong, F.K.W. (2020). An exploratory study of safety communication networks of ethnic minority crews in the Hong Kong construction industry. *Engineering, Construction and Architectural Management,* 28 (4). pp. 1156–1175. DOI: http://dx.doi.org/10.1108/ECAM0720190368

Manjourides, J. and Dennerlein, J.T. (2019). Testing the associations between leading and lagging indicators in a contractor safety pre-qualification database. *American Journal of Industrial Medicine*, 62 (4). pp. 317–324. DOI: http://dx.doi.org/10.1002/ajim.22951

Manu, P., Ankrah, N., Proverbs, D. and Suresh, S. (2014). The health and safety impact of construction project features. *Engineering, Construction and Architectural Management,* 21 (1). pp. 65–93. DOI: http://dx.doi.org/10.1108/ECAM-07-2012-0070

Marks, E.D., Wetherford, J.E., Teizer, J. and Yabuki, N. (2013). Potential of Leading Indicator Data Collection and Analysis for Proximity Detection and Alert Technology in Construction. *Proceedings of 30th ISARC* Montreal, Canada. pp. 1029–1036. DOI: https://doi.org/10.22260/ISARC2013/0113

Mashi, M.S., Subramaniam, C. and Johari, J. (2020). The effect of management commitment to safety, and safety communication and feedback on safety behavior of nurses: the moderating role of consideration of future safety consequences. *The International Journal of Human Resource Management* 31, pp. 2565–2594. DOI: https://doi.org/10.1080/09585192.2018.1454491

Maynard, S., Jones, W., Filtness, A., Gibb, A. and Haslam, R. (2020). Going underground: fatigue and sleepiness in tunnelling operations. Available from: https://repository.lboro.ac.uk/articles/journal_contribution/Going_underground_fatigue_and_sleepiness_in_tunnelling_operations/12764189/1. [Accessed 16th November 2021].

Mazzetti, G., Valente, E., Guglielmi, D. and Vignoli, M. (2020). Safety Doesn't Happen by Accident: A Longitudinal Investigation on the Antecedents of Safety Behavior. *International Journal of Environmental Research and Public Health*, 17 (12). p. 4332. DOI: https://doi.org/10.3390%2Fijerph17124332

Mearns, K. (2009). From reactive to proactive – Can LPIs deliver? *Safety Science*, 47 (4). pp. 491–492. DOI: http://dx.doi.org/10.1016/j.ssci.2008.07.028

Mearns, K., Whitaker, S.M. and Flin, R. (2003). Safety climate, safety management practice and safety performance in offshore environments. *Safety science*, 41 (8). pp. 641–680. DOI: http://dx.doi.org/10.1016/S0925-7535(02)00011-5

Meng, X. and Chan, A.H.S. (2020). Demographic influences on safety consciousness and safety citizenship behaviour of construction workers. *Safety Science*, 129. p. 104835. DOI: http://dx.doi.org/10.1016/j.ssci.2020.104835

Mengolini, A. and Debarberis, L. (2008). Effectiveness evaluation methodology for safety processes to enhance organisational culture in hazardous installations. *Journal of Hazardous Materials*, 155. pp. 243–252. DOI: https://doi.org/10.1016/j.jhazmat.2007.11.078

Merton, R. K. (1967). *On Theoretical Sociology*. New York: Free Press.

Mikkelsen, K.L., Spangenberg, S. and Kines, P. (2010). Safety walkarounds predict injury risk and reduce injury rates in the construction industry. *American Journal of Industrial Medicine*, 53. pp. 601-607. DOI: http://dx.doi.org/10.1002/ajim.20803

Minchin, R.E., Glagola, C.R., Guo, K. and Languell, J.L. (2006). Case for Drug Testing of Construction Workers. *Journal of Management in Engineering*, 22 (1). pp. 43–50. DOI: http://dx.doi.org/10.1061/(ASCE)0742-597X(2006)22:1(43)

Mitchell, R. (1999). OHS performance measurement in the construction industry: development of positive performance indicators. Available from: https://www.safeworkaustralia.gov.au/system/files/documents/1702/ohsperformance measurement_construction_ppis_1996_archivepdf.pdf

Mohammadi, A. and Tavakolan, M. (2020). Identifying safety archetypes of construction workers using system dynamics and content analysis. *Safety Science*, 129. p. 104831. DOI: http://dx.doi.org/10.1016/j.ssci.2020.104831

Mohammadi, A., Tavakolan, M. and Khosravi, Y. (2018). Factors influencing safety performance on construction projects: A review. *Safety Science*, 109. pp. 382-397. DOI: https://doi.org/10.1016/j.ssci.2018.06.017

Mohd, N.I. and Ali, K.N. (2014). Addressing the Needs of Gaming Approach in Hazard Identification Training. In: *2014 International Conference on Teaching and Learning in Computing and Engineering*. Kuching, Malaysia. pp. 212–215. DOI: 10.1109/LaTiCE.2014.48.

Mollo, L.G., Emuze, F. and Smallwood, J. (2019). Improving occupational health and safety (OHS) in construction using Training-Within-Industry method. *Journal of Financial Management of Property and Construction*, 24 (3). pp. 655–671. DOI: http://dx.doi.org/10.1108/JFMPC-12-2018-0072

Moore, L.L., Wurzelbacher, S.J., Chen, I.-C., Lampl, M.P. and Naber, S.J. (2022). Reliability and validity of an employer-completed safety hazard and management assessment questionnaire. *Journal of Safety Research*, 81. pp. 283–296. DOI: https://doi.org/10.1016/j.jsr.2022.03.005

Mousavi, S.S., Cudney, E.A. and Trucco, P. (2018). Towards a Framework for Steering Safety Performance: A Review of the Literature on Leading Indicators, In: Arezes, P. (Ed.), *Advances in Safety Management and Human Factors.* Springer International Publishing. pp. 195–204. DOI: https://doi.org/10.1007/978-3-319-60525-8_21

Müngen, U. and Gürcanli, G.E. (2005). Fatal traffic accidents in the Turkish construction industry. *Safety Science,* 43 (5–6). pp. 299–322. DOI: https://doi.org/10.1016/j.ssci.2005. 06.002.

Murray, P. (2015). Process Safety Management - What's Missing? In: *All Days. SPE Offshore Europe Conference and Exhibition*. Aberdeen, Scotland, UK, SPE, p. SPE-175511-MS.

Namian, M., Albert, A., Zuluaga, C.M. and Behm, M. (2016). Role of safety training: impact on hazard recognition and safety risk perception. *Journal of Construction Engineering and Management,* 142(12). 04016073. DOI:10.1061/(ASCE)CO.1943-7862.0001198.

Neamat, S.D.S. (2019). A Comparative Study of Safety Leading and Lagging Indicators Measuring Project Safety Performance. *Advances in Science, Technology and Engineering Systems Journal*, 4 (6). pp. 306–312. DOI: https://dx.doi.org/10.25046/aj040639

Neitzel, R.L., Seixas, N.S. and Ren, K.K. (2001). A Review of Crane Safety in the Construction Industry. *Applied Occupational and Environmental Hygiene*, 16 (12). pp. 1106–1117. DOI: http://dx.doi.org/10.1080/10473220127411

Nemeth, C.P. and Herrera, I. (2015). Building change: Resilience Engineering after ten years. *Reliability Engineering and System Safety*, 141. pp. 1–4. DOI: http://dx.doi.org/10.1016/j.ress.2015.04.006

Ni, G., Zhu, Y., Zhang, Z., Qiao, Y., Li, H., Xu, N., Deng, Y., Yuan, Z. and Wang, W. (2020). Influencing Mechanism of Job Satisfaction on Safety Behavior of New Generation of Construction Workers Based on Chinese Context: The Mediating Roles of Work Engagement and Safety Knowledge Sharing. *International Journal of Environmental*

Research and Public Health, 17 (22). p. 8361. DOI: http://dx.doi.org/10.3390/ijerph17228361

NPORS (2024). National Plant Operators Registration Scheme- The UK's leading accrediting and registration body NPORS. Available from: https://npors.com/ [Accessed 07.03.24].

Nykänen, M., Puro, V., Tiikkaja, M., Kannisto, H., Lantto, E., Simpura, F., Uusitalo, J. and Lukander, K. (2020). Implementing and evaluating novel safety training methods for construction sector workers: Results of a randomized controlled trial. *Journal of Safety Research*, 75. pp. 205–221. DOI: 10.1016/j.jsr.2020.09.015.

O'Connor, P., Cowan, S. and Alton, J. (2010). A Comparison of Leading and Lagging Indicators of Safety in Naval Aviation. *Aviation, Space, and Environmental Medicine*, 81 (7). pp. 677–682. DOI: http://dx.doi.org/10.3357/ASEM.2734.2010

Øien, K., Utne, I.B. and Herrera, I.A. (2011). Building Safety indicators: Part 1 – Theoretical foundation. *Safety Science*, 49 (2). pp. 148–161. DOI: http://dx.doi.org/10.1016/j.ssci.2010.05.012

Okorie, V.N. and Musonda, I. (2018) An investigation on supervisor's ability and competency to conduct construction site health and safety induction training in Nigeria. *International Journal of Construction Management,* 20 (5). pp. 357–366. DOI: http://dx.doi.org/10.1080/15623599.2018.1531808

Oliveira, P. and Pais, R. (2018). Study of the Influence of Training in Occupational Safety and Health in the Human Factors of the Construction Sector. In: Arezes, P. ed. *Advances in Safety Management and Human Factors*, Advances in Intelligent Systems and Computing. Cham, Springer International Publishing. pp. 186–194. DOI: https://doi.org/10.1007/978-3-319-60525-8_20

Olivencia, E., Lopez del Puerto, C., Perdomo, J. and Gonzalez-Quevedo, A. (2017). Developing and Assessing a Safety Training Module to Reduce the Risk of Cave-ins in the Construction Industry. In: *2017 ASEE Annual Conference and Exposition Proceedings.* Columbus, Ohio: ASEE Conferences. 28141. DOI: 10.18260/1-2--28141.

Omidi, L., Dolatabad, K.M. and Pilbeam, C. (2023). Differences in perception of the importance of process safety indicators between experts in Iran and the West. *Journal of Safety Research,* 84. pp. 261–272. DOI: https://doi.org/10.1016/j.jsr.2022.11.002

Oswald, D. (2020). Safety indicators: questioning the quantitative dominance. *Construction Management and Economics*, 38. pp. 11–17. DOI: https://doi.org/10.1080/01446193.2019.1605184

Oswald, D., Ahiaga-Dagbui, D.D., Sherratt, F. and Smith, S.D. (2020). An industry structured for unsafety? An exploration of the cost-safety conundrum in construction project delivery, *Safety Science*, 122. p. 104535. DOI: 10.1016/j.ssci.2019.104535.

Oswald, D., Sherratt, F., Smith, S.D. and Hallowell, M.R. (2018) a. Exploring safety management challenges for multi-national construction workforces: a UK case study. *Construction Management and Economics*, 36 (5). pp. 291–301. DOI: http://dx.doi.org/10.1080/01446193.2017.1390242

Oswald, D., Zhang, R.P., Lingard, H., Pirzadeh, P. and Le, T. (2018). The use and abuse of safety indicators in construction. *Engineering, Construction and Architectural Management*, 25. pp. 1188–1209. DOI: https://doi.org/10.1108/ECAM-07-2017-0121

Paletz, S.B.F. and Schunn, C.D. (2009). A new metric for assessing group level participation in fluid teams, In: *2009 Atlanta Conference on Science and Innovation Policy.* Presented at the 2009 Atlanta Conference on Science and Innovation Policy. pp. 1–6. DOI: https://doi.org/10.1109/ACSIP.2009.5367817

Patriarca, R., Bergström, J., Di Gravio, G. and Costantino, F. (2018). Resilience engineering: Current status of the research and future challenges. *Safety Science*, 102. pp. 79–100. DOI: https://doi.org/10.1016/j.ssci.2017.10.005

Patriarca, R., Falegnami, A., De Nicola, A., Villani, M.L. and Paltrinieri, N. (2019). Serious games for industrial safety: An approach for developing resilience early warning indicators. *Safety Science,* 118. pp. 316–331. DOI: https://doi.org/10.1016/j.ssci.2019.05.031

Patterson, M. and Deutsch, E.S. (2015). Safety-I, Safety-II and Resilience Engineering. *Current Problems in Paediatric and Adolescent Health Care*, 45(12). pp. 382–389. DOI: 10.1016/j.cppeds.2015.10.001.

Peñaloza, G.A., Torres Formoso, C. and Abreu Saurin, T. (2021). A resilience engineering-based framework for assessing safety performance measurement systems: A study in the construction industry. *Safety Science,* 142, 105364. DOI: https://doi.org/10.1016/j.ssci.2021.105364

Pereira, E., Ahn, S., Han, S. and Abourizk, S. (2020). Finding Causal Paths between Safety Management System Factors and Accident Precursors. *Journal of Management in Engineering*, 36. 04019049. DOI: https://doi.org/10.1061/(ASCE)ME.19435479.0000738

Pérez-Alonso, J., Gómez-Galán, M., Agüera-Puntas, M., Sánchez-Hermosilla, J. and Callejón-Ferre, Á.-J. (2021). Approach for Assessing the Prevalence of Psychosocial Risks of

Workers in the Greenhouse Construction Industry in South-Eastern Spain. *International Journal of Environmental Research and Public Health*, 18 (9). p. 4753. DOI: https://doi.org/10.3390/ijerph18094753

Perlman, A., Sacks, R. and Barak, R. (2014). Hazard recognition and risk perception in construction. *Safety Science*, 64. pp. 22–31. DOI: 10.1016/j.ssci.2013.11.019.

Pettinger, C.B. (2013). Predicting, Preventing and Eliminating: The 4 Safety Truths from your Inspections, Audits and Observations. DOI: ASSE-13-686

Pham, K.-T., Vu, D.-N., Hong, P.L.H. and Park, C. (2020). 4D-BIM-Based Workspace Planning for Temporary Safety Facilities in Construction SMEs. *International Journal of Environmental Research and Public Health*, 17 (10). p. 3403. DOI: http://dx.doi.org/10.3390/ijerph17103403

Podgórski, D. (2015). Measuring operational performance of OSH management system – A demonstration of AHP-based selection of leading key performance indicators. *Safety Science*, 73. pp. 146–166. DOI: http://dx.doi.org/10.1016/j.ssci.2014.11.018

Poh, C.Q.X., Ubeynarayana, C.U. and Goh, Y.M. (2018). Safety leading indicators for construction sites: A machine learning approach. *Automation in Construction*, 93. pp. 375–386. DOI: https://doi.org/10.1016/j.autcon.2018.03.022

Posillico, J., Edwards, D.J., Roberts, C. and Shelbourn, M. (2021). Curriculum development in the higher education literature: A synthesis focusing on construction management programmes. *Industry and Higher Education*, 36 (4). DOI: https://doi.org/10.1177/09504222211044894

Prakash, S.B., Kirkham, R., Nanda, A. and Coleman, S. (2023). Exploring the complexity of highways infrastructure programmes in the United Kingdom through systems thinking. *Project Leadership and Society*, 4. 100081. DOI: https://doi.org/10.1016/j.plas.2023.100081

Price, J., Wills, G., Dror, I.E., Cherrett, T. and Maynard, S. (2008). Risk Assessment Education: Utilizing Interactive Video for Teaching Health and Safety. In: *2008 Eighth IEEE International Conference on Advanced Learning Technologies.* Santander, Cantabria, Spain: IEEE. pp. 727–729. DOI: 10.1109/ICALT.2008.245.

PUWER (1998). The Provision and Use of Work Equipment Regulations 1998-Part II-Regulation, 9. Available from: https://www.legislation.gov.uk/uksi/1998/2306/regulation/9/made [Accessed 07.03.24].

Qi, R., Prem, K.P., Ng, D., Rana, M.A., Yun, G. and Mannan, M.S. (2012). Challenges and needs for process safety in the new millennium. *Process Safety and Environmental Protection,* 90. pp. 91–100. DOI: https://doi.org/10.1016/j.psep.2011.08.002

Qiao, W., Liu, Y., Ma, X. and Lan, H. (2021). Cognitive Gap and Correlation of Safety-I and Safety-II: A Case of Maritime Shipping Safety Management. *Sustainability*, 13 (10). p. 5509. DOI: http://dx.doi.org/10.3390/su13105509

Quaigrain, R.A. and Issa, M.H. (2021). Comparative analysis of leading and lagging indicators of construction disability management performance: an exploratory study. *International Journal of Construction Management*, 23. pp. 1205–1213. DOI: https://doi.org/10.1080/15623599.2021.1963921

Quigley, D., Freshwater, D., Alnajjar, M., Siegel, D., Kuntamukkula, M. and Simmons, F. (2012). Use of chemical information database accuracy measurements as leading indicators. *Journal of Chemical Health and Safety*, 19. pp. 18–22. DOI: https://doi.org/10.1016/j.jchas.2011.08.002

Raben, D.C., Bogh, S.B., Viskum, B., Mikkelsen, K.L. and Hollnagel, E. (2018). Learn from what goes right: A demonstration of a new systematic method for identification of leading indicators in healthcare. *Reliability Engineering & System Safety*, 169. pp. 187–198. DOI: https://doi.org/10.1016/j.ress.2017.08.019

Rabianski, J.S. (2003). Primary and secondary data: Concepts, concerns, errors, and issues. *The Appraisal Journal,* 71, pp. 43–55. Available from: https://www-proquest-com.bcu.idm.oclc.org/scholarly-journals/primary-secondary-data-concepts-concerns-errors/docview/199981547/se-2?accountid=10749

Raviv, G. and Shapira, A. (2018). Systematic approach to crane-related near-miss analysis in the construction industry. *International Journal of Construction Management*, 18 (4). pp. 310–320. DOI: http://dx.doi.org/10.1080/15623599.2017.1382067

Raviv, G., Fishbain, B. and Shapira, A. (2017). Analyzing risk factors in crane-related near-miss and accident reports. *Safety Science*, 91, pp. 192–205. DOI: http://dx.doi.org/10.1016/j.ssci.2016.08.022

Raviv, G., Shapira, A. and Fishbain, B. (2017) a. AHP-based analysis of the risk potential of safety incidents: Case study of cranes in the construction industry. *Safety Science*, 91, pp. 298–309. DOI: http://dx.doi.org/10.1016/j.ssci.2016.08.027

Rawlinson, F. and Farrell, P. (2010). UK construction industry site health and safety management: An examination of promotional web material as an indicator of current direction. *Construction Innovation*, 10 (4). pp. 435–446. DOI: http://dx.doi.org/10.1108/14714171011083597

Raza, S.A. (2021). Managing ethical requirements elicitation of complex socio-technical systems with critical systems thinking: A case of course-timetabling project. *Technology in Society*, 66. 101626. DOI: https://doi.org/10.1016/j.techsoc.2021.101626

Read, G.J.M., Shorrock, S., Walker, G.H. and Salmon, P.M. (2021). State of science: evolving perspectives on 'human error.' *Ergonomics,* 64, pp. 1091–1114. DOI: https://doi.org/10.1080/00140139.2021.1953615

Reiman, A., Pedersen, L.M., Väyrynen, S., Airaksinen, O., Sormunen, E. and Räsänen, T. (2020). Multi-organisational approach to safety training: the case of a Finnish Safety Training Park. *Construction Management and Economics*, 38 (7). pp. 659–672. DOI: 10.1080/01446193.2019.1675893.

Reiman, A., Pedersen, L.M., Väyrynen, S., Sormunen, E., Airaksinen, O., Haapasalo, H. and Räsänen, T. (2017). Safety Training Parks – Cooperative Contribution to Safety and Health Trainings. *International Journal of Construction Education and Research*, 15 (1). pp. 19–41. DOI: http://dx.doi.org/10.1080/15578771.2017.1325793

Reiman, T. and Pietikäinen, E. (2012). Leading indicators of system safety – Monitoring and driving the organizational safety potential. *Safety Science*, 50 (10). pp. 1993–2000. DOI: https://doi.org/10.1016/j.ssci.2011.07.015

Rhodes, D.H., Valerdi, R. and Roedler, G.J. (2009). Systems engineering leading indicators for assessing program and technical effectiveness. *Systems Engineering*, 12. pp. 21–35. DOI: https://doi.org/10.1002/sys.20105

Riascos, C.E.M., Ensslin, S.R. and Merino, E.A.D. (2021). Development of performance indicators for Occupational Health and Safety: a constructivist multicriteria approach for PPE. *Production* 31. e20200106. DOI: https://doi.org/10.1590/01036513.20200106

Riaz, Z., Edwards, D.J., Holt, G.D. and Thorpe, T. (2011). Data flow analysis of plant and equipment health and safety management. *Journal of Engineering, Design and Technology*, 9 (2). pp. 178–203. DOI: http://dx.doi.org/10.1108/17260531111151069

Roberts, C.J. and Edwards, D.J. (2022). Post-occupancy evaluation: Identifying and mitigating implementation barriers to reduce environmental impact. *Journal of Cleaner Production* 374, 133957. DOI: https://doi.org/10.1016/j.jclepro.2022.133957

Robson, C. and McCartan, K. (2016). *Real world research: a resource for users of social research methods in applied settings*. 4th edn. Chichester, England: Wiley.

Robson, L.S., Ibrahim, S., Hogg-Johnson, S., Steenstra, I.A., Van Eerd, D. and Amick, B.C. (2017). Developing leading indicators from OHS management audit data: Determining the measurement properties of audit data from the field. *Journal of Safety Research*, 61. pp. 93–103. DOI: https://doi.org/10.1016/j.jsr.2017.02.008

Rowlinson, S. and Jia, Y.A. (2015). Construction accident causality: An institutional analysis of heat illness incidents on site. *Safety Science*, 78, pp. 179–189. DOI: https://doi.org/10.1016/j.ssci.2015.04.021

Rozenfeld, O., Sacks, R. and Rosenfeld, Y. (2009). 'CHASTE': construction hazard assessment with spatial and temporal exposure. *Construction Management and Economics*, 27 (7). pp. 625–638. DOI: http://dx.doi.org/10.1080/01446190903002771

Sadeghi, S., Soltanmohammadlou, N. and Rahnamayiezekavat, P. (2021). A systematic review of scholarly works addressing crane safety requirements. *Safety Science*, 133. p. 105002. DOI: http://dx.doi.org/10.1016/j.ssci.2020.105002

Sadeghpour, F. and Andayesh, M. (2015). The constructs of site layout modelling: an overview. *Canadian Journal of Civil Engineering*, 42 (3). pp. 199–212. DOI: http://dx.doi.org/10.1139/cjce-2014-0303

Salas, R. and Hallowell, M. (2016). Predictive Validity of Safety Leading Indicators: Empirical Assessment in the Oil and Gas Sector. *Journal of Construction Engineering and Management,* 142. 04016052. DOI: https://doi.org/10.1061/(ASCE)CO.19437862.0001167

Salguero-Caparrós, F., Pardo-Ferreira, M.C., Martínez-Rojas, M. and Rubio-Romero, J.C. (2020). Management of legal compliance in occupational health and safety. A literature review. *Safety Science*, 121. pp. 111–118. DOI: https://doi.org/10.1016/j.ssci.2019.08.033

Salmon, P.M., Hulme, A., Walker, G.H., Waterson, P. and Stanton, N.A. (2022). Towards a unified model of accident causation: refining and validating the systems thinking safety tenets. *Ergonomics,* 66. pp. 644–657. DOI: https://doi.org/10.1080/00140139.2022.2107709

Salvendy, G. (2012). *Handbook of Human Factors and Ergonomics*. John Wiley & Sons, Inc. 4th edn. Hoboken, New Jersey. DOI: 10.1002/9781118131350

Samuel, R. and Das, B. (2015). Well Integrity as Performance Metrics in Deepwater Drilling. In: *Offshore Technology Conference*, *OnePetro*. Houston, Texas, USA. DOI: https://doi.org/10.4043/25766-MS

Santos, L., Haddad, A. and Luquetti, S. I. (2019). Process safety leading indicators in oil storage and pipelines: Building a panel of indicators. *Chemical Engineering Transactions*, 77. pp. 73–78. DOI: https://doi.org/10.3303/CET1977013.

Sapeciay, Z., Wilkinson, S., Costello, S.B. and Adnan, H. (2019). Building Organisational Resilience for the Construction Industry: Strategic Resilience Indicators. *IOP Conference Series: Earth and Environmental Science* 385, 012068. DOI: https://doi.org/10.1088/1755-1315/385/1/012068

Saqib, N. and Siddiqi, M. T. (2008). Aggregation of safety performance indicators to higher-level indicators. *Reliability Engineering & System Safety*, 93 (2). pp. 307–315. DOI: http://dx.doi.org/10.1016/j.ress.2006.10.028

Sarkar, S. and Maiti, J. (2020). Machine learning in occupational accident analysis: A review using science mapping approach with citation network analysis. *Safety Science*, 131, 104900. DOI: https://doi.org/10.1016/j.ssci.2020.104900

Saunders, M. N. K., Lewis, P. and Thornhill, A. (2019). *Research methods for business students*. 8th edn. Harlow, England: Pearson. Available from: https://www.pearson.com/nl/en_NL/higher-education/subject-catalogue/business-and-management/Research-methods-for-business-students-8e-saunders.html

Sauni, R., Toivio, P., Esko, T., Pääkkönen, R. and Uitti, J. (2015). Effective information campaign for management of exposure to hand–arm vibration in the metal and construction industries. *International Journal of Occupational Safety and Ergonomics*, 21 (2). pp. 158–165. DOI: http://dx.doi.org/10.1080/10803548.2015.1029287

Schmitz, P., Reniers, G., Swuste, P. and van Nunen, K. (2021). Predicting major hazard accidents in the process industry based on organizational factors: A practical, qualitative approach. *Process Safety and Environmental Protection*, 148, pp. 1268–1278. DOI: http://dx.doi.org/10.1016/j.psep.2021.02.040

Schwabe, K., Teizer, J. and König, M. (2019). Applying rule-based model-checking to construction site layout planning tasks. *Automation in Construction*, 97. pp. 205–219. DOI: http://dx.doi.org/10.1016/j.autcon.2018.10.012

Schwatka, N.V., Goldenhar, L.M., Johnson, S.K., Beldon, M.A., Tessler, J., Dennerlein, J.T., Fullen, M. and Trieu, H. (2019). A training intervention to improve frontline construction leaders' safety leadership practices and overall jobsite safety climate. *Journal of Safety Research,* 70. pp. 253–262. DOI: 10.1016/j.jsr.2019.04.010.

Schwatka, N.V., Hecker, S. and Goldenhar, L.M. (2016). Defining and Measuring Safety Climate: A Review of the Construction Industry Literature. *The Annals of Occupational Hygiene,* 60. pp. 537–550. DOI: https://doi.org/10.1093/annhyg/mew020

Shafiq, M.T. and Afzal, M. (2020). Potential of Virtual Design Construction Technologies to Improve Job-Site Safety in Gulf Corporation Council. *Sustainability,* 12 (9). p. 3826. DOI: http://dx.doi.org/10.3390/su12093826

Shaikh, A.Y., Osei-Kyei, R. and Hardie, M. (2020). A critical analysis of safety performance indicators in construction. *International Journal of Building Pathology and Adaptation* 39. pp. 547–580. DOI: https://doi.org/10.1108/IJBPA-03-2020-0018

Shea, T., De Cieri, H., Donohue, R., Cooper, B. and Sheehan, C. (2016). Leading indicators of occupational health and safety: An employee and workplace level validation study. *Safety Science*, 85. pp. 293–304. DOI: https://doi.org/10.1016/j.ssci.2016.01.015

Sheehan, C., Donohue, R., Shea, T., Cooper, B. and Cieri, H.D. (2016). Leading and lagging indicators of occupational health and safety: The moderating role of safety leadership. *Accident Analysis & Prevention*, 92. pp. 130–138. DOI: http://dx.doi.org/10.1016/j.aap.2016.03.018

Shendell, D.G., Milich, L.J., Apostolico, A.A., Patti, A.A. and Kelly, S. (2017). Comparing Online and In-Person Delivery Formats of the OSHA 10-Hour General Industry Health and Safety Training for Young Workers. NEW SOLUTIONS: *A Journal of Environmental and Occupational Health Policy,* 27(1). pp. 92–106. DOI: 10.1177/1048291117697109.

Sherratt, F. (2014). Exploring 'Zero Target' safety programmes in the UK construction industry. *Construction Management and Economics*, 32 (7–8). pp. 737–748. DOI: http://dx.doi.org/10.1080/01446193.2014.894248

Sherratt, F., Farrell, P. and Noble, R. (2013). UK construction site safety: discourses of enforcement and engagement. *Construction Management and Economics*, 31 (6). pp. 623–635. DOI: http://dx.doi.org/10.1080/01446193.2012.747689

Shrestha, S., Morshed, S. A., Pradhananga, N. and Lv, X. (2020). Leveraging accident investigation reports as leading indicators of construction safety using text classification. *American Society of Civil Engineers*, pp. 490–498. DOI: https://doi.org/10.1061/9780784482872.053

Sinelnikov, S., Inouye, J. and Kerper, S. (2015). Using leading indicators to measure occupational health and safety performance. *Safety Science,* 72. pp. 240–248. DOI: https://doi.org/10.1016/j.ssci.2014.09.010

Sipilä, J., Auerkari, P., Holmström, S. and Vela, I. (2014). Early Warning Indicators for Challenges in Underground Coal Storage. *Risk Analysis* 34, pp. 2089–2097. DOI: https://doi.org/10.1111/risa.12273

Smith, D.N., Baldrey, S., Holm, C., Gordon-Smith, E. and Barrett, W. (2023). Integration of Circular Economy Approaches into a Major Infrastructure Project Case Study National Highways' A303 Circular Economy Pathfinder Project. *Circular Economy and Sustainability*, 3. pp. 1793–1818. DOI: https://doi.org/10.1007/s43615-022-00219-0

Soltanzadeh, A., Mohammadfam, I., Moghimbeigi, A. and Ghiasvand, R. (2016). Key factors contributing to accident severity rate in construction industry in Iran: a regression modelling approach. *Archives of Industrial Hygiene and Toxicology,* 67 (1), pp. 47–53. DOI: http://dx.doi.org/10.1515/aiht-2016-67-2687

Sparer, E.H., Herrick, R.F. and Dennerlein, J.T. (2015). Development of a Safety Communication and Recognition Program for Construction. *Journal of Environmental and Occupational Health Policy*, 25 (1). pp. 42–58. DOI: http://dx.doi.org/10.1177/1048291115569025

Sparks, A., Ingram, H. and Phillips, S. (2009). Advanced entry adult apprenticeship training scheme: a case study. *Education and Training*, 51(3). pp. 190–202. DOI: 10.1108/00400910910960722.

Stauffer, T. and Chastain-Knight, D. (2021). Do not let your safe operating limits leave you S-O-L (out of luck). *Process Safety Progress*, 40 (1). p. e12163. DOI: http://dx.doi.org/10.1002/prs.12163

Sujan, M.A., Furniss, D., Anderson, J., Braithwaite, J. and Hollnagel, E. (2019). Resilient health care as the basis for teaching patient safety – a Safety-II critique of the World Health Organisation patient safety curriculum. *Safety Science*, 118. pp. 15–21. DOI: 10.1016/j.ssci.2019.04.046.

Sultana, S., Andersen, B.S. and Haugen, S. (2019). Identifying safety indicators for safety performance measurement using a system engineering approach. *Process Safety and Environmental Protection* 128, pp. 107–120. DOI: https://doi.org/10.1016/j.psep.2019.05.047

Sun, J., Liu, C. and Yuan, H. (2019). Evaluation of Risk Management Maturity: Measurable Proactive Indicators Suitable for Chinese Small and Medium-Sized Chemical Enterprises. *IOP Conference Series: Earth and Environmental Science* 242, 042006. DOI: https://doi.org/10.1088/1755-1315/242/4/042006

Swallow, M. and Zulu, S. (2019). Benefits and Barriers to the Adoption of 4D Modeling for Site Health and Safety Management. *Frontiers in Built Environment*, 4. p. 86. DOI: http://dx.doi.org/10.3389/fbuil.2018.00086

Swuste, P. (2013). A 'normal accident' with a tower crane? An accident analysis conducted by the Dutch Safety Board. *Safety Science*, 57. pp. 276–282. DOI: https://doi.org/10.1016/j.ssci.2013.03.002

Swuste, P., Nunen, K. van, Schmitz, P. and Reniers, G. (2019). Process safety indicators, how solid is the concept? *Chemical Engineering Transactions*, 77. pp. 85–90. DOI: https://doi.org/10.3303/CET1977015

Swuste, P., Theunissen, J., Schmitz, P., Reniers, G. and Blokland, P. (2016). Process safety indicators, a review of literature. *Journal of Loss Prevention in the Process Industries*, 40. pp. 162–173. DOI: dx.doi.org/10.1016/j.jlp.2015.12.020

Talebi, E., Rogers, W.P., Morgan, T. and Drews, F.A. (2021). Modeling Mine Workforce Fatigue: Finding Leading Indicators of Fatigue in Operational Data Sets. *Minerals*, 11. 621. DOI: https://doi.org/10.3390/min11060621

Tamim, N., Karlsen, G., van Loopik, G. and Pettigrew, J. (2020). Preventing the Next Big Well Control Event – A Leading Indicators Approach. In: *the SPE Annual Technical Conference and Exhibition*, OnePetro. DOI: https://doi.org/10.2118/201373-MS

Tamim, N., Laboureur, D.M., Hasan, A.R. and Mannan, M.S. (2019). Developing leading indicators-based decision support algorithms and probabilistic models using Bayesian network to predict kicks while drilling. *Process Safety and Environmental Protection,* 121. pp. 239–246. DOI: https://doi.org/10.1016/j.psep.2018.10.021

Tamim, N., Laboureur, D.M., Mentzer, R.A., Hasan, A.R. and Mannan, M.S. (2017). A framework for developing leading indicators for offshore drillwell blowout incidents. *Process Safety and Environmental Protection,* 106. pp. 256–262. DOI: https://doi.org/10.1016/j.psep.2017.01.005

Tang, K.H.D., Md Dawal, S.Z. and Olugu, E.U. (2018). A review of the offshore oil and gas safety indices. *Safety Science*, 109. pp. 344–352. DOI: https://doi.org/10.1016/j.ssci.2018.06.018

Tang, S., Golparvar-Fard, M., Naphade, M. and Gopalakrishna, M.M. (2020). Video-Based Motion Trajectory Forecasting Method for Proactive Construction Safety Monitoring Systems. *Journal of Computing in Civil Engineering* 34, 04020041. DOI: https://doi.org/10.1061/(ASCE)CP.1943-5487.0000923

Taylor, E.L. (2015). Safety benefits of mandatory OSHA 10h training. *Safety Science*, 77. pp. 66–71. DOI: 10.1016/j.ssci.2015.03.003.

Teizer, J. (2016). Right-time vs real-time pro-active construction safety and health system architecture. *Construction Innovation*, 16(3). pp. 253-280. DOI: https://doi.org/10.1108 /CI-10-2015-0049

Teizer, J., Golovina, O., Wang, D. and Pradhananga, N. (2015). Automated Collection, Identification, Localization, and Analysis of Worker-Related Proximity Hazard Events in Heavy Construction Equipment Operation. In: *32nd International Symposium on Automation and Robotics in Construction*, Oulu, Finland. DOI: https://doi.org/10.22260/ISARC2015/0005

Tepaskoualos, F. and Chountalas, P. (2017). Implementing an integrated health, safety and environmental management system: The case of a construction company. *International Journal for Quality Research,* 11. pp. 733–752. DOI: http://dx.doi.org/10.18421/IJQR11.04-01

Terwel, K.C. and Jansen, S.J.T. (2015). Critical Factors for Structural Safety in the Design and Construction Phase. *Journal of Performance of Constructed Facilities*, 29 (3). p. 04014068. DOI: http://dx.doi.org/10.1061/(ASCE)CF.1943-5509.0000560

Tezel, A. and Koskela, L. (2023). Off-site construction in highways projects: management, technical, and technology perspectives from the United Kingdom. *Construction Management and Economics*, 41. pp. 475–499. DOI: https://doi.org/10.1080/01446193.2023.2167218

Thakur, A. (2018). *Identification and Comparison of Accidents on Dam and Highway Construction sites.* Jaypee University of Information Technology Waknaghat, Solan-173234:77.

Thomson, J.M., Foldnes, N., Uppstad, P.H., Njå, M., Solheim, O.J. and Lundetræ, K. (2020). Can children's instructional gameplay activity be used as a predictive indicator of reading skills? *Learning and Instruction*, 68. 101348. DOI: https://doi.org/10.1016/j.learninstruc.2020.101348

Thorsen, H. and Njå, O. (2014). Monitoring major accident risk in offshore oil and gas activities by leading indicators. In: *Probabilistic Safety Assessment and Management*. Honolulu, Hawaii

Ting, H.-I., Lee, P.-C., Chen, P.-C. and Chang, L.-M. (2020). An adjusted behavior-based safety program with the observation by front-line workers for mitigating construction accident rate. *Journal of the Chinese Institute of Engineers*, 43. pp. 37–46. DOI: https://doi.org/10.1080/02533839.2019.1676654

Tixier, A.J.-P., Albert, A. and Hallowell, M.R. (2018). Proposing and Validating a New Way of Construction Hazard Recognition Training in Academia: Mixed-Method Approach. *Practice Periodical on Structural Design and Construction*, 23(1). 04017027. DOI: 10.1061/(ASCE)SC.1943-5576.0000347.

Toellner, J. (2014). Lessons Learned in Executing Leading Safety Indicators. Presented at the *SPE International Conference on Health, Safety, and Environment, OnePetro*. DOI: https://doi.org/10.2118/168377-MS

Tomic, A., Huang, T. and Kariyawasam, S. (2018). System Wide Risk Assessment in the 21st Century: TransCanada's Approach. In: *12th International Pipeline Conference, American Society of Mechanical Engineers Digital Collection*. DOI: https://doi.org/10.1115/IPC2018-78657

Tomlinson, C., Craig, B. and Meehan, M.J. (2011). Enhancing Safety Performance with a Leading Indicators Program, in: *Human Factors in Ship Design and Operation*, London, UK. pp. 43–52. DOI: https://doi.org/10.3940/rina.hf.2011.06

Training Hebrides (2023). S/NVQ Awards-Training Hebrides- Outer Hebrides. Available from: https://www.amtraininghebrides.co.uk/snvqs [Accessed 07.03.24].

Tsai, M.-K. (2014). Streamlining information representation during construction accidents. *KSCE Journal of Civil Engineering*, 18 (7). pp. 1945–1954. DOI: http://dx.doi.org/10.1007/s12205-014-0240-9

Tsai, M.-K. (2017). Applying physiological status monitoring in improving construction safety management. *KSCE Journal of Civil Engineering*, 21 (6). pp. 2061–2066. DOI: 10.1007/s12205-016-0980-9

Uddin, S.M.J., Albert, A., Alsharef, A., Pandit, B., Patil, Y. and Nnaji, C. (2020). Hazard Recognition Patterns Demonstrated by Construction Workers. *International Journal of Environmental Research and Public Health.* 17(21). 7788. DOI: 10.3390/ijerph17217788.

Vahdatikhaki, F., Langari, S.M., Taher, A., El Ammari, K. and Hammad, A. (2017). Enhancing coordination and safety of earthwork equipment operations using Multi-Agent System. *Automation in Construction*, 81. pp. 267–285. DOI: http://dx.doi.org/10.1016/j.autcon.2017.04.008

Vašíček, B., Žigraiová, D., Hoeberichts, M., Vermeulen, R., Šmídková, K. and de Haan, J. (2017). Leading indicators of financial stress: New evidence. *Journal of Financial Stability,* 28, pp. 240–257. DOI: https://doi.org/10.1016/j.jfs.2016.05.005

Versteeg, K., Bigelow, P., Dale, A.M. and Chaurasia, A. (2019). Utilizing construction safety leading and lagging indicators to measure project safety performance: A case study. *Safety Science*, 120, pp. 411–421. DOI: http://dx.doi.org/10.1016/j.ssci.2019.06.035

Vinodkumar, M.N. and Bhasi, M. (2010). Safety management practices and safety behaviour: Assessing the mediating role of safety knowledge and motivation. *Accident Analysis and Prevention*, 42 (6), pp. 2082–2093. DOI: https://doi.org/10.1016/j.aap.2010.06.021

Vinodkumar, M.N. and Bhasi, M. (2011). A study on the impact of management system certification on safety management, *Safety Science*, 49 (3). pp. 498–507. DOI: 10.1016/j.ssci.2010.11.009.

Walker, G. (2017). Redefining the incidents to learn from: Safety science insights acquired on the journey from black boxes to Flight Data Monitoring. *Safety Science*, Learning from Incidents 99. pp. 14–22. DOI: https://doi.org/10.1016/j.ssci.2017.05.010

Walker, G. and Strathie, A. (2015). Leading indicators of operational risk on the railway: A novel use for underutilised data recordings. *Safety Science,*74. pp. 93–101. DOI: https://doi.org/10.1016/j.ssci.2014.11.017

Walter, A.I., Helgenberger, S., Wiek, A. and Scholz, R.W. (2007). Measuring societal effects of transdisciplinary research projects: Design and application of an evaluation method. Evaluation and Program Planning. *Special Section*: *Ethics in Evaluation*, 30. pp. 325–338. DOI: https://doi.org/10.1016/j.evalprogplan.2007.08.002

Wang, F., Tian, J. and Lin, Z. (2020). Empirical study of gap and correlation between philosophies Safety-I and Safety-II: a case of Beijing taxi service system. *Applied Ergonomics*, 82. 102952. DOI: 10.1016/j.apergo.2019.102952.

Wang, J., Zou, P.X.W. and Li, P.P. (2016). Critical factors and paths influencing construction workers' safety risk tolerances. *Accident Analysis and Prevention*, 93. pp. 267–279. DOI: http://dx.doi.org/10.1016/j.aap.2015.11.027

Wang, J.-M., Liao, P.-C. and Yu, G.-B. (2021). The Mediating Role of Job Competence between Safety Participation and Behavioural Compliance. *International Journal of Environmental Research and Public Health,* 18 (11). p. 5783. DOI: http://dx.doi.org/10.3390/ijerph18115783

Waterson, P. (2014). Health information technology and sociotechnical systems: A progress report on recent developments within the UK National Health Service (NHS). *Applied ergonomics*, 45 (2). pp. 150–161. DOI: https://doi.org/10.1016/j.apergo.2013.07.004

Waterson, P., Robertson, M.M., Cooke, N.J., Militello, L., Roth, E. and Stanton, N.A. (2015). Defining the methodological challenges and opportunities for an effective science of sociotechnical systems and safety. *Ergonomics*, 58 (4). pp. 565–599. DOI: https://doi.org/10.1080/00140139.2015.1015622

Weerasinghe, R.P.N.P., Yang, R.J., Too, E. and Le, T. (2021). Renewable energy adoption in the built environment: a sociotechnical network approach. *Intelligent Buildings International*, 13 (1). pp. 33–50. DOI: http://dx.doi.org/10.1080/17508975.2020.1752134

Whiteoak, J. and Appleby, J. (2019). Mate, that was bloody close! A case history of a near-miss program in the Australian construction industry. *Journal of Health, Safety and Environment*, 35(1). pp 1-12. DOI: 99451231402621

Wickizer, T.M., Kopjar, B., Franklin, G. and Joesch, J. (2004). Do Drug-Free Workplace Programs Prevent Occupational Injuries? Evidence from Washington State. *Health Services Research,* 39 (1). pp. 91–110. DOI: http://dx.doi.org/10.1111/j.14756773.2004.00217.x

Wilkins, J.R. (2011). Construction workers' perceptions of health and safety training programmes. *Construction Management and Economics*, 29 (10). pp. 1017–1026. DOI: 10.1080/01446193.2011.633538.

Williams, J.H. and Roberts, S. (2018). Integrating the best of BBS and HOP: a holistic approach to improving safety performance. *Professional Safety*, 63 (10). pp. 40–48. Available from:https://aeasseincludes.assp.org/professionalsafety/pastissues/063/10/F1Williams_1018.pdf

Williamson, A. and Friswell, R. (2013). Fatigue in the workplace: causes and countermeasures. *Fatigue: Biomedicine, Health & Behaviour*, 1. pp. 81–98. DOI: https://doi.org/10.1080/21641846.2012.744581

Winge, S. and Albrechtsen, E. (2018). Accident types and barrier failures in the construction industry. *Safety Science*, 105, pp. 158–166. DOI: http://dx.doi.org/10.1016/j.ssci.2018.02.006

Winge, S., Albrechtsen, E. and Arnesen, J. (2019). A comparative analysis of safety management and safety performance in twelve construction projects. *Journal of Safety Research*, 71, pp. 139–152. DOI: http://dx.doi.org/10.1016/j.jsr.2019.09.015

Woods, D.D. (2009). Escaping failures of foresight. *Safety Science*, Process Safety Indicators / SRAE 2006 47, pp. 498–501. DOI: https://doi.org/10.1016/j.ssci.2008.07.030

Woods, P.D.D., Leveson, P.N. and Hollnagel, P.E. (2012). *Resilience Engineering: Concepts and Precepts.* Ashgate Publishing, Ltd. DOI: https://doi.org/10.1201/9781315605685

Woolley, M., Goode, N., Salmon, P. and Read, G. (2020). Who is responsible for construction safety in Australia? A STAMP analysis. *Safety Science*, 132, p. 104984. DOI: http://dx.doi.org/10.1016/j.ssci.2020.104984

Woolley, M.J., Goode, N., Read, G.J.M. and Salmon, P.M. (2019). Have we reached the organisational ceiling? a review of applied accident causation models, methods and contributing factors in construction. *Theoretical Issues in Ergonomics Science*, 20 (5), pp. 533–555. DOI: http://dx.doi.org/10.1080/1463922X.2018.1558305

Wu, W., Gibb, A.G.F. and Li, Q. (2010). Accident precursors and near misses on construction sites: An investigative tool to derive information from accident databases. *Safety Science*, 48 (7). pp. 845–858. DOI: http://dx.doi.org/10.1016/j.ssci.2010.04.009

Wu, X., Li, Y., Yao, Y., Luo, X., He, X. and Yin, W. (2018). Development of Construction Workers Job Stress Scale to Study and the Relationship between Job Stress and Safety Behavior: An Empirical Study in Beijing. *International Journal of Environmental Research and Public Health*, 15 (11). p. 2409. DOI: http://dx.doi.org/10.3390/ijerph15112409

Xing, X., Zhong, B., Luo, H., Rose, T., Li, J. and Antwi-Afari, M.F. (2020). Effects of physical fatigue on the induction of mental fatigue of construction workers: A pilot study based on a neurophysiological approach. *Automation in Construction*, 120, p. 103381. DOI: http://dx.doi.org/10.1016/j.autcon.2020.103381

Xu, J., Cheung, C., Manu, P. and Ejohwomu, O. (2021). Safety leading indicators in construction: A systematic review. *Safety Science*, 139. pp. 1-16. DOI: https://doi.org/10.1016/j.ssci.2021.105250

Xu, J., Cheung, C., Manu, P., Ejohwomu, O. and Too, J. (2023). Implementing safety leading indicators in construction: Toward a proactive approach to safety management. *Safety Science*,157. 105929. DOI: https://doi.org/10.1016/j.ssci.2022.105929

Yamauchi, T., Sasaki, T., Takahashi, K., Umezaki, S., Takahashi, M., Yoshikawa, T., Suka, M. and Yanagisawa, H. (2019). Long working hours, sleep-related problems, and near-misses/injuries in industrial settings using a nationally representative sample of workers in Japan. *PLOS ONE*, 14 (7). p. e0219657. DOI: http://dx.doi.org/10.1371/journal.pone.0219657

Yanar, B., Robson, L.S., Tonima, S.K. and Amick, B.C. (2020). Understanding the organizational performance metric, an occupational health and safety management tool, through workplace case studies. *International Journal of Workplace Health Management*, 13 (2). pp. 117–138. DOI: http://dx.doi.org/10.1108/IJWHM0920180126

Yang, L., Branscum, A., Smit, E., Dreher, D., Howard, K. and Kincl, L. (2020). Work-related injuries and illnesses and their association with hour of work: Analysis of the Oregon construction industry in the US using workers' compensation accepted disabling claims, 2007-2013. *Journal of Occupational Health*, 62 (1). p. e12118. DOI: http://dx.doi.org/10.1002/1348-9585.12118

Yao, Q., Li, R.Y.M., Song, L. and Crabbe, M.J.C. (2021). Construction safety knowledge sharing on Twitter: A social network analysis. *Safety Science*, 143. p. 105411. DOI: http://dx.doi.org/10.1016/j.ssci.2021.105411

Yi, J., Kim, Y., Kim, K. and Koo, B. (2012). A suggested colour scheme for reducing perception-related accidents on construction work sites. *Accident Analysis and Prevention,* 48, pp. 185–192. DOI: http://dx.doi.org/10.1016/j.aap.2011.04.022

Yin, R.K. (1994). *Case Study Research: Design and Methods*. 2nd edn., Thousand Oaks, CA: Sage.

Yin, R.K. (2018). *Case study research and applications: design and methods*. 6th edn., Los Angeles, SAGE.

Yorio, P.L., Haas, E.J., Bell, J.L., Moore, S.M. and Greenawald, L.A. (2020). Lagging or leading? Exploring the temporal relationship among lagging indicators in mining establishments 2006–2017. *Journal of Safety Research*, 74. pp. 179–185. DOI: http://dx.doi.org/10.1016/j.jsr.2020.06.018

Zarges, T. and Giles, B. (2008). Prevention through Design (PtD). *Journal of Safety Research*, 39 (2). pp. 123–126. DOI: https://doi.org/10.1016/j.jsr.2008.02.020

Zhang, J., Zhang, W., Xu, P. and Chen, N. (2019). Applicability of accident analysis methods to Chinese construction accidents. *Journal of Safety Research*, 68. pp. 187–196. DOI: http://dx.doi.org/10.1016/j.jsr.2018.11.006

Zhao, D. and Lucas, J. (2015). Virtual reality simulation for construction safety promotion. *International Journal of Injury Control and Safety Promotion*, 22(1). pp. 57–67. DOI: 10.1080/17457300.2013.861853.

Zhao, D., McCoy, A.P., Kleiner, B.M., Smith-Jackson, T.L. and Liu, G. (2016). Sociotechnical Systems of Fatal Electrical Injuries in the Construction Industry. *Journal of*

Construction Engineering and Management, 142 (1). p. 04015056. DOI: http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001036

Zhen, X., Vinnem, J.E., Han, Y., Peng, C. and Huang, Y. (2022). Development and prospects of major accident indicators in the offshore petroleum sector. *Process Safety and Environmental Protection*, 160. pp. 551–562. DOI: https://doi.org/10.1016/j.psep.2022.02.050

Zheng, L., Baron, C., Esteban, P., Xue, R., Zhang, Q. and Yang, S. (2019). Using Leading Indicators to Improve Project Performance Measurement. *Journal of Systems Science and Systems Engineering,* 28. pp. 529–554. DOI: https://doi.org/10.1007/s115180195414-z

Zhong, D., Lv, H., Han, J. and Wei, Q. (2014). A Practical Application Combining Wireless Sensor Networks and Internet of Things: Safety Management System for Tower Crane Groups. *Sensors*, 14 (8). pp. 13794–13814. DOI: https://doi.org/10.3390/s140813794

Zhou, W., Whyte, J. and Sacks, R. (2012). Construction safety and digital design: a review. *Automation in Construction*, 22. pp. 102–111. DOI: 10.1016/j.autcon.2011.07.005.

Zhou, W., Zhao, T., Liu, W. and Tang, J. (2018). Tower crane safety on construction sites: A complex sociotechnical system perspective. *Safety Science*, 109. pp. 95–108. DOI: http://dx.doi.org/10.1016/j.ssci.2018.05.001

Zohar, D. (2010). Thirty years of safety climate research: Reflections and future directions. *Accident Analysis & Prevention*, Safety Climate: New Developments in Conceptualization, Theory, and Research, 42. pp. 1517–1522. DOI: https://doi.org/10.1016/j.aap.2009.12.019

Zwetsloot, G., Leka, S., Kines, P. and Jain, A. (2020). Vision zero: Developing proactive leading indicators for safety, health and wellbeing at work. *Safety Science* 130, 104890. DOI: https://doi.org/10.1016/j.ssci.2020.104890

Zwetsloot, G.I.J.M. (2009). Prospects and limitations of process safety performance indicators. *Safety Science*, Process Safety Indicators / SRAE 2006 47, pp. 495–497. DOI: https://doi.org/10.1016/j.ssci.2008.07.032

Zwetsloot, G.I.J.M., Drupsteen, L. and de Vroome, E.M.M. (2014). Safety, reliability and worker satisfaction during organizational change. *Journal of Loss Prevention in the Process Industries,* 27. pp.1–7. DOI: https://doi.org/10.1016/j.jlp.2013.10.008

APPENDICES

Appendix 1- Screen dump of database table consisting of safety leading indicator examples identified in previous literature.

	A	B	C	D	E
1	**Authors**		**Number of LIs**	**Leading indicators**	**Description and examples in practice**
2	1. Almost *et al.,* 2019	Almost et al., 2019	1	Senior management commitment	Inclusion of occupational safety and health in strategic plan; Safety round meeting (including staff and senior managers)
3		Almost et al., 2019	1	Employee involvement	Safety round meeting (including staff and senior managers)
4		Almost et al., 2019	1	Communication	Safety round meeting (including staff and senior managers)
5		Almost et al., 2019	1	Continuous improvement	Simplifying incident reporting- (generating Incident reporting flowchart from 10+ page document)
6		Almost et al., 2019	1	Competence	Leading indicator for promoting occupational health and safety
7		Almost et al., 2019	1	Occupational health management	Leading indicator representing management of occupational health risks such as violence, musculoskeletal disorders, and infectious diseases which are monitored and controlled based on the findings of a risk assessment.
8		Almost et al., 2019	3	Percentage of planned training completed;	No description
9		Almost et al., 2019		Number of recommendations from workplace inspections;	No description
10		Almost et al., 2019		Number of accident investigations that received attention.	No description
11		Guo and Yiu, 2015	3	Principal contractors are selected in part on the basis of satisfying historical safety performance;	Leading indicators for client manager safety leadership
12		Guo and Yiu, 2015		Frequency with which safety representatives of client visit the site;	Leading indicators for client manager safety leadership

Appendix 2- Analytical framework in a tabular format used to identify leading indicators from case study materials and normative documents.

Case ID	Documents included (and relevant normative documents considered)	Leading indicators identified in the case, i.e. the unit of analysis	**Active leading indicator-** Emergent LI in the form of sign and signals that provide information that helps the user respond to changing circumstances and take actions to achieve desired outcomes or avoid unwanted outcomes	**Passive leading indicator-** LI measuring the status of safety management systems, including policies, objectives and plans, procedures, and guidelines.	**Qualitative leading indicator-** LI representing quality side of measured object that helps to reveal experience, meaning and perspective and explains 'how' and 'why' (e.g., quality of safety activity, fitness level of WMS element, etc.)	**Quantitative leading indicator-** LI representing quantity of measured object (e.g., frequency, rate, percentage, number count, length of time)	**Implicit leading indicator-** LI that requires inference and subjective interpretation	**Explicit leading indicator** - LI that is directly observed and objectively measured	**Negative leading indicator-** LI measuring and focusing on occurrences of unfavourable events that an entity is planning to eliminate and avoid	**Positive leading indicator-** LI measuring and focusing on occurrences of favourable events that an entity is planning to achieve and maintain

Appendix 3 - List of newly developed leading indicators that have not been identified in previous studies.

No	Leading indicators
1	Review/assess the planned work to avoid disturbing services where possible.
2	Location of utility is known prior to any work being undertaken on site.
3	Excavation work should not start until steps have been taken to identify and prevent any risk of injury arising from underground services.
4	A number of steps need to be taken before the selection of the most appropriate form of trenchless technique: site survey; ground investigation to determine the soil and groundwater conditions; site investigation to determine the location of existing pipelines, other services and potential obstacles; inspection to determine the condition of the existing pipeline (if applicable)
5	Planning for installation, replacement and renovation of underground services (using trenchless and minimum excavation techniques) requires carrying out topographical surveys, collecting information on existing buried pipes and cables and carrying out site investigation, including ground investigation and utility surveys.
6	Ensuring to determine the method and technique for excavating near underground services before work starts, taking account of the nature and scope of the work
7	Ensuring to determine the method and technique for excavating near underground services before work starts, taking account of the type, position and status of underground services
8	Ensuring to determine the method and technique for excavating near underground services before work starts, taking account of the ground conditions
9	Ensuring to determine the method and technique for excavating near underground services before work starts, taking account of site constraints
10	Company may need to make underground cables dead for the work to proceed safely. Be aware that electricity companies are required to give five days' notice to customers whose supply is to be disconnected.
11	Plans or other suitable information about all buried services in the area should be obtained and reviewed before any excavation work starts.
12	Ensuring to contact the service owners/operators for information about the location and status of the services, when planning or undertaking work that may disturb underground services
13	Ensuring that the service owners/operators provide any relevant information about the location of services in the work area, when planning or undertaking work that may disturb underground services
14	Ensuring that the service owners/operators are prepared to help locate and identify the services (e.g. by sending a representative to the site) when planning or undertaking work that may disturb underground services
15	Ensuring to arrange long-term plans (or other formal arrangements) for co-operation with other utilities, local authorities and contractors who carry out road and footway excavation, when planning or undertaking work that may disturb underground services
16	There must be adequate information available about the electrical system and the work to be done. In the case of a newly constructed electrical system (or newly installed equipment), there should be drawings and schedules relating to the design and these should have been updated, if necessary, by the people carrying out the installation.
17	The workers must be supplied with and use correct and appropriate information, such as electrical drawings, tools, instruments
18	Ensuring to make electricity cables dead for the work to proceed safely
19	Ensuring to contact electricity companies as early as possible to allow them to isolate supplies (i.e. make electricity cables dead)
20	If the cable cannot be made dead, an alternative safe way of doing the work will be required.
	Total of 'Pre-project/planning LIs' cluster: 20
1	Sufficient time availability for task completion
2	Time pressure: the operators time scale to complete the work had been reduced
3	Time pressure: request for 2x shut offs to be completed in the morning rather than one.
4	Ensuring to plan project schedules to allow sufficient time for service providers to make electricity cables dead
5	Goals conflict: rushing and aggregating tasks (consolidating two in different time, planned shutoffs) due to unwillingness to cause disruption to water supply
6	Allow sufficient time for lines to be diverted or made dead, or for other precautions to be taken
	Total of 'Time vs safety LIs' cluster: 6
1	Before work begins, underground cables must be located, identified and clearly marked.

2	Checking for availability of appropriate PPE and sufficient number of cones, signs and barriers on site
3	The position of the cable in or near the proposed work area should be pinpointed as accurately as possible by means of a locating device, using plans, and other information as a guide to the possible location of services and to help interpret the signal.
4	Ensuring that the work only starts after proving that the equipment or circuit is dead
5	Clearly identify the extent of the work area and find out what underground services are within the area before considering whether they are likely to be disturbed
6	Absence of preparation work prior to performing main task (location and identification of the service was not completed; safe dig process/trial holes was not followed; the main was not identified and marked up to show it was present)
	Total of 'Pre-task LIs' cluster: 6
1	Ensuring that operators are aware about the difficulty of spotting overhead lines, when they are tired, rushing or cutting corners
2	Ensuring that operators are aware about the difficulty of spotting overhead lines in foggy or dull conditions
3	Ensuring that operators are aware about the difficulty of spotting overhead lines when they blend into the surroundings at the edge of woodland, or when they are running parallel to, or under, other lines
4	Any work near electric overhead power lines must be carefully planned and carried out to avoid danger from accidental contact or close proximity to the lines
5	The first step (i.e. at planning and preparation step) is to find out whether there is any overhead power line within or immediately adjoining the work area or across any route to it
6	(Whenever possible) Avoiding carrying out the work under or near overhead lines to eliminate danger
7	(Whenever possible) Diverting all overhead lines clear of the work area to eliminate danger
8	(Whenever possible) Making lines dead while the work is in progress to eliminate danger
9	Making defined passageways for plants where they are under lines to control danger
10	Providing barriers, goal posts and warning notices to control danger
11	Maintaining safe clearance limit between the overhead lines and plant/equipment/hand tools to control danger
12	Plant such as cranes and excavators should be modified by the addition of suitable physical restraints so that it cannot reach beyond the safe clearance limit
13	Ensuring that plant working near overhead power lines are not approaching closer than 15m (plus length of jib) if the line is suspended from steel towers
14	Ensuring that plant working near overhead power lines are not approaching closer than 9m (plus length of jib) if the line is supported on wooden poles
	Total of 'Overhead lines avoidance' cluster: 14
1	Flooded ground
2	Ensuring that operators are aware of the dewatering technique in case of ground flood, which involves channelling water to sumps from where it can be pumped out
3	Ensuring that operators are aware of the effect of pumping from sumps on the stability of the excavation while dewatering the excavation in case of a ground flood
4	Ensuring that alternative techniques for de-watering (such as ground freezing and grout injection) are considered by designers
	Total of 'Ground condition LIs' cluster: 4
1	Refraining from over-relying (refers to operators) on the accuracy of the labelling
2	Plans alone are not sufficient to identify and locate services before starting work. They provide basic information on which to base a thorough site survey before work begins.
3	Ensuring that operators are aware that plans are not always drawn accurately to scale and should not rely on them to obtain distances or depths.
4	Ensuring that operators are aware that plans might include some errors made during drafting
5	Ensuring that operators are aware that reproduction may have changed the scale indicated in the plan, especially if the plan was obtained from a microfiche slide or digital map
6	Ensuring that operators are aware that the position of reference points (e.g. the kerb line) may have changed since the plans were drawn
7	Ensuring that operators are aware that services, particularly cables, may have been moved without the knowledge of their owners/ operators
8	Ensuring that operators are aware that in many cases service connections are not marked

9	Ensuring that operators are aware that services marked as straight lines may, in practice, snake
10	Ensuring that operators are aware that excessively long cables may have been laid in horizontal loops outside substations, switch rooms etc
11	Ensuring that operators are aware that plans may show spare ducts
12	Ensuring that operators are aware that the routes of older services in particular may not have been recorded
13	Ensuring that operators never take the absence of records as proof that the area in question is free of underground services
14	Plans give only an indication of the location, and number of underground services at a particular site. It is essential that a competent person traces cables using suitable locating devices.
15	Over relying on drawings as being accurate
16	Over reliance on drawings: Inaccurate and unreliable drawing of existing utility lines (2)
17	Making operators aware that plans do not normally show the position of gas service connections and their existence should be assumed
18	Ensuring that the person doing the survey appreciates the limitations of plans and drawings provided by the service owners
19	Ensuring that the person doing the survey has attained NVQ qualification in utility mapping
20	Competency of the team to read and understand the utility drawing
21	Ensuring that operators are aware of the ways of improving records (e.g. by a combination of surveying, testing and labelling) when working with old installations where records may be poor
22	Provide adequate instruction and training in how to read and interpret plans to anyone who needs to use them. Ideally, plans should be in colour to assist their interpretation and understanding.
23	Traced and located 8 ducts that were not shown on any drawings
24	Team correctly read and understood the utility drawing
25	Ensuring that operators selecting detection tools and survey methods are warned against false sense of security (that may rise from overreliance on drawings or device signals)
26	Ensuring that operators selecting detection tools and survey methods are aware that false readings or signals in certain techniques may lead to inaccurate information being included in the plan of work
	Total of 'LIs for underground utility lines detection: using utility drawing/maps' cluster
1	Survey the site to identify the services and other underground structures. Record the location of any services.
2	Ensuring that the person doing the survey has sufficient knowledge and experience in the use of survey equipment and techniques
3	Ensuring that the person doing the survey understands the limitations of the equipment
4	Ensuring that the person doing the survey understands and is aware of the effect of differing ground conditions on the survey results
5	Ensuring that the person doing the survey understands how to survey a given area effectively
6	Ensuring that the person doing the survey has taken a (training) course for service detection and mapping
7	Avoid underground services – use relevant service drawings, service locating devices and safe digging practice
8	Actual physical identification will be necessary and this may be aided by the use of appropriate drawings, diagrams and other written information
9	Ensuring that operators are warned against over-reliance on a single source of information (e.g., solely relying on a label) when checking records before working on an installation
10	The team marked up the cables with the use of the Cat and Genny (2)
11	Ensuring that operators selecting detection tools and survey methods are aware of the range of methods and tools and their respective limitations
12	Ensuring that operators selecting detection tools and survey methods are aware of the potential for false readings or signals
13	Locators should be used frequently and repeatedly during the course of the work
14	Make frequent and repeated use of locators during the course of the work
15	Inadequate and inefficient use of the tool (continuous sweeps with the CAT locator whilst digging is required)
16	Incomplete service location and identification
17	Duration of scanning for underground utility detection and inspection

18	Failure of cable avoidance equipment (i.e. CAT or Genny) to detect/locate the damaged apparatus or utility line
19	The accuracy of cable avoidance equipment to detect and locate the utility apparatus and line
20	(Missing) Data from CAT tool
21	Avoid using malfunctioning CAT tool
	Total of 'LIs for underground utility lines detection: using detection equipment' cluster: 21
1	Making operators aware of probable estimation of the location of service connection pipe from the gas meter position, or from the point of entry into the premises
2	Checking for team's awareness of HSG47 (which focuses on the requirement to survey and mark all services)
3	Presence and visibility of markings of the existing utilities (utility apparatus and lines) on the surface
4	Emphasising on the work on site to locate services and excavate safely
5	Ensuring that operators are warned against cutting corners or running unacceptable or avoidable risks when performing service location and digging
6	Ensuring that the work of service location and digging are performed by individuals with sufficient knowledge and experience
7	Ensuring that specialised instruments are used as a cable locating technique, when underground cables are being identified
8	It may be necessary to identify the cable both before and after switching operations and cable spiking
9	Careless performance of consulting the drawing. Careless performance of frequent dig walk
10	The team checked the utility plans and discussed the job and were given a location to dig by the jointers
11	Failure to identify and mark the presence of main
12	Presence (use) and effectiveness of visual identification method
13	Using visual identification methods (such as looking for scarring or street furniture) to detect/locate the damaged apparatus or utility line
14	Accuracy of inspecting the utility depth, utility condition, existence of any protection (i.e. marker tape or tiles) and its working condition
	Total of 'Safe digging LIs: prior to digging' cluster: 14
1	Ensuring that the operator planning to dig uses plans, detecting devices and trial excavations to locate existing services (in the same way as for open-cut excavation methods)
2	Ensuring that the operator planning to dig plans the route of the device being used accordingly to avoid colliding with, and damaging (service lines and cables)
3	Ensuring that the operator planning to dig is aware that undertaking the practice of moling or pipe bursting too near to other services or ducts may damage or enter them (i.e. other services or ducts)
4	Sufficiency (number of) of hand excavated trial holes for the complexity of the work
5	Ensuring that operators are aware of using insulated tools when hand digging near electric cables
6	Ensuring that operators are aware that spades and shovels with curved edges are preferable to use than other tools, when hand digging near electric cables
7	Ensuring that operators are aware that digging tools are not to be thrown or spiked into the ground when hand digging near electric cables
8	Ensuring that operators are aware of using digging tools by easing them in with gentle foot pressure when hand digging near electric cables
9	Ensuring that operators are aware of safely using picks, pins or forks to free lumps of stone etc, and to break up hard layers of chalk or sandstone, when hand digging near electric cables
10	Ensuring that operators are aware not using picks in soft clay or other soft soils near to underground services, when hand digging near electric cables
11	Ensuring to take precautionary approach when breaking ground
12	Absence or non-compliance with safe dig process (trial holes was not followed)
13	Failure to complete location and identification of the service (trial holes was not used)
14	Ensuring that safe digging practices (i.e. proceeding excavation only after 2 steps service detection practice) are followed when performing excavation work
15	Ensuring that the step of determining the position and route (with detecting device) is always followed by the step of digging trial holes (using hand tool or vacuum excavation) to confirm the position of any detected services

16	Ensuring that a special care is taken when digging above or close to the assumed line of a service
17	Sufficiency of trial holes for the complexity of the works/Sufficiency (number of) of hand excavated trial holes for the complexity of the work/Not sufficient number of trial holes according to complexity of the work
18	Using trial holes technique (as the source) to identify the presence and location of underground apparatus or line
19	Ensuring to detect and identify the underground services through trial holes to verify their location, depth and identity, in addition to other steps of service location techniques (i.e., using drawing/map and using detection device)
20	Safe excavation (the size of excavation does not exceed the surface marking)
21	Checking for team's awareness of safe digging techniques (no mechanical excavation within 500mm of services)
22	Presence of adequate protection against accidental damage on the exposed/damaged utilities (2)
23	Identified services should be carefully exposed and clearly marked
24	Ensuring to pass a tracing device through a pipe or tunnel, in addition to other steps of service location techniques (i.e., using drawing/map and using detection device)
	Total of 'Safe digging LIs: during digging' cluster: 24
1	Deviation to unsafety: moling towards a known utility without exposing the utility
2	Deviation to unsafety: launching the mole without using moling cradle
3	Ensuring that operators are aware that moles can be prone to deflection from their original course
4	Ensuring to use a mole-tracking device when performing moling step, if there are existing services in the vicinity
5	Ensuring that all equipment are effectively earthed at all times it is in use using an equipotential mat to avoid hitting a power cable and causing the machinery to become live
	Total of 'Safe moling' cluster: 5
1	Cable ducts shall be proved by drawing a mandrel
2	Absence of procedure for effective identification of ducts
3	Ensuring that continuous sections of ducts and sub-ducts (including sub-ducts jointed as part of a modular inner and outer duct arrangement) are tested and proven by blowing a close-fitting foam plug (or similar arrangement) that tests the integrity of the duct in respect of diameter and airtightness in a single operation
4	Ensuring that operators are aware that additionally test for the outer main duct that houses a sub-duct is not required, when testing and proving ducts
5	Ensuring that operators are aware that the design and dimension of the foam plug shall inhibit the progression of the foam plug within the duct where the diameter of the duct has suffered deformity or presents a discontinuity in size that is outside of the duct manufacturer's written specifications
6	Reviewing the suitability of particular equipment and work types. (Identifying the types of work that Stihl saws should not be used)
7	Lesson learnt: changing the procedure for proving of duct to the rodding of ducts, trial holes and proving points, instead of cutting into ducts
8	Safe work description: rodding (instead of cutting) the duct to prove it (to check if they are empty and can be used)
9	Ensuring that operators are aware of the most frequently occurring reactive force (i.e. kickback and pull-in) and their risks (i.e. fatal cuts) when using cut-off machine
10	Ensuring that operators are aware of how kickback might occur (i.e., when the cut-off machine is suddenly thrown up and back in an uncontrolled arc towards the operator)
11	Ensuring that operators are aware of what might cause a kickback (e.g. if the cutting wheel becomes jammed; or above all in the upper quarter; or is severely braked through frictional contact with a solid object)
12	Ensuring that operators are aware of the ways of reducing the risk of kickback
13	Ensuring that operators work cautiously and methodically when using cut-off machine
14	Ensuring that operators are aware of safe method of work when using cut-off machine which requires to hold the cut-off machine firmly with both hands and maintain a secure grip
15	Ensuring that operators are aware of not using the upper quarter of the cutting wheel for cutting, when using cut-off machine
16	Ensuring that operators are aware of introducing the cutting wheel into the cut with extreme care, without twisting and without pushing when using cut-off machine

17	Ensuring that operators are aware that the object to be cut may move and other factors may cause the cut to close and jam the cutting wheel when using cut-off machine
18	Ensuring that operators are aware that the object to be cut must be secured and supported so that the cut remains open during and after cutting, when using cut-off machine
19	Ensuring that operators work with water and adopt wet cutting technique when using diamond cutting wheels
20	Ensuring that operators are aware that composite resin cutting wheels are suitable for dry cutting or wet cutting only when using cut-off machine
21	Ensuring that operators are aware to always use wet cutting with composite resin cutting wheels that are suitable only for wet cutting
22	IP was trained and aware of the risks of using the tool (Stihl saw) but failed to apply the training knowledge
23	Ensuring that operators consider the safety of themselves and others when working with a cut-off saw
24	Ensuring that operators use suitable personal protective equipment, such as hard hats, safety glasses and ear defenders when working with a cut-off saw
25	Ensuring that PPE are worn correctly and are suitable for operators to use together, when working with a cut-off saw
26	Ensuring that the work only starts after proving that the equipment or circuit is dead
27	The danger created by damaging a gas pipe with an excavator is much greater than if the damage is done with a hand-held power tool, the opposite is true for work near electricity cables
	Total of 'LIs for proving duct/utility lines' cluster: 27
1	Drivers should be trained to follow safety procedures
2	Drivers should be trained to wear proper seat restraints
3	Drivers should be trained to spot hazards and avoid them
4	Ensuring that the driver remains seat belted/restrained throughout the operation to prevent them from jumping off an overturning vehicle
5	Making the driver aware of the safe response to the case of vehicle overturning, where driver brace themselves against the back of the driver's seat and hold firmly on a secure part inside the cab
6	Ensuring that the driver is aware and warned against an attempt of jumping out of vehicle that is toppling over.
7	Operator's seat belt is on (and PPE worn correctly)
8	Unsafe use of equipment: failure to extend the tracks of the digger
9	Drivers should be monitored to ensure they follow safe systems of work, e.g. they are wearing seat belts which should be used even if a roll-over protection system (ROPS) is fitted
10	Failure to induct and assess the competence (or plant familiarisation requirement) of the excavator operator
11	Providing drivers with a list of the daily checks to be signed off at the start of each shift
12	Monitoring drivers to ensure they properly carry out the checks
13	Whilst the tracks are being extended or retracted the boom and cab must be central
14	Failure to extend tracks before the works starts (rather than in the middle of the work)
15	Failure to use warning system in place (an electronic GKD system- the height restrictor is assumed to be not used (switched on) during the operation)
16	Presence of a competent banks person throughout the excavation
17	Carry out an inspection of the machine, once it is recovered to its upright position (from overturning) for a potential damage or spillage from the vehicle or generator
18	Recovering/ deviation to safety: machine operator stopped digging and explained to the banksman that he will move back to extend the tracks in order to provide more stability for the machine.
19	Failure to provide a site specific/ familiarisation briefing to newcomer excavator operator
20	Failure to assign a banksman role in the site-specific risk assessment
	Total of 'Safe use of machinery' cluster: 20
1	Ensuring that operators are aware that jetting guns should be a minimum of 1 metre long for standard operations
2	Ensuring that operators are aware that the trigger mechanism should be free from debris and never locked or wedged in the on position
3	Operatives should take regular breaks to recover from fatigue (manual jet gun use)

4	Manual High-Pressure Jetting, if not handled competently is a potentially hazardous process due to the power of the jet and the proximity of the operator to the jetting equipment
5	In most on site situations, only the use of personal protective equipment (PPE) represents a reasonably practicable means of reducing the risk to an acceptable level (refers to manual jetting)
6	Inherent poor workplace layout (poor visibility due to the height of screens)
	Total of 'Using jet guns' cluster: 6
1	Unsafe condition of material handled (lifting holes in the chamber cover were worn to excess; the cover is heavy)
2	Failure to follow correct method of lifting covers (using pit lifter number 5 and placing the roll bar in front of injured person's (IP) feet would be safe process)
3	Assess the risk of injury from any hazardous manual handling operations that cannot be avoided
4	Make sure the person doing the lifting has been trained to lift as safely as possible
	Total of 'Material handling' cluster: 4
1	Availability of emergency team
2	Ensuring public members are kept well clear away from the area where gas main was damaged
3	Ensuring that operators are aware of performing emergency work to repair damaged services in order to make them safe or restore them
4	Ensuring that operators are capable of deciding whether the service damage requires an immediate temporary fix (before a permanent repair can be done) or a permanent repair
5	Ensuring to follow steps of planning and assessment of the risks arising from the work, as part of emergency work
6	Swift response of emergency team: adjacent building evacuated
7	Absence and unavailability of emergency (fault team) team; absence of incident response
8	(Improper, inadequate) Provision of first aid to IP (IP drove himself to a hospital after sustained laceration)
9	Electrical accidents often occur during fault-finding after a plant breakdown when pressure to repair the equipment results in risks being taken. To anticipate this, you should plan and establish safe fault-finding procedures to be implemented during breakdown maintenance
10	First aid provision at the time of incident (wound cleaned with wipes and dressing applied)
	Total of 'LIs for emergency preparedness' cluster: 10
1	Every employer shall ensure that work equipment is so constructed or adapted as to be suitable for the purpose for which it is used or provided.
2	Suitability of equipment with task or site condition (e.g. good/poor/negative); equipment used is identified as not suitable for the task (other examples are positive or identified as suitable)
3	Choosing the right vehicle for the job is an essential part of effective vehicle management. The vehicle selected needs to be capable of performing its designated tasks safely
4	All equipment should be checked daily by users and weekly by supervisors for any damage or corrosion in accordance with the manufacturer's instructions
	Total of 'Equipment suitability and fitness' cluster: 4
1	Information (documents to be reviewed) overload
2	Checking for team members' safety passport
3	Absence of point of work risk assessment (POWRA) (2)
4	Careless performance of completing permit forms
5	Failure to complete DRA (dynamic risk assessment)
	Total of 'Safety documentation' cluster: 5
1	Segregation between teams (despite the joint work: worker from joint team refusing to answer questions as per their supervisors' instruction)
2	Poor collaboration between different teams/subcontractors
3	Inaccurate (misrepresentation of event for the purpose of financial gain) description of events provided by IP
4	Falsified personal injury claims (for financial gain)s

5	Investigation of an alleged accident does not necessarily imply that sick pay will be paid. This will depend on the result of the investigation.
6	Reluctance to assist with investigation
7	Incomplete (non-application of procedure as required) task by previous relevant to task team; (Failure of dig team to leave tubes cut to correct length)
8	The team conducting the work (without the assigned coach) is not adequately trained, qualified or suitably experienced for the activity
9	Workers' unawareness of their authorised and unauthorised work
10	Failure to recognise the unauthorised and unsafe work (practiced by workers) that was common practice prior to current incident
11	Implementing a process to ensure that new teams have the necessary competence and experience to undertake the works
	Total of 'LIs for safety culture' cluster: 11
1	Ensuring that operators securely fix labels to equipment, after the completion of work (i.e. installation of the equipment) in order to clearly identify their function
2	Checking contractors' learning capacity in the aftermath of incident (checking contractors for their learnt lesson, change adopted, improvement steps taken after the incident)
3	Lesson learnt: ensure banksman is alert all the time to detect unknown (potentially not indicated in the drawing) utility
4	No rectification steps are applied post incident (since the team followed adequate and sufficient steps to avoid any service strikes)
5	The Director responsible for Health & Safety will then ensure, so far as reasonably practical, that proper action is taken to help prevent the accident being repeated
	Total of 'LIs for safety learning' cluster: 5

Appendix 4 - Areas of interest and corresponding questions to inquire in focus group interview

Themes/ areas of interest	Questions	Checks (+)	Prompts
Process and tools (conceptual model)	Does the model (or process illustrated on Figure1 on page 3 in your document) make logical sense?		-Do you think the process is user-friendly?
			-What are the good features of the model and why?
			-What improvements could you make?
			-Do you think the process is complete and accurate?
			-With some modification, would you use the model?
Applying the research in practice (analytical framework)	How easy or difficult the framework is to use to identify LIs?		-If you answered 'difficult' to the previous question, what would you change in the framework to make it easier/useful to identify LIs from qualitative dataset?
	Would you be prepared to apply this research in your organisation's safety management?		-What level of support would you need?
			-Is it possible to apply this as case study?
Newly developed LIs	Referring to your Table 1 on page 1, what are your initial thoughts when you read these LIs?		-Are they too long or short structurally?
			-Are they difficult to grasp?
			-Are they relevant or useful to CE work?
	Leading on from previous question, which of the following LI feature is the most important than others: 1) measurable; 2) preventative; or 3) relevant?		-Based on which of the features would you select LIs and adopt in your safety management?
Generic (LIs' development and implementation)	What are the good practices that you may have encountered in terms of LIs development and implementation?		-Development explicitly
			-Implementation explicitly

Appendix 5- Supplementary information provided for focus group interview participants prior to interview.

Figure 1. Conceptual model developed through the research.

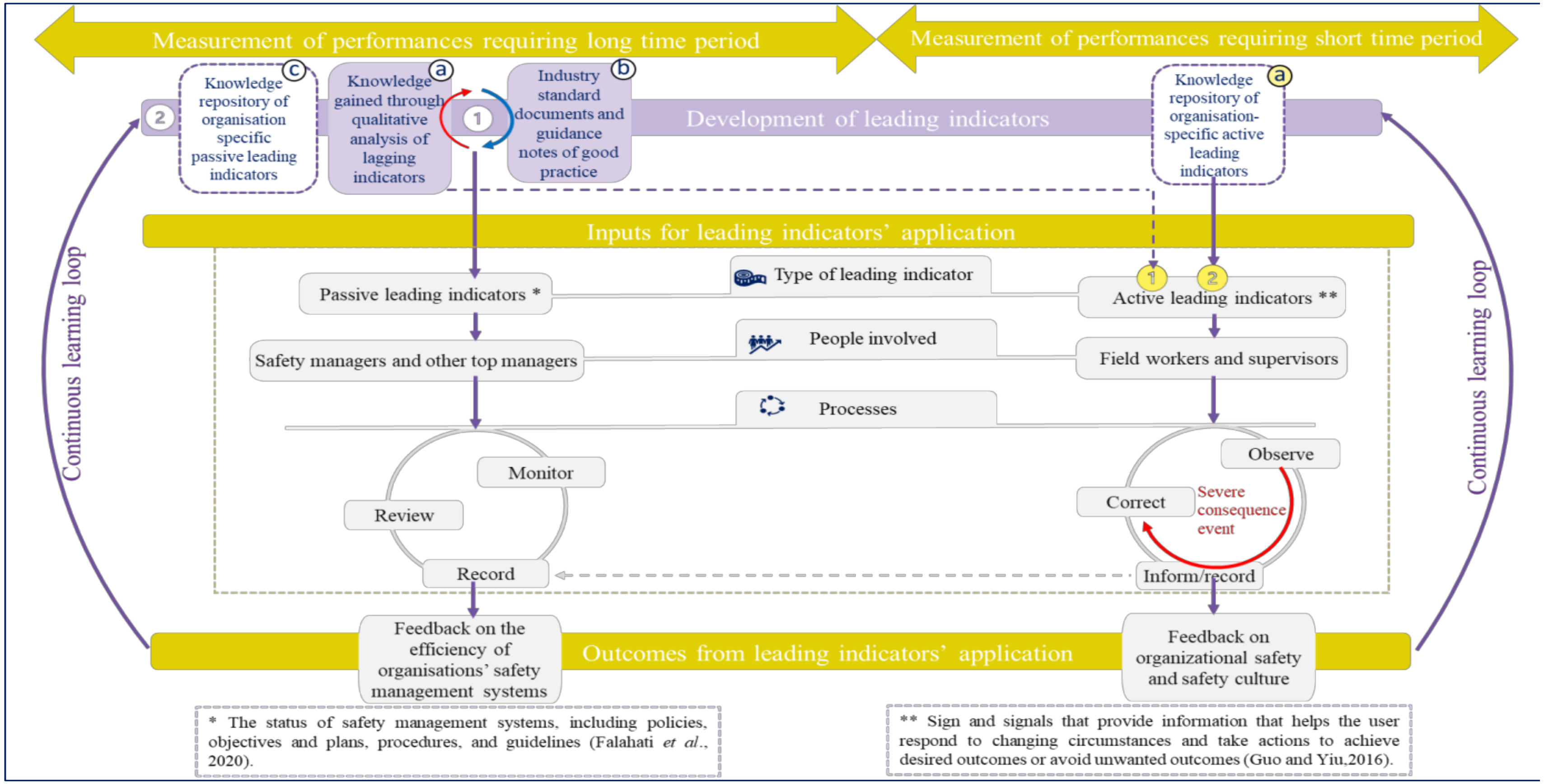


Figure 2. Analytical framework developed through the research.

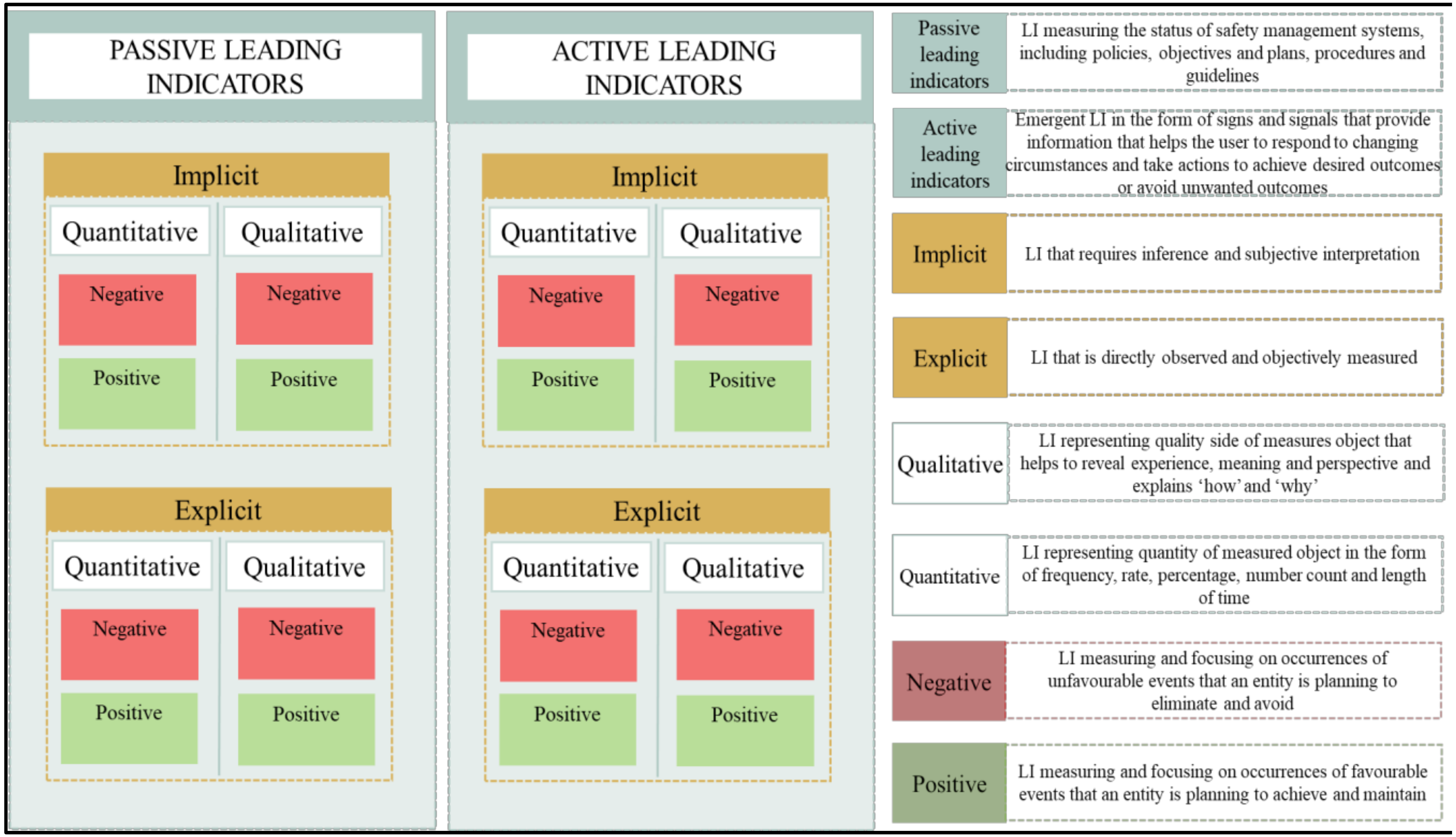


Table 1. Examples of leading indicators developed through the research.

No	Cluster name	Leading indicator examples
1.	Pre-project/planning LIs	Excavation work should not start until steps have been taken to identify and prevent any risk of injury arising from underground services.
2.	Time vs safety LIs	Time pressure: request [from top managers] for 2x shut offs [i.e. road closures] to be completed in the morning rather than one.
3.	Pre-task LIs	The position of the cable in or near the proposed work area should be pinpointed as accurately as possible by means of a locating device, using plans, and other information as a guide to the possible location of services and to help interpret the signal.
4.	Overhead lines avoidance LIs	Ensuring that operators are aware about the difficulty of spotting overhead lines when they [overhead lines] blend into the surroundings at the edge of woodland, or when they are running parallel to, or under, other lines.
5.	Ground condition LIs	Ensuring that operators are aware of the effect of pumping from sumps have on the stability of the excavation while dewatering the excavation in case of a ground flood. *
6.	LIs for underground utility lines detection: using utility drawing/maps	Ensuring that operators are aware that plans are not always drawn accurately to scale and should not rely on them to obtain distances or depths.
7.	LIs for underground utility lines detection: using detection equipment	Ensuring that the person doing the survey understands the limitations of the equipment.
8.	Safe digging LIs: prior to digging	Presence and visibility of markings of the existing utilities (utility apparatus and lines) on the surface.
9.	Safe digging LIs: during digging	Ensuring that the operator planning to dig is aware that undertaking the practice of moling** or pipe bursting *** too near to other services or ducts may damage or enter them (i.e. other services or ducts).
10.	Safe moling	Ensuring that operators are aware that moles can be prone to deflection from their original course.
11.	LIs for proving duct/utility lines ****	Ensuring that continuous sections of ducts and sub-ducts (including sub-ducts jointed as part of a modular inner and outer duct arrangement) are tested and proven by blowing a close-fitting foam plug (or similar arrangement) that tests the integrity of the duct in respect of diameter and airtightness in a single operation.
12.	Safe use of machinery	Drivers should be trained to spot hazards and avoid them.
13.	Using jet guns	Operatives should take regular breaks to recover from fatigue (manual jet gun use).
14.	Material handling	Assess the risk of injury from any hazardous manual handling operations that cannot be avoided.
15.	LIs for emergency preparedness	Ensuring that operators are aware of performing emergency work to repair damaged services in order to make them safe or restore them.
16.	Equipment suitability and fitness	Choosing the right vehicle for the job is an essential part of effective vehicle management. The vehicle selected needs to be capable of performing its designated tasks safely.
17.	Safety documentation	Absence of point of work risk assessment (POWRA).
18.	LIs of safety culture	Inaccurate (misrepresentation of event for the purpose of financial gain) description of events provided by IP [injured person].
19.	LIs for safety learning	Lesson learnt: ensure banksman is alert all the time to detect unknown (potentially not indicated in the drawing) utility.

* Sump pumping is one of the simplest dewatering techniques: groundwater seeps into the excavation and is allowed to collect in sumps – which can either be the lowest point of the excavation or may be an area specially created into which water may seep naturally e.g. a well or sump.

** Moling is a trenchless method used to lay pipes. During the moling process, a pneumatically or hydraulically driven machine known as a mole forces its way through the soil along the desired path of the pipe. Moling avoids the need to dig a trench and can be used to lay water pipes and the heating coils of heat pump systems.

*** Pipe bursting is a trenchless method of replacing buried pipelines (such as sewer, water, or natural gas pipes) without the need for a traditional construction trench. "Launching and receiving pits" replace the trench needed by conventional pipe-laying.

**** Duct integrity/Proving: Mandrel are pulled through duct to prove joint integrity and test duct integrity for round duct, conduit or interdict used in telecom, gas & water networks. Each mandrel has a Teflon body with two braided steel loop eyes on each end for versatility and strength. (Also known as pigging, mandrel inspections test flexible pipes for deflection or out of roundness. The mandrel is pushed or pulled through each pipe to locate problems. A mandrel is a tool made with metal rods and fingers that will stop itself when it encounters an issue or blockage.)

Appendix 6- Transcript of focus group interview.

N	Questions and prompts	Speaker	Discussion
1.	Question 1	AB-interviewer	Looking at this model, does the model make logical sense to you ?
2.		IE-1	Yes. Yep, I do. Yep
3.		AB-interviewer	OK. So can you please expand more on that? Can you give me some examples?
4.		IE-1	The way you've got with the the, the, the monitoring, the reviewing, the recording of the information. So you, you, you you've got a system there where you've got the the the element you've got and what you're then doing to monitor that review that record it. So you then got that close out at the end of it. So you've looked at what the issues are, you've looked at how you're going to monitor that by monitoring it, you're reviewing it to make sure that it's it is working, it is doing what you're doing, what you've you're hoping it's going to achieve and then recording it all. All of that information, so that you've then got that document documented at the end of it.
5.	Prompt 5	AB-interviewer	Yeah.Yeah. OK. Yeah, that's that's that's that's great point. Thank you. So given that feedback, would you be willing to use this in in safety management.
6.		IE-1	I I believe in some aspects not all aspects, but in some aspect we're already using this type of scenario. This is stuff where IE-2, with the business management system that we already have in place, is already developed in that way. So with, with ourselves, with looking at incidents, whether they're negative or positive, that's exactly, I think, the systems we've got in place. IE-2 may have some more to add to that, but I believe we've already got a similar thing in place where we're doing that.
7.		AB-interviewer	Yeah.OK.Oh,that's great.That's great.OK. That's that's great, yes.
8.		IE-2	Yeah, I'd agree. I'd agree. I mean, I like the knowledge repository piece where you spoke about earlier in terms of it's [being] updated and there's the continuing loop go feeding back information into that. Because one area I've come across in the past for organisations developing KPIs- whatever you want to call them leading indicators they, produce a set of indicators and they never change from year to year to year to year.
9.		IE-1	Change them no.
10.		IE-2	And actually all all it does, the danger of it is you start with 10 for example. Or, I mean you've got 19 on your list, it becomes 30, it becomes 50 and before you know it, the organisation is absolutely overwhelmed with trying to measure 50 indicators every month or wherever. Often they will say that they review these things and actually yeah, some of them just become, you know.
11.		IE-1	Complacency.
12.		IE-1	Spinning plates.
13.		IE-2	Out of date basically, and they never, they never remove them off of the list because of the fear. There's almost a fear that actually because they've got onto these onto a list initially.
14.		IE-1	Yeah.
15.		AB-interviewer	OK.
16.		IE-1	Documented them.
17.		IE-2	The they, they've someone there's nobody capable of making a decision to actually say remove it. It's no longer relevant to what we do or it's no and it stays on there and they keep measuring it and actually what you get is a lot of employee engagement saying why

			are we doing this? Why are we measuring this? It's irrelevant. But but nobody seems capable of making that decision to to remove it.
18.		IE-1	That, but yeah, we've moved on. Done. yeah.
19.		AB-interviewer	Yeah. OK.
20.	Additional question from participant	IE-2	Whether it's fear or what, I don't know. But, but that's one risk with the the knowledge repository piece there. So it's good that when you spoke about, you know we feed into it, we keep reviewing it, we keep updating it. That's that to me is very important part of this, this model that you've built. The other question I would have on it to be fair would be where you talk about other top managers. What sort of level of top management are you talking about there?
21.		AB-interviewer	So that's that's involves around. Decision makers around safety manager, so getting their acceptance is not easy and again I can we can discuss this towards the end of the session. There's lots of things or challenges going around that acceptance of their top managers because they look for numbers whereas it's not all everything about numbers. So you you you saw the examples we can measure frequency but how about quality? That's the ambition here. So that's that's great points. Thank you so much for your comments. It's it's really rich discussion here and we haven't heard from academic part side others. So AE-1, would you like to add more comment if you have?
22.		AE-1	Yes, certainly. I think thinking back to my own thesis and kind of very much the mantra was the circularity of it. So I think having this, it's clear that there's a, there's a process. It isn't a start and finish. This is a process that's repeated. You learn from it, you almost tighten, tighten it up as you go along. And I think relating to the previous comment about that list of indicators gets longer and longer and longer and longer and it becomes an unmanageable task where you've got that circularity built in. You're constantly reviewing, refining and making it more sophisticated and effective. So yeah, I tend to agree with the other two participants' views on this as well. They, yeah, I think it fits my academic viewpoint.
23.		AB-interviewer	Mm hmm. OK. Thank you. And yeah, AE-2 ?
24.		AE-2	Thank you, AB-interviewer. Yes, I think instead of commenting on what you've said, I will comment on some of the points that IE-2 and and IE-1 have made. I I was really, really interested in similar to to AE-1 really about this expansive list of know people are unwilling to change and and IE-2 mentioned about fear now. Now I've seen myself where where people feel that the finger's gonna be pointed on them at some point if they if they're bold enough to change. So I think that says something about the culture really…
25.		IE-1	It does
26.		AE-2	..where maybe people feel as though they're being blamed. I mean, you you seem to agree with that IE-1, would you?
27.		IE-1	Yeah.I I do because I I'm. I'm gonna be honest with our own. Our only organisation, myself and IE-2. Cause IE-2 works with me and we we we struggle sometimes, as I say with some of our our our items where we've documented things now myself and IE-2 will discuss it and certain things that are no longer relevant. We will remove them if if it's not required anymore we will remove it. But I can tell you now if we went to some of our.
28.		AE-2	Tell.Yes.
29.		IE-1	Senior management and asked that same question They would not want to make that decision. They would put that back on to us and me and IE-2 are trying to educate them in regards to how we think they need to look at this, look at the information study, understand it better for them to make those kind of decisions going forward. We're always there to help and advise where required, but it needs to be more from that senior management team and I think that's where IE-2 was alluding to with who are you, who are you putting as your senior because.

			From our point of view, I can tell you now this goes right up to the MD.
30.		AB-interviewer	OK.
31.		IE-2	Yeah, and that, sorry, that's IE-1. That's exactly where I was alluding to in terms of how high are we going with this, because for me any of these models, they're great. But if you haven't got the buy-in of the top leadership of the CEO or the main main people, they're not going to succeed because you know everything's pushed down levels to the safety managers as IE-1 has spoken about there and it's all put on the SHEQ team and the safety team.
32.		AB-interviewer	No.OK.Mm hmm.
33.		IE-1	Yeah, waste of time
34.		AB-interviewer	Yeah. Mm. Absolutely.
35.		IE-2	To make all of the decisions almost and then they feedback in these leading indicators to the, to the main people, but unless those main those CEOs, et cetera, understand the risks that they sit on as a business almost in terms of safety as well.
36.		AB-interviewer	Mm hmm.Yeah.M.
37.		IE-2	It's it's very difficult to get to get the progress and to get the continuous improvement that you're looking for and to actually get the full use of some of these leading indicators that you've created and that you you know, you're getting good information from, but. They're just not. They just go nowhere, almost, and for want of a better word. And for me, you know, I I've sat in directors meetings where it's very clear that that's those directors don't understand their responsibilities in terms of safety, they don't understand even, you know, even more poorly, almost they don't understand some of the risks that they sit on at the major risks. You know, the big risks in that organisation. I'll give you one example just for, you know, for your own benefit.
38.		IE-1	Yep.Yeah, some of the systems. Yep. Yep, the processes.
39.		IE-2	I sat on a on a discussion where we were talking we we used to run the power station on company A.
40.		AB-interviewer	Mm hmm
41.		IE-2	And when the director of the the operations was asked, well, what are the biggest risks in that power station? You know what? What if something major goes wrong there? What could it be? And they didn't know. And they're running a £10 million, you know, power station on Essential line that if that goes wrong company A's got no power. Basically, you take the whole of the island out and and so it's about and. And that's really poor for me that that director doesn't doesn't understand those risks that the safety valve needs to work because if the safety valve doesn't blow, the whole station blows and you know, so there's there's it's all about the knowledge and the competence to me of those senior people as well as the the safety managers and the other managers, the operational managers almost within those businesses.
42.		AB-interviewer	Yeah.Yeah.Mm hmm.
43.		IE-1	Gotta start from the top.
44.		AB-interviewer	Oh, that's great example. Yeah. Thank you. Thank you so much. That's that is great point as well.. yes, AE-2?
45.		AE-2	Yeah. Sorry. Yeah. The the other question I wanted to ask just a a brief one is there's obviously IE-2, Do you? Do you think that what you've described today applies to other companies you work with? In terms of the fear factors and all of those sort of things.
46.		IE-1	Yeah, my answer is yes. I I believe it is rife within our industry not, not just our industries, but within business itself. I I I don't believe when certain senior managers are brought into the sectors or the industries that as IE-2 has alluded to, they're they're not fully briefed they they don't understand, they aren't educated, they aren't trained. And that one of the things that, myself, IE-2 and my team are about to do, everyone in our organisation is about to do a IOS course, whether that be all of the office staff, the mechanics, they're all doing one day, anybody supervisor to management level, they are going to be doing a three day managing safety course and the

			directors are going to be doing the director course that way they will have a better understanding when you're looking at these leading indicators and everything is kept. IE-2 has alluded to. They should then have a better understanding to say, well, hold on a minute. Yep.great or no, we're no longer needing this one. This can now be removed. It just educates them a little bit better and hopefully makes our lives a little a little bit better as well and and safer, of course.
47.		AB-interviewer	OK. OK. Thanks. Thanks for that. Yeah. Yeah. IE-2 . Yes, please.
48.	Additional question from participant	IE-2	So just one, one other question for me on this model is what did you consider the size of organisation that this may apply to you know, because if you're a, if you're a four man company? Is this relevant to a four? You know, a small business, a medium business, or are you aiming this at large businesses where where are you looking to this model to be applied to in terms of business size?
49.		AB-interviewer	Yeah, yeah, of course. So, yeah, the the actually that question opens up opportunity because again this can be applied well. We can try and test this model. So as I said, this is in theory. So we developed it. We started on the testing. The developments are part of it, but that can be tested again. In different sizes of organisations, and again, if we have future partners in the in the why not, we can try and apply with different group of organisations, different sizes, different sizes and cross compare And now to continue with the question, I would like to have views from other participants, can I can I ask you IE-3, please. What is your initial thoughts when you're looking at this? Mm hmm.So looking at this process, do you think this makes logical sense?
50.		IE-3	It it is totally logical for me. It our our experience that we we do targeted inspections within within our business, some of the reason why we do targeted inspections, we used to do do an average weekly inspection. We call that the site, you know, health and safety inspection or SHE because it's classified as her environment as well and we went off that. Because the data showed us that a person with. So we had like 40 questions, say 40 questions. And they and the guys would do this every seven days. You know, Monday to Friday, so once a week. Maximum of seven days and.What we found was most of the people, if they didn't understand what the question was and it was simple, you know, is the fire extinguishers, you know, they didn't then delve into where they all in date, you know, with the clips on, you know, blah blah blah wasn't that but they would, they would default to housekeeping. 'Cause, that's the thing they could see that's in front of them. And actually that's where they in their mindset was. If if I remove that pallet out that walkway, nobody will jump over it. So therefore they go, there's an inspection done. Yeah. So we moved away from that model and then we set a number of questions per subject. So if you went to back to fire extinguishers, there'd be 12 questions on fire extinguishers and then three that you could think of specific to your location, your site, your contract that you were on, so. So. So using that analogy, that model that you've just put there works well in that environment. So for me, yeah, that works perfectly well.
51.		AB-interviewer	Mm hmm.And.OK. Thank you. Thank you for your comment. And can we hear from others? IE-4, maybe do do you have anything else to add to the comment?
52.		IE-4	But then I don't, I don't. I I think it's perfectly operational model.
53.		AB-interviewer	Hmm ok
54.		IE-4	It looks to align very closely with the continuous loops. I think that most organisations use in terms of health and safety or any other real function you know, with a continuous learning loop. It I can see how it works, I've, you know, seen it's in practise again for me. I think all organisations, I think with ISO-18001 safety standard that has something very similar in it.It's actually. Implementing it ; Getting people's buy into it, we can have a a lot of it happens, you know, industry standard notes of good practise and that sort of stuff. Those are the bits. It's capturing the data to make the system actually work. I think is the biggest thing that I see where it's. Oh, yeah, it's OK. Oh, yeah, it's all right. You know, we learned from the major events because everybody's shaking up and goes. We need to do something.It's the implementation. It's the little bit that I think you know, once you've got a safety system in place that's provable measurable of work and you can see the impacts of it, you know, getting to the next stage, you know, we're all out, you

			know, 0 harm and zero accidents. You're only, I believe you're only going to do it in small increments now, not the major steps that we have when health and safety became.
55.		AB-interviewer	Yeah.Yeah.Mm hmmMm hmm.Absolutely.Mm hmm.
56.		IE-4	A subject that people took as seriously as perhaps they otherwise should have done. That would be my comment.
57.		AB-interviewer	OK. Thank you so much. Thanks for that. And IE-5, can I have your thoughts about it? Yeah.
58.		IE-5	So so. So I echo some of IE-3's comments say that that is added in in them about expanding on those sort of almost those checklist pieces. But to get people…
59.		AB-interviewer	Oh, yes, yes, please. Yeah.Mm hmm.Yeah.
60.		IE-5	… to feel and understand. So one things we a lot of this the questions we ask is trying to get our teams to almost self assess where they are in terms of where they perceive their risk profile is. So yes, we've got a set of five extinguishers, but what does that really mean? Where does that go? Without almost alienating some of our team too. So we've got to be very careful that. Especially our SHEQ teams don't turn into policemen. That they are part and parcel of that team. But it's in how we record that. So we almost went too far as a part past the team. There's lots of stuff in the report. What they they can get overlooked. We don't get the database behind what we've got. Because we don't mark them as an issue because they've been dealt with there and then and it's how we pull that together without that that policeman type. So. But in terms of the model, yeah, as as IE-4 and IE-3. Is it's what we do, isn't it?
61.		IE-4	Yeah.
62.		AB-interviewer	Yeah. OK. Yes, thank you. AE-2, Yeah. I see your hand up. Can so do you have something else to add yet?
63.		AE-2	Yeah, just a a question of clarity for IE-5, really. But when you talk about, I think I know what you mean, IE-5. Cause, obviously I've I worked in the industry for about 10-15 years for coming into academia. But when you use the word policeman, are you describing someone here who simply comes along with a big stick as opposed to someone who comes with help and advice and support? What's your definition of policeman?
64.		IE-5	So yeah, so, so, so, so. So you've you've got it right and then there's a fine balance between our our sort of safety advisors coming through to some support the team as they they tread a very fine line between you've got to do it this way because that's what it was. What we need to do and you're not going to you're not doing it. Here's not conformance there's your big stick and it gets escalated versus actually you haven't done it with intent but but we need you to be over here. How do we coach? How do we get you there? How do we? How do we improve that position? Yeah, you should have a segregated walkway over there. Or why haven't we? Or did you perceive that there was a risk there in the first place?
65.		AE-2	Yes. OK,. That was really. That, you know, if there's terminologies you use in that could be interpreted. You know, I'm just picking up on that just to get that clarification. That's it. thanks
66.		AB-interviewer	Yeah. Thank you.Yeah, absolutely. That's shared responsibility that we're missing out. Yeah. And also, IE-3, you have something to add, please.
67.		IE-3	Yeah, it was just it reiterate what IE-5 said really. It's for me what the policeman is. It's the guy that turns up with the millboard in front of him and he starts taking notes and he doesn't engage with the chaps who were doing it wrong, you know, and he and he goes back to the office and sends a big e-mail to everybody, you know, look at this. These are so dangerous. These people should be shot, you know, that sort of stuff. Well, actually really what we want that the SHE team or SHEQ team and IE-5's respect is is to engage with the chap or the chaps or the lady you know.
68.		AB-interviewer	M. OK, I see. Yeah.Mm hmm.Yeah.OK.OK.Yeah, absolutely.

69.		IE-3	You know the way we sort of try and educate our guys through this is is ask them what they're doing and mainly get them to tell you how and why they are doing in the way they are doing it. Now you may or may not have read the RAMS before you have get to that point. Cause I don't know what about you but I am in my 60ies and I cannot remember what I did 5 mins ago, never mind to read the whole set of 25 pages of RAMS form. To make sure that the chap walking down the road is actually left four and from the right foot and not right foot and from the left foot and you know it's it's so. I can't remember everything. So I'm generally speaking would go out and and ask them is is this what is this what's in your hands lads? Because if it doesn't look right, it generally speaking isn't you know but but that's only experience. So would you get an 18 year old asking a 29 year old that same question probably not and and there's a big learning piece there to to try and change the world if you like but but yeah it was more to just say to IE-5 yeah.
70.		IE-5	You. I'm alright.
71.		IE-3	We, we, we we suffer from the same issue. Yeah. And she get a graduate engineer to go out on his own and do an inspection is really unfair on that chap or that or that Lady because they may not know everything. They're they're intelligent people, etcetera, but they may not. They may not be street wise as to that chap who's doing something that's not quite right. Whether that is quite right or not. So we try to pair them up with somebody that's got a bit more experience on the project. So they don't get hoodwinked or they don't get mistreated or sworn at all. You know 'cause people, people when they're in the being viewed start doing things wrong without without intentionally doing it wrong it you know. Yeah. Yeah. Sorry.
72.		IE-5	So yeah, I mean being a bit more lenient then.
73.		AB-interviewer	Yeah. Yeah, absolutely. Yeah. That comes to human element again. No, thank you so much. Yeah, I can. I can definitely share your views on that (IE-3). And also, IE-4, I I, I, I, I guess you have something to add to this point as well. Yeah, please.
74.		IE-3	Yeah, no problem.
75.		IE-4	Yes. Real interesting topic and subject that we've done quite a lot of work up. And because we've had very similar issues and I think every organisation will have had with how the health and Safety Department is perceived. And what we're trying to do with ours is the health and safety departments tend to go out. They do their inspections, identify things that are non-compliant. Walk around with the site managers or whatever you go. You know, we're not sure this is right. You know, we're giving the example of the walkway not being correctly set out. And historically, they've gone, you know, walkway's not right. It should look like this. Thank you very much. And off they go and you've got a week to correct it and be back in a week to check it. We've tried to actively involve our health and safety inspectors with actually correcting it. The locate you know your walkway is not right.Let me help you put it right to make them a part of the team. They're not then seen as the guy who comes and points and leaves, but actually gets involved with the correction of it. You know, if they've gone out, they've seen somebody doing something they don't think is right. You know, question the guy. Why are you doing it this way? What is it you know and take on board experience of health, safety. They've probably not. They're unlikely to have actually done the task that they're observing, but to work with the guy who's doing it. So why are you doing it? Why are you doing it that way? Because they'll be doing it that way for a reason. They're not doing it for fun because this is what works. OK, why does it work so in the bigger picture now? How can we make the way that works safer, rather than having the method statement that says this, we need. This has been written in the office which comes back to what I was saying it would be really good if you did it that way. Sat here in the room. Actually, let's give it to the people on the ground and get their feedback because their input is as important and let's make what they do safe rather than tell them what to do safely.
76.		AB-interviewer	Mm hmm.Mm.OK. Yeah.Mm hmm, yes, yes.Thanks a lot now.Yes, yes, yeah, absolutely.
77.		IE-4	Kind of makes sense. So that's kind of how we're trying to get around these issues. And that's where you develop your good practise.

78.	Question 2	AB-interviewer	Yeah. OK. That is that is great example and insightful discussion. OK, so moving on to the next area of discussion, which is concerning the framework. So how easy or difficult to define to use it. So you you you had a go at it and what do you think how easy or difficult it is to use? So can I can I start with you, IE-2? Yeah.
79.	Additional question from participant	IE-2	Thank you.OK. Yeah. No, I'll. I'll be absolutely honest. I didn't find it easy at all. It it's quite a a busy infographic. It it's, I suppose the first question I had was, what's the real difference here? What's what's the implication of whether it is a passive or whether it's an active leading indicator at the end of the day, they're at their leading indicators and I think for me, any business is looking at a leading indicator indicator. So does it matter really it's over time and it's a passive or does it? What's the real impact of a passive against an active and I think that's the bit I was struggling with in the when I first saw it in terms it was almost the. So what question I had at that point because.
80.		AB-interviewer	That is great question.Yeah.OK.
81.		IE-2	As a you know, a practitioner, you just have leading indicators, full stop and and and and that's how they're used for me in business. So, but I understand the purpose. What what you're trying to do here, but I I it was a bit of a So what? And I didn't find it particularly easy to. And the proof of the proof of the pudding for me is when you ask the question and AE-1 started to look at it. And volunteered quite kindly is to to start with the test question. It was almost like I'm not is it is it? Isn't it? I'm not sure. So there was a bit of there was a bit of indifference in there for me and I didn't find it overly easy to use personally.
82.		AB-interviewer	Yeah.Yeah.OK. Yeah, that's that's that's great point. And just to quickly to answer your question again, it is helpful when when we think about users we we we have users at their work site and users who are will be sitting at this knowledge repository looking at it and analysing this leading indicators and it is particularly useful for them because then we know and especially for for work people at work site too for once you you know whether it's passive or active or active it's it's.
83.		IE-2	That's being honest.
84.		AB-interviewer	And then you can know how you're going to act upon it, whether it's active, if work sites at work sites or people are noticing active leading indicator, they can correct it in a timely manner, whereas passive leading indicator cannot be in a in a timely manner corrector. So then it has to be referred to top managers to look at it and corrective. So thank you so much for that point. And next would you like AE-1 again? Oh, AE-2, you have your hands up. Yeah, AE-2,You have your hands.
85.		AE-2	Yeah. I mean, one of the things I've I think I think IE-2 has made a fair point there an about the user friendliness of this and I'm sure you'll come on to what you're thinking about developing later. But I think to for IE-2 and and IE-1's position, if you if you use an application today on your phone, your phone, all you want to do is click a button. And for whatever feature searching for just to appear or for the the data to appear, or the prediction to appear, or the choice of clothing to appear whatever it is, you, you just so to to enable you to get to that point, you have to develop the back end, and that's what I has done here. She's she's broken it down into granulation. So she understands all the complexities of whether it's something that can be actioned on site or something for more for senior management to get involved and then trying to break it down into all the classifications so that we can then move to user friendly solution moving forward…
86.		IE-2	Hmm.
87.		AE-2	…which again, I'll let AB-interviewer to talk about. So I don't want to steal a thunder. So. So that's why we've started off with a complex just to understand all the nitty gritty. So it's almost as though we can pull the cutscene testings out and understand all the little bits that are fitting together before we then put it all back together so they can. Somebody can see they don't want to know the insurance and outs and all the rest of it.
88.		IE-2	OK.

89.		IE-1	No. And then make it simplistic for the end user.
90.		IE-2	Yeah, we're not interested in the algorithm. We just want the output.
91.		AE-2	That's it
92.		IE-1	Yeah, they output the output and how we can how we can rectify or or or praise for positive yeah.
93.		IE-2	Ultimately, yeah.
94.		AE-2	OK, so sorry to interrupt
95.		AB-interviewer	No, no, no, that's that's that's absolutely fine. So do you want to add your own comments on on on the framework?
96.		AE-2	Yeah. I think in terms of my own comments, I think IE-2 and and and IE-1 have highlighted the point I was making. me being an old tradesman myself for 10 years and then sort of going into academia. You're taking the opposite approach when you're going into academia and then talking to to industry. So it's about presenting things in a in a format that that people can use moving forward. Well, I think that's the future of direction of work to to turn it into a a huge user friendly product that somebody can briefly understand, you know, understand the basics of the mechanics, but then just literally press buttons, get an answer. You know, that's not what.
97.		IE-1	That's that's certainly how we're how we're developing stuff within our our own organisation. Every time me and IE-2r another one of any collegue are looking at the stuff we're trying to do it where the end user we're trying to make it as simplistic as we possibly can. So that as AE-2's alluded to all that all the work he's done in the background, but when it gets to gets to that person. It's simple. It's yes. Well done, pat. On the back. That's really good. Positive work, fantastic or no, you've gone a little bit wrong here. What we need to do is we need to implement this. We need to change this process. This is this is how it's going to happen.
98.		AE-2	Hmm.
99.		AB-interviewer	OK, AE-1, Do you have anything else to add?
100.		AE-1	Yeah, I think I see. I see the points being raised and I think I think they are. They're very fair points. I think I obviously haven't ended up in industry. I've ended up in, in, in academia. So I think I'd do very much enjoy the the kind of the intricate granularity of it. But I I do see the point that this is almost you know if you're writing a report, it's really in depth. It's you know it's got all this fantastic detail. You still put an executive summary at the front and that's what that's what gives you the the real output. So I think it's fantastic because you can tweak this, you can see how it works in the background you can. You know, as as new things merge, new new insights come to the fore. You're going to be in a fantastic position to to, you know, monitor this and and and to amend as needed. But in terms of that user friendliness, if you're, if you're going to be in an organisation, you're in a board meeting or a safety meeting or whatever it is you're going to want. Quick. Yeah. So I think the combination of the two, I think that's my thesis. I had some similar, there was a very in depth model and then there was the, this is what you want to see first. So I think, yeah, I think the comments are fair, but I must admit I do enjoy the categorisation and the definitions and what have you, but I think that's perhaps reflective on me, yeah.
101.		AE-2	Yeah, me too.
102.		AE-2	I think that was the point that I was making it. It's it's right to get the detail and the granulation right. But now what we're hearing from practise and we've got to listen to this is about turning to a manner that the average person on the street can use and use it, you know simply.
103.		AB-interviewer	So can I ask the same question to IE-4 ? So how easy or difficult did you find using this framework ? So you, you, you practised using it.
104.		IE-4	In all honesty, I think it's very confusing. And that's probably because of the nature of the terminology. You know in the quantitative and qualitative implicit explicit that they're probably not sort of Even so much as passive and active leading indicators. I suggest

			they're probably more academic terms than commercial terms. If I put that in front of most of my guys and said this is how we're going to do it. Then all go off and go. Yeah, I wouldn't really understand it. If that's, that's my initial view of it. It's it's quite a hard read. And you know when you've got words like emergent ALIs can probably work because I've had a look at all this before in advance, though. Wow, this is complicated. I don't think it is actually. And it's it's quite logical. It's just an issue, perhaps with some of the terminology, and I don't know what the alternatives are.
105.		AB-interviewer	Mm hmm. OK.
106.		IE-5	I think I think IE-4 agree with you. I picked up and looked to it [the analytical framework] and when actually to try and break this down without being taken through it, you wouldn't.
107.		IE-4	Yeah.
108.		IE-5	Yeah, your [AB-interviewer's] explanation was absolutely bang on, but it needed that verbal piece to layer up on top of it to make it make sense.
109.		IE-4	And and I think it if it needs that level of explanation, if you're running it through an organisation. The explanation will. Be changed, filtered down and misunderstood by the time you've got six people away from you. So if I took this and showed it to my health and safety organisation at the moment, your explanation is infinitely better than I'll produce and it will. Just so by the time it gets to where it needs to be, everybody will look at it and go what? Don't understand it. Too difficult and they do tend to, yes, absolutely. It's it's not, it is Chinese whispers, but it it's it's just that lack of knowledge. It'll get watered down. They'll look at it and if you give people something that looks complicated in my experience they won't say hang on, let me sit down and work out what they're trying to tell me. They will switch off. Look at the pictures. If you ask them, do you understand it? You'll get a yes and Ihave not clue what it said.
110.		AB-interviewer	No, these are great points. Thank you. Thank you, really.
111.		IE-4	And
112.		IE-5	I I I.
113.		IE-4	And I think, and I think that is true, I mean IE-3 mentioned, you know his questionnaire with his 34 questions on it and that sort of stuff. You give that to a bloke of the kind of guys at the coalface who are doing the work. They're not there because they're academics and they're great at reading and writing. They're there because they're practical. It you know, as IE-3 said, and I'm it's positive because I'm in the 60s as well. You know, I can't remember breakfast. We give them a 34 page RAMS document and then questions on it. Really, most of my guys, the only time they read 34 pages is when there's a World Cup on and they're reading it all the sports reports in the paper. They don't read this stuff. And that's just my experience. They'll have it. They've got it. It's here. You know, I do my site inspections and I get absolutely accurate RAMS, and they're happily telling me it's a positive mark. We've kept these clean because we knew you were coming out to have a look, and we'd keep them clean and we'd use them. I want you to read them. But that's the mentality of the people that we're trying to protect. And I think I think it's great and I think it works, I think and I'm sure you know might come on as development an interactive version.
114.		AB-interviewer	Mm hmm. Yes, that's a yes.
115.		IE-4	Of this would be really good. So when you've picked your passively leading, you get something else and work through it. I think we really, really useful. Then I think you get buy-in because you're only asking them a question at the time.
116.	Question 3	AB-interviewer	Yeah.Yeah, that is, that is really great point. You you tapped into two things. First of first of all, you [IE-4 and IE-5]actually already started to answer my third question, which would be around. No, no, no, no, both of you. You started answering the third question, which is around whether you would.

			apply this in your own safety management and second of all you you, you you started to tap on the opportunity here. So again so this is in in theory. So this is theoretically or the background background or.Things that are happening at the at the knowledge level, but this to which form do we apply it? Do we turn it into an application or software where they can use it in their mobile phone and how we rephrase it to make it more acceptable for end users? Again, that's an opportunity for us to maybe work together in the future, so that's really great point. So I didn't hear from IE-3. I think do you have anything to add? Do you agree with the comments made earlier?
117.		IE-3	I've attended. Yes, I would tend to. I would tend to agree the I think within within the constructions industry. We tend to try and keep away with a page that's for the words. You haven't done that; you've got lots of colours in here and you can map across the colours, there's no problem. But I suppose if you hadn't explained it in the beginning, some people may have struggled with reading it and mapping it across. But for me it was fine because I understood what you were trying to do. So in that respect, I'd agree with the chaps. I'd agree with the other two chaps.
118.		AB-interviewer	Mm hmm.OK.That's great. Thank you. That's that's encouraging. Thank you. And vid. Yeah. You AE-2 have something to add?
119.		AE-2	Yeah, I'm. I will interject on this.And we, we So we we've we've actually suggested to organisation B to now apply this work in practise but then work on something which is more simplistic. That any basic user could could then use as an app or a piece of software or whatever. To apply it in practise. So this really is the back end. This is the sort of the the key thinking that the sort of difficult bit if you like, but but it's how we now get that and transform it into something that's more far more user friendly. He's really key. So what you've what you've all said today actually supports that idea that you know we need to simplify this and and develop into something more usable. So thank you.
120.		AB-interviewer	OK. Thanks for your comments. I agree with AE-2. I would just like to reframe this. I think so one other problems that we have in this whatever we are building is like software engineers knowing just the the the part that they do, so they're turning. Their any knowledge into a software piece? Whereas they they don't have subject matter expertise in in the area. So I'm thinking so this framework is that.Middle middle ground where software engineers coming to that building up on on this can develop their their their software or whatever the application they're building whereas they they say safety subject matter expert is put down here as a as a framework so that I think that I think that's that's the objective of this framework so.Building on that, do you think having that support, would you be willing to to use this in, in your safety management, in your organisation? So next over to you IE-2.which I had alreadymentioned here, you partially answered this already. Would you be prepared to apply this research in your organisation, safety management ?
121.		IE-2	I'll answer from my perspective, yes, I mean, software's becoming ever more important, you know, in in life and in the world and and in in business. So if you've got a decent software product that that drives safety performance and improve safety culture, then I I certainly would think that our organisation would be willing to explore further and to look at it. I don't know about IE-1's opinion, but I'm sure he's probably the same.
122.		IE-1	Yeah, I mean, I I sit on the I sit on the check board for all the other divisions. So I I can 100% agree with what IE-2 is saying. We're always looking at how we can improve, make things better. But again, going back to making sure that and I understand exactly what AE-1 and AE-2 are saying. You've got all this information that's got to sit in the background, but the person at the end who's using that, some of the supervisors, the management, the operatives themselves, we just need to try and make it as easy and simplistic as we possibly can. For them to get the right results from it.

123.	Question 4	AB-interviewer	OK. Thank you. Thank you for your feedback on that again. And this is the last area we are moving on to. So this is examples of leading indicators. So referring to this table, what are your initial thoughts? When you when you start looking at them and reading them.
124.		IE-2	Well, I'll go. I'm not an expert in molling and in some of this construction stuff compared to IE-1, who's done, you know, he's been involved in it for 23 years, etcetera. So he's got far more knowledge than I have on some of these activities that you've defined on this list. It's good list and and you know they're all. I'm sure they're all valued leading indicators for me. What? When I looked at it, I'm thinking it seems very much around information, instruction, training and supervision to be fair. So you talk about things like safe use of machinery and operatives using jet guns and material handling, etcetera. They're very much what I would call as an old practitioner probably. And I'm sure AE-2 probably is with me on this one as well. And IE-1, you know that's what we would call the IIT, the information instruction and training. And if you get that right, a lot of these leading indicators almost. You know, they they they're measurement, but I'm not sure you would need all all of them for me personally personally.The other thing I felt when I read it, there's not much around. I would say people things like health surveillance, welfare, you know, fit. Yeah. Fitness to work stuff and things like that maybe come into some of this and there's there wasn't much in this list around that, I mean, but you what you've said is that you've clustered them down to 19 from 100 and odd and they, you know, they may well be of included in some of those others.
125.		IE-1	Direct what capabilities?
126.		IE-2	And and the other thing that's you know that I've spoke about earlier, it's about attitudes and it's about behaviours and you can have all of these leading indicators, but if the people on the ground haven't got the right attitude, haven't aren't behaving in the right way there, that's where your problems start ultimately for me so. It's the attitudes behaviours, it's the leadership, competence and knowledge and it's the information, instruction and training for me. So but but yeah, they're all valid as far as I when I read them leading indicators.
127.		IE-1	Yeah. Sorry, just for me, for me to it's like IE-2 saying certainly the competency side is a is a key player. It's like I know you've you've you've indicated about underground drawings and bits and pieces like that, somebody with knowledge and expertise, because you can look at as many drawings as you want and you'll say the gas pipe is in the left hand pavement 2 metres in the sewer pipe is then in the road, blah blah, blah. When it comes down to it, I can tell you now most of the drawings are wrong. So you could dig in that pavement that gas pipe is not in that pavement. The gas pipe is in the road, but what you will get from an experienced person is looking at the furniture that is around i.e. covers, signage, lids, those sort of things will tell you where those items actually are. That only comes from experience. So someone like myself, yes, I will look at the drawings. I will read the drawings. I will get an understand of what they are. But I'm also using my experience from looking at ah, there's the lid for the gas valve, or there's the lid for the water hydrant so that pipe isn't where they're saying it is, it's that it's over there, those sort of experience. I can tell you myself from digging down where also drawings have the depth never have I ever took any notice of what the depth is on a drawing because they're nine times out of ten they're wrong and it's not just down to the drawing either, where it can come from is the Council may have come in and where it was a concrete road. They've now decided well, what we're going to do, we're going to resurface it, but they're not going to dig the old out. They're just going to keep going. So all of a sudden the depth has changed, but not due to when the person put the utility in the ground. It's what's happened afterwards. A prime example I'll give you quickly is on the Project A worked on that site where they were bringing the the the training from Point A to go across to Point B. I laid water pipe down in that one, which I had to insert into a concrete pipe first because they were putting 14 metres of soil on top of that afterwards .So when I laid it, it was only a metre deep when the whole work was finished and they'd done all the groundwork. That thing was 14 metres underground
128.		AB-interviewer	Yeah. OK.Yeah. Yeah. So that.

129.		IE-1	So it's just it's it's it's it's it's having that experience and that knowledge in regards to to to that the other thing I noticed was you you said a few things about ground conditions and bits and pieces, some of the other things is in certain areas you can add things like chalk. Well, chalk is fine when you're digging, but then it gets wet, you get fumes off of that. So all of a sudden you've got an added risk, but again comes from knowledge comes from experience. So training and competency has got to play a big part in this.
130.		AB-interviewer	Yeah.Mm hmm.Yeah.OK.Yeah.OK. Absolutely. Yeah. And I I think you were you were tapping on this one of the examples of leading indicator when you were referring to this drawings being not accurate #6 there. That is exactly true. Yeah, that's that's the things that we we managed to do is from this accident records and moving on to other. Yeah. AE-1 please. Yeah
131.		AE-1	Just a quick one to back up one up as well. When I moved into I'm I'm based in Location A. So when when I moved into our property, we got some problems with the sewer, Company X came out because they managed to sewer network in the area, Victorian property. They thought the sewer went out into the street. It didn't even run the length of our garden and goes into a shared street at the back that is an even contemporary. This is a Victorian sewer. It's been out remapping the area.
132.		IE-1	Yep, Yep. And that's and that's normally the same for the water as well. What you have there, AE-1, is whereas on new builds, you've got the, the the pipe will run through the centre of the street and then you've got the off pipes service pipes as they call them that go into the individual houses, Victorian times what they did, they had one pipe, they run it through all the back gardens and then had to feed off of that. So when they used to come and put the water metre in the first house in the street was getting the bill for the other 12 houses because it was ripped. Until somebody found out
133.		AE-1	I'm 3rd that works for me
134.		AB-interviewer	Ha ha ha.
135.		AE-1	But yeah, no, just thought I'd add to that one that you know, right the way back, yeah.
136.		IE-1	Yeah. So it's it. Is it a lot of knowledge and a lot of experience and unfortunately we're starting to lose that within the industry. That's that's the other problem we've got now of course.
137.		AB-interviewer	OK. Thank you. Thank you for for your comments. It's really it really is a really good, good points you are making there. AE-2, do you have something to add? Yeah.
138.		AE-2	Well.Yeah, I think I think IE-1 picked up on there about losing experience and from what I'm noticing, there's a big push for people at very senior positions to be almost like accountants. And what what I've seen in some companies, I'm not sure about your organisation, but I've seen in some companies is the training the and the safety teams. Been reduced as a cost cutting exercise mark when when you said that we're losing that experience it is that one of the things you've seen or were you referring to something different?
139.		IE-1	You, you you've got a certain element that that is the case, but it's also the the, the youth of today do not want to come in and dig holes for a living. They want to sit like we are behind a desk, tapping keys in a nice clean warm home environment or office environment. They don't want to be at the end of a shovel digging holes in pouring rain in the snow and all of that. So we're we're not getting, we're finding it hard to recruit those type of people that are willing to come in and do that kind of manual work.
140.		AE-2	OK, fantastic. Sorry, I just wanted to pick up on that point.
141.		AB-interviewer	Yeah. Thank you. You you are indeed really active group. IE-3, maybe, can I continue with you? So we already answered to my previous question about your interest in adopting the framework for safety LIs. But moving into last area of our discussion- which is leading indicators themselves. So looking at this examples of leading indicators, what are your initial thoughts, just reading around them?

142.		IE-3	Certainly no, no problem, no problem. The yeah. Again, it's it's a slight slide full of words, so maybe slightly. You know you need to take time to read it really to understand. What what the meaning of each cluster name is? But actually what you've written in what is the the description of it is right. You know, when I've when I've taken a quick view and I've, you know, obviously not taken that long to to read those the. I'm not sure whether there's an easier route into that because. Every worksites leading indicators will be completely different or could be could be completely different from the one next door. So there's no one happy medium in in live data. Because because it depends on what you electricians will face a different issue than the guy digging the trench to lay a water pipe. But but but the grand title will be exactly the same, you know falls from here, you know. Permits what? Whatever. Whatever. The The thing is so. But for me that that that's fine. That's that's fine. It's just, yeah. I'm not sure if you could ever do it pictorially, but. And they're like, because our leading indicators dashboard as we call it, we'd send on the monthly thing and I could share the screen, but it's really confusing if you don't know what it really where it came from, if you didn't know where it came from, you go, Oh my God, what's that? You know, especially when it comes to you month 12 and now it's full and all the colours are there. I think it's really, really confusing because it's too small because there's too much data on it and and, you know, so there's no happy medium, I don't think is to how you, how you do a global report in that respect.
143.		AB-interviewer	Yeah, I'm.Hmm.OK.OK. Yeah. OK. I see. So next step is make it more acceptable for users.
144.		IE-3	Yeah, if you if you can simplify it in some way, I'm yeah, yeah, yeah, something similar
145.		AB-interviewer	Yeah.Yeah.OK, AE-2, you had your hands up next and after that I'll hand over to IE-4 as well.
146.		AE-2	Just just a question for for IE-3 on that point you make some really interesting points, IE-3. I just wonder if do you do you see merit in having lead indicators made more specific for work tasks or types of projects that rather than going through hundreds of these for and applying them as one shoe fits all hat they're actually tailoring them for those specific activities, would that be more beneficial for industry?
147.		IE-3	Do you know? That's it? That's interesting, AE-2, actually.Yeah, in some respects, yes, you could. So for instance, with within our organisation we have a dashboard with lots of lead indicators on it and we have a lagging indicator in the middle and we basically ignore the lagging indicators, the AFR action frequency rate, you know they, they they prove where you were yesterday. They don't prove what's happening tomorrow or today. And so we try to not focus on that as a business. We do not go RFR rate is this today, never ever mentioned it. We say on the board report at the end of the year well done, what we focus in is the number of people we injured. So how to how to stop that? So yes, going back to that to try and answer the question. Yeah, I think so, because I think our dashboard even even our dashboard is too complicated in a in a in a global way. You're trying to get everything on a piece of a three piece piece of paper and and you know and there's 1010 billion man hours in a year, you know and all that information on this one thing. So we then have another one that delves down into the divisions, there is 2 divisions within our organisation. So and they've got it's exactly the same format but but the detail is different slightly.
148.		AE-2	Yes.Yes.Hmm.
149.		IE-3	And I would. Yeah, I do see merit in that. And we do that on project level because on the project level, you're not really bothered about the group dashboard. That's for somebody else to worry about. Our one is what's facing me today, right, these these lads say they're going to be digging this trench, what's their risk? We know. How did we get it wrong last time? How can we? How can we make sure they don't get it wrong this time if they ever got it wrong, they may not got it wrong, you know, but nine times out of 10 we'll find fault somehow. You know, if you want to be. So I think yes, it would merit. Yes, we could. We could we could. We could do that definitely.
150.		AE-2	Mm hmm mm.OK.Alright, thank you. Sorry to interrupt, to AB-interviewer.

151.		AB-interviewer	OK. Thank you. No, no, that's that's fine. So, IE-4, please, over to you. Sorry to keep being waiting
152.	Additional question from participant	IE-4	Yeah. No, no, no, that's fine. I'm here to listen and learn in all honesty. I would wonder whether 11 specifically.Is a health and safety issue, rather quality issue. I'm not quite sure as we put in a lot of ducts and subducts quite how that works. I think the issue that I would have with this and I've had a chance to have a quick read through of it is they are. With the exception of that one. Potentially leading indicators. But I think you've got to decide for me how broad or how narrow you want to make the indicator. These some of these are very specific to a very specific task. Some of them are really broad and would cover almost any task. So. So I think to make it 'cause, I think the danger is if you publish this and said these are the leading indicators. There wouldn't be usable in 99.9% of circumstances other than probably the ones they came from.
153.		AB-interviewer	Mm.OK. OK. So yeah, that's that's really good point again. So just give, I'm trying not to give things in advance because there are things that the development that we have made that is under review, so which will be out for publication. Again, please do let me know at the end of the session if you are interested. I will be more than happy once they are published or already published studies we have to share with you. So you are touching on really good point about this specific. And generic leading indicators. The thing is, we need them all and there are different functions of different leading indicators. We need those generic leading indicators in order to to generically measure or the things that we are could be missing out. So they're useful in a way to know more about unknown unknowns that we might have that the things that we don't know that actually exist and threats that we don't know, whereas specifically the indicators we need to include them, we need that specific. Specificity. In order to take those actions so generic leading indicators, they just warns us about, we need to pay attention to this, but specific, they helps us to understand what are the steps we can take to correct it so.
154.		IE-4	Umm.Yep. Mean.
155.		AB-interviewer	This is really great point. So there there will be. So the publications coming out. So I'm more than happy to say in the future. So, but the point is we need them both.
156.	Additional question from participant	IE-4	Is it OK? So no. And I would like a copy of. OK, so our so would you not? Consider.Clustering under the sort of general activities, whereas you're leaving indicator examples would probably be come from your control measures in your RAMS
157.		AB-interviewer	Yeah.Yeah.Mm hmm. Mm hmm, yes, yes, absolutely it's.Mm hmm.Yeah.Mm hmm.
158.		IE-4	Which would then link through to what people have already got. On your control meausures these are that we do now and these are the leading indicators that are required. So I would make it general to across the industry.But in a specifically usable way for the implementation
159.		AB-interviewer	Yeah, that that is true. And again, that's an opportunity for us to, if you, if you are interested to, to work together in the future. So if you remember in the in the slide in the process there, there is knowledge repository and that's where this this all all comes together. So that that's the moment when analysts sit there dividing this leading indicators and learning more about this. So and we continuously revising and generic goes for, for, for for things to apply and specific again specific again this specific. Will probably best use with with end users the people in the work site. They will benefit more from that, so not every leading indicator is useful for people at the work site or for top managers for that matter, because again for for top managers to get their buy in we need more.Quantitative leading indicators, I think they they're more interested in this type of leading indicators because they want to see statistics they want to see improvement. Tangible quantification. Whereas for workers playing at their work site, that might not be the priority they want to be kept safe. So for them it will be different kind of leading indicator. So thank you so much that's that's very useful. So I'm really glad you tapped on that point. So and.

			I kind of lost track of the IE-5. Did I have your opinion on this? No. Can I have your opinion please? Yeah.Yes.
160.	Additional question from participant	IE-5	No. So, so, so, yeah, absolutely. There's a lot. There's a lot there, but we're we're talking about industry wide or task or sort of sector specific. The only comment to near is. We haven't actually described whether which sector this is aiming at.
161.	Prompt 3	AB-interviewer	Yes, and yeah, that's that's a good point. So would you.Which which sector do you think this could be applying when? When you read through them?
162.		IE-5	So so so I'm looking at this and a lot of this feels as if it's sort of highways driven and I'm probably cheating slightly because I saw the highways logo on the first model slide. But so we've just got to be careful in the language we're talking about industry wide know we're talking sector specific within that industry that these are leading indicators are sat within.
163.		AB-interviewer	Yeah, mm hmm.Yeah, that's that's so to answer your question, Sir. Yeah, that that was actually one of the questions. So whether it is, it looks relevant or useful for civil engineering sector. So that that, that, that that is one of the prompts. So thanks for touching on that. But again yes that's that's again this is just one example of identify leading indicators from number of other accident reports from which we just selected 12 of them. This can be applied. In in different and again it cannot be generalised from one to another. We cannot just take it and apply it in our interest. That's why we need that process. That's why we need that framework. So using that again in the future, we can identify leading indicators in other sectors or in other organisation for that matter, because again, even from 1 organisation to another, they're not similar, so they they can be using different leading indicators. So thanks for that.
164.		AB-interviewer	Yeah. Uh, AE-2, you had your hand up? Yes.
165.		AE-2	I was. I was only going to add a bit of explanation there. The the one thing I would say is, I suppose, IE-5, we're a little bit of a victim of focusing on utilities and highways because they are the funder of of of this. Two of the projects that we're running. So you'd sort of expect that. But I very eloquently said, you know, we it's about the framework and the approach that's generic, you know? So she answered that perfectly.
166.	Question 5	AB-interviewer	OK. No, no, no, that's fine. Thanks No, yeah. So again, another penultimate question of today. So around this leading indicators. So looking at these features of leading indicator that you described here, you mentioned about structure you mentioned about how easy or difficult it is to understand this. Looking at these leading indicators, so they have different features, so. Which feature do you think is the most important and the features are? I'll give you options, measurable, preventative or relevant. So what do you think is more important than others? Is it important for leading indicators to be measurable, preventative or rather relevant?
167.		IE-2	For me, it's preventative. It's it's. It's about being preventative in, in, in.
168.		IE-1	100%.
169.		IE-2	You know, because every incident you can prevent is it's it could be life saving. It could be financially, you know, economical. It's all of that. And so you know, everything you're doing here is about preventing for me.
170.		IE-1	Yeah, being proactive, being preventative.
171.		IE-2	Yeah, you know, relevance important. Don't get me wrong, because there's a little point in measuring the wrong things and measurable is important as well. But but the aim of the all of this is to prevent personally.
172.		IE-1	Yep. Agreed.
173.		AB-interviewer	I see. OK. Yes, AE-2, have something more to add.
174.		AE-2	Yeah, no, I would agree with with IE-2 there and and IE-1. Prevention has to be has to be the top of the agenda. But actually you you get to that by using measurable and relevant data, so it it's almost as though these other two are supporting preventative goal that you want that's that's the way I would think of it.

175.		IE-2	I agree,AE-2. In terms of you, you can't make decisions unless you've got the data to help you. You know you want data-driven decisions ultimately.
176.		AB-interviewer	Hmm. Yeah.Absolutely.OK. And we haven't heard from yet, sorry. OK. And we haven't heard from AE-1. You from your perspective, which which feature do you think you would?
177.		AE-1	Yeah.It's on, isn't it? Because I think there's there are triumvirate. They're all. They're all very important. I think it has to be relevant. If it's not relevant, why are you doing it? It has to be measurable so that you can take some sort of action afterwards. However, having come from, I kind of looked at facilities management in the past as well. There's this whole thing about reactive maintenance versus proactive maintenance. And actually, to me, preventing it happening is king here. So, I'm on the same page as everybody else. It's all three of them are important.Actually, it's preventing what's what. What you don't want to occur. That is the most important. So, yeah, I'm. I'm, I'm, I'm. I sit with. I sit with everybody else's. If you want this one, it's preventative. But they're on important.
178.		AB-interviewer	See as important. Mm hmm mm.Mm.OK. Mm hmm. OK, so we'll have consensus there.
179.		IE-2	The other thing I'd say sorry, sorry, AE-1, the other thing I'd say is that it's all about this provides real time, you know, information that's the important piece of it. It's it's not, it's not lagging, it's real time and you can take actions based on real time data.
180.		AB-interviewer	That's fine. OK. Thanks for your insight, IE-2. So can I continue with you IE-5.
181.		IE-5	Straight to me, the the good week they could be relevant because if they're not relevant, I don't mind if they can measure it or prevent it. If if it's not going to affect the guys then then then why look at it.
182.		AB-interviewer	So which one do you think?Ha ha ha.OK.OK. That's very interesting point there. Thank you. So that that's so if it's not relevant, the other features for you, OK, not not that important. OK. Thank you so much. That's that's that's very precise and to the point. OK and. With moving on to IE-3, can I, can I ask your opinion on that which which, yeah.
183.		IE-3	Yeah, yeah, sure. No, I think I think IE-5 nailed it there, but I was going to say it was a score draw between preventative and relevant. But given that I accepted that all that leading indicator we're going to be talking about at any particular project are all relevant. Because you wouldn't be talking about them if they weren't relevant. That's where I was, my brain was at. But preventative is where you need to… You need all three, honestly, but preventative for me there is the top one.
184.		IE-5	Yeah.
185.		IE-4	Yeah.
186.		AB-interviewer	Absolutely
187.		IE-3	You did? That's where you're trying to reduce harm to, you know, as as IE-4 said earlier to you know, the 0 harm tag. They're all tags. Absolutely. But if you're not, if you're not looking at trying to prevent. You know the injury the 1st place, then you may not. You may be missing a trick, so preventative for me was the top one.
188.		AB-interviewer	Mm.OK.OK. OK. And IE-4, can I have your opinion, do you agree with the comments made?
189.		IE-4	Yeah. Not not, no, I do. I'm still going back to my original thought. When you first asked me or first posed the question is that this, these three are just a new name for the time cost quality triangle. And I think you've got all three and all of them will fit somewhere within that. I think all of them are important. In their own individual way, because if it's not measurable, it won't be done and you can be doing the wrong thing. So you need to have an element of measurability in it. You absolutely need to have a degree of relevance in it.And you must and the object of the exercise is it for is, it is for it to be preventative. And you so each one ideally will have an element of all three of them. And if it's not got relevant to all three in it, it's probably not. It shouldn't be in there. But it but. But you can't say it's if it's all this or it's all that, or it's all that. I don't think it works in the model.

190.	Question 6	AB-interviewer	Hmm.OK, I see that's that's a different way of seeing that. I yeah, we haven't thought of that. So that's great. Yeah. That's how we learn in the process. And last piece of questions which actually applies to all these three elements we have discussed here. So based on your own experience, what are the good practises that you may have encountered in your practise or like is it in in terms of leading indicator development and implementation? If you can give me example of good practise that you may have encountered?
191.		IE-1	Yeah, I'm. I'm more I'm more than happy to go. So from our point of view, certainly with this this side of things.We've been looking more at the behavioural side of things with the individuals that are doing these tasks. So say for instance with the cable location systems. We have a system now which is called the cat G4 that has gone from when I was using it to just a a machine that used to bleep at you to tell you when it's indicated an electric or or a metal type. Pipe in the ground.To the newest system now actually tells you it gives you live feed to a supervisor on how that piece of equipment is being used, i.e.. they are using each of the correct modes, the time frame they're actually using it for in those modes, and also that they're actually holding and positioning the device in the correct way. Now that's been life fed where you can look at that. So me as a manager can look at that and go. Hold on a minute. He's only used it in the electric mode for three minutes. There's no way he scan that pavement correctly. So I'm on the phone. Can you just explain to me why this has happened? Oh, sorry. Yeah, I'm. I'm just about to go back over it again and do it. So you you're getting that proactive thing. That's just one element where I think from our point of view, it has certainly reduced the amount of cable or utility strikes that we're actually have, knowing that this information is is there. We use it from a point of view, investigating after an incident, unfortunately, where we can look and then see that they haven't used it in that correct way and then we can give education and training to hopefully prevent them from doing that again in the future.
192.		AB-interviewer	OK, so I believe that in terms of the development or it and implementation of so that's that's a example.
193.		IE-1	Again, it's the training. It's the education making, making the people aware of how that device can help them in regards to moving forward. Yep.
194.		AB-interviewer	OK.OK. And IE-2, do you have any other examples you can give us on on that?
195.		IE-2	Yeah. Well, the two things for me are that we focus on near miss reporting and and and driving employee engagement in developing that near-miss reporting. And we've seen big I think improvements in terms of prevention of of things happening that possibly in the past would have happened. So we've seen I think massive improvement on from that perspective. And the other thing I think from us, you know we.In all the PUWER checks on on a regular basis, we're we're making changes to maintenance regimes and time scales and we're we're maintaining equipment and changing bearing on trailers a lot earlier than probably manufacturers would recommend based on information gathered. And you know some of it is lagging obviously because it's historical data, but also as we're doing PUWER checks, we're highlighting stuff that we can actually take action on and and do something about before before anything happens. So I think you know we we've really looked at maintenance and timescale things like that. And and and do things earlier, sooner, more regularly than than even manufacturers would recommend. Recommend you know that's where we're getting we would get benefit from this tie, these type of indicators certainly.
196.		IE-1	Agreed.
197.		IE-2	And I have seen in another organisation where we drove that more of an initiative scheme, I suppose, by rather than the leading indicator scheme. But that's saving millions of pounds on employee engagement. I think that's the other key thing that if you get the people in the organisation to come up with the ideas and they know where the savings can be made in some of this stuff, you know that you can make big, big financial savings and as well as moral and an ethical improvements through through that, those through that map, through that engagement. And I've seen, you know, just literally the the safety team highlighted that they subcontracted,

			for example, all of the safety training to outside organisations.They had 35 health and safety advisors within the business. All of them could deliver manual handling training. All of them could deliver.A lot of the safety stuff and they brought it in house and they saved a lot, a lot, a lot of money by doing it. So the employee engagement, I suppose this is a message there that to drive as well because you do get big benefit from getting people on board with you.
198.		AB-interviewer	Yeah.Mm hmm.Absolutely, yeah.Yes.Yeah, absolutely. OK, thank you. These are excellent comments. Thank you so much. Well, let's carry on with you. IE-4. Is that OK?
199.		IE-4	No thanks. I'm just trying to think of leading indicator good practise. I I think it's been the the best thing that we've done and I didn't touch on it earlier is the integration of the health and safety specialist with the site teams. It's been it's not strictly measurable. It is quite subjective. But it's interesting to note how people from the SHE team who've taken it on board. Are viewed on some sites as to others. And I think and that's been really where we've made those small changes. That they're a part of the team. They're not sitting outside looking in. They understand the stresses and the pressures that are on the site and the operatives. And and I also think that and have seen certain instances of it where they actually get more out of it.Because people are more prepared to open up to them because they're not stood their finger pointing. It's not your report. It's a much more of a come on. How can we sort this out? How can we make this vested for you? Not me having to produce. I think there's also been a change. In the reporting of events and incidents.We had quite a major event.Well, it was. It wasn't on one of our sites, but we're involved with it.An RMD came down, stood in front of everybody and said right chaps, you know, culture for this is we want to know what happened. Something's gone wrong, obviously. So at some point there's been a failure. We don't know if it's the people or the processes. Tell us nobody's losing the job over this.We need to know the truth to stop it happening again. So this is your opportunity. To tell us what's happened. Without fear in a safe space so we can get the most learning out of it. And I think that was a really significant cultural change because whether we got that out and that culture would be for me one of the most important leading indicators. Difficult to measure.
200.		AB-interviewer	OK. OK, that's that's. Yeah, absolutely. That's that's that's that's great example. So yeah, what I hear is so the the example of good practise here is integration of teams work site and and the the analyst analytical side of safety management that's that's a really good example. Thank you. And can we hear from others who wants to add any comment to this and give me some more examples yeah.
201.		IE-4	But. I think that's where we need to get to as an, as an industry.Yeah.
202.		IE-5	So so I think, yeah, I think very similar to IE-4 and the same it came with a sort of change in terminology. We moved away from health and safety inspectors. To advisors to being part and parcel that team to be actually, I'll, I'll, I'll pick the phone up to the my my, my my SHEQ.representative and and. have to crack with them. We're we're we're trying to do this. I can see these problems. How? How do we how do we solve it as a team rather than I'm going to go and do this and then you can bulk me later.These are the challenges and and.It's it's confronting those challenges up front and. You can't stress enough of the what we'll talk about here is integration. Team is one team, there's there's a collective goal to ensure that everyone goes home safe and it is that that shifted us and them. They are here to help. That, that, the then they're not the enemies I've used quite most of policemen, enemy bits and mobs there. But it's that it's that that that shift off.And it's a very fun life for sometimes for their SHEQ advisors. Because for us to get the data. To inform our leading indicators, there's some sort of report. Because without the without the data.That database, that knowledge.You, you your model don't work because you're you're relying upon.The information there to be able to go and the mine. To give us give.A point in the right direction.
203.		AB-interviewer	Yeah, so am I right to understand from your your experience then the the example or good practise would be having this psychological safety within organisations when people are willing to share their concerns, their their they're ready to put this out and stress test that

			concerns or that they or maybe inadequacy or whatever is they are experiencing their own.Task completion so they. Happily sharing those, so am I right to understand. So OK.
204.		IE-5	Yeah, absolutely. It was summed up. It was summed up with a conversation I had with with our Health Executive director of the day says she goes, these are top of conversations we should be having at this stage rather than having the discussion of going, why didn't we have the discussion after something's happened?
205.		AB-interviewer	OK.Yeah. So yeah, that's that. That's great point. So in the in this case, we need that safety, psychological safety where? Yeah, yeah, absolutely.
206.		IE-5	Yeah, we, we we go. We always need to have something happens. We have a conversation. We we sit here and look at each other and go. Why don't we have that two week ago?
207.		AB-interviewer	Yeah. OK. And that is, by the way is one of the leading indicators for of safety culture. So that's that's another example. Yeah. Thank you so much for for that comment. And so next we have IE-3. Do you have anything yet? Do you have anything to add or agree disagree with the previous comments?
208.		IE-3	Yeah, that's that's that's yeah, yeah. Yeah, bit of bit of bit of both. I've stole my Thunder so into into the SHE The SHE person been integrated into the team is something our organisation has done for many, many years. I've only ever been ithis organisation, so I don't know any other company really. So. So although I've been in a long time, I'm sort of hot wired. I thought that was it. I thought that everybody did that and clearly don't. So if you look at other major tier one contractors we you know we've got a SHE department of 150 personnel. You know, there's 5000 workers in costume, but so wherever there's a project, there's a SHE person.Yes, there are some frameworks where there's a visiting person because you know life's not that easy.And it and both as IE-4 and IE-5 said it, it is about that integration of that person into the project team. So the way we we we act on, I'm trying to get the best practise bit here is yes you want to be integrated because you want everybody to be talking to that person. And we're gonna build this bridge. We're gonna do this road. We're gonna do this. So we're gonna whatever. And if they don't talk to the SHE person, that they become the policeman because they walk down, they go. Why? Why isn't there? Why isn't there walkway? You know? But if they'd had that conversation, we can't put a walkway in today. We're all going to be. We're going to travel in the bus then, right? OK, cool. You know, brilliant. You know? So you then know. So while you walk in there because there's a bus. So. You know, there is that. So if I if I try and give you a specific well, I'll, I'll give you a global one and then I'll try and be specific. So what what we did as a company.We try to let the projects contracts.Focus on those those bits of the physical risk on the side as a company. Then we looked at the bigger issue. So are we inspecting? Are we picking things up? Are we closing things out in good time? You know? Is there is there a meeting that talks about health and safety every week or month or whatever? Is there a temporary works plan? Is that reviewed by everybody that should be there. You know there's a list of people that should be there around. And we measure it. We're measuring those because if we get those things right, generally speaking, the other things we look at and it's about the pounds of the pence, really, you know,one will look after the other in a way in a way.Yes, but it's all about human interaction. You're quite right. So the so the best practise I wanted to just try and move on. I've been in two sectors that are really, really difficult. When you're the safety person. And what is marine. And luckily I did Marine in a previous life so I could talk the same language because I could operate the machine. That they were using? Yes, it's a lot newer and mine was 1940s technology, but it's the same principle. So the SPNTKRV as AE-2 will know it, you know it that machine was we used at a place called Company C. So so you know and I could talk the hind legs off a donkey with how to use that machine, etcetera. And in tunnelling, although it was fairly new to me, the processes are naturally the same but the but the team of people are all just as difficult because they won't talk to the SHE person. You've got to gain their trust. So if you gain their trust and it's going back to the old Army Sergeant major thing, if you go in there like a Sergeant major,

210			they'll close down, shut the shutters and they'll never talk to you ever again about anything. If you gain their trust, they'll tell you everything as long as it doesn't appear in an e-mail 20 minutes later. You know, creating massive tidal waves and stuff like this, so you've got to be on this. You've got to really understand how that works. But for us, as the SHE people, we've got a document quite a lot of things that the lads say. Without naming anybody you know, because we we need to fix things aren't right. And and without that, without that knowledge, you can't have the indicator. So you know you've got, you've got to you've got to. It's got to be measurable that you're saying, you know, etcetera. And you know, and it and it falls on. So if I if I go to the what is the best practise I think is on the last project I did in tunnelling, I would appear. At all sorts of times of the day or the night, and definitely a night shift.Loved it, loved it. I'd loved walking in at 4:00 AM in the morning because look at go. What are you, what are you doing here? I've come to help you fellas. What do you mean, help? Well, you know, let's go and have a chat. You know, I'll. I'll just do my thing. You carry on and I walk past them and walk off. And then 10 minutes later, I'll walk back and you know, and it. And it wasn't that, but you'd stand there and just chat and I wouldn't get a notebook out. Wouldn't take a photograph, wouldn't do anything and walk away again. And and I did lots of stuff like that. So. So you gain their trust and. And I'm actually.So I'll I can't name the site, but but I wasn't actually residents on that site, but that's where my desk was. I was like one of the leaders when that's where my desk was. So it's the easiest place for me to walk out to and do at 4:00 AM in the morning. So you know that was that was that was easy. But what? What the thing was is we we have the hazards and observations that come through on our on an app and a bit of paper and post it on your desk or whatever and that would get onto a spreadsheet of some description by somebody mainly electronic these days but you know etcetera.Myself and the works manager and his oppo would have reviewed all of them that came in yesterday and overnight before the 7:00 o'clock start shift briefing that day. So if somebody raised an issue that we could fix. We'd have that solution by 7:00 AM, so by the time we're doing the starter shift, we're telling the chaps. This happened yesterday. This is what we're doing about it. We've got to change this because that happened this this was. This is a good practise idea. We'll do that.My colleague who was my actual boss will turn over half eight. I would never read them because he's looking at figures on a bar graph. I've had loads of these environmental ones today. Yeah, we haven't read the detail and you need to read the detail and that's the and that's the bit. So it was the engagement with the works managers, particularly on that But if you're not talking to the lads on the ground, the lady's on the ground in the tunnel. You you would know half of them. So they they may not put it on the app and I'll go up and the app for you and you'd fill it in. No names, no back drill and you'd fill it in and you gain their trust. And I think that's that's one of the best practises about leading. Indicates all those hazards and observations are leading in the case. In in them there's quite a lot of them about crap, you know, but more bacon, more brown sauce, you know. But some of them are bang on, there's no toilet. There's no running water. You know that. We've got to fix that. You know, there might be something. There might be something more, infinitely dangerous, but you know. Quite a lot of actually about the salary, but anyway we bypassed most of that because we couldn't change that. We couldn't change that. But so yeah, so I echo basically what IE-4 and IE-5 had said, really it's about the SHE team being integrated.
209.		AB-interviewer	OK. So yeah, what what I hear from your your discussion, especially all three of yours discussed, so it's all coming down to human element as I see it. So it's like integration, how how we communicate and I I really like your comments when you said.Are we doing it right at the source of this reflexive? Exercise.So you you're just reflecting the things as you go and keep testing. Whether we have done and and also I like that element when you're referring it. Are we doing it right? So because it it's collective achievement at the end of the day. So thank you so much. It's it's it's really rich discussion here. There's a lot of thing to pick on and learn from here as well.
210.	Concluding question	AB-interviewer	Thank you so much for that. Thank you. And I think this is the final question just to like concluding our session, so of all the things that we have discussed today, what to you is the most important. Is there anything we have missed today to mention or is there anything you would like to add? Based on this session we had today.IE-2, do you have anything to add now?

211.		IE-2	Other than that, this forms a big part of the safety management system, you know, and it's it's it's one element of the safety management system that that is is important and can drive the improvement. So yeah, I'm all for, you know, the what you've done here is really good and and I think people don't tend to focus enough on leading the exact leading examples. The focus is on lagging you know on the accident information and everything else and I think.
212.		AB-interviewer	Mm.Thank you.Yeah, yeah.Oh.
213.		IE-2	There's a lot to be learned on the leading side from, from organisation. Certainly you know in, in, in the, in the big wide world out there.
214.		AB-interviewer	Yeah.Well, thank you. That's that's very encouraging. Thank you. I appreciate your comment. Is anyone else have anything to add as a final thought for the session?Yeah, that's the AE-1.
215.		AE-1	I must admit I do very much like #18 safety culture, so I'm aware of a accident. It's not utility strike or or or you know, on a construction site. But I'm aware of an accident that occurred in the building that I work in and. I'm of the opinion that we had all of the information that we required in advance to know that this could potentially happen and whether it would. Yeah, it was. It was, whether it was, you know, whose responsibility is it, whether it was it was not stored in a, you know, that there wasn't a repository of knowledge as you've as you've brought up or you know, I'd I'd we had the information.
216.		IE-1	Nobody acted.
217.		AE-1	We didn't act on it, and then we're now gonna look at it as a as a lagging indicator and not a lead indicator. And actually we had what we needed for it to be leading indicator. So I very much like that one, just put that out there.
218.		AB-interviewer	Mm hmm.OK. Thank you.Thank you. Then, yeah. Yes, yes, please.
219.		IE-1	Yeah, I think that's sorry. I think that's the key. Key key once just to add a little bit onto AE-1's, I think that's one of the key things these days with the technology, the information that a lot of this, I mean we've got lots of different systems systems within our organisation. We've got data coming from absolutely everywhere. One of the key things that can come back and bite you is having that amount of data but not acting upon it as I think AE-1 has alluded to because as I say from the point of view of an incident or an accident that happens. The HSE come in, they look at that, whether that's a road traffic incident or an incident on a on a building site or whatever, they'll look at that and if they see that you've actually got data, I mean say for instance we have we have telematics in our vehicles. It will tell you if someone's harsh braking, someone's harsh cornering, you look at that, see that somebody's had an incident and a fatality is happening to that. They look back at that data and say, well, hold on a minute. He's had 14 harsh break events. He's had 10 sort of harsh cornering events. You've done nothing in regards to that information. The, the, It's, he's now at the incident. So yeah, it's very much along those lines. So sorry, I just wanted to add a little bit to what AE-1, I think had already alluded to.
220.		IE-4	Oh, no. I was gonna say from from my point of view
221.		IE-5	I I think I think I think you've got the tumbleweed moment there, haven't you?
222.		IE-4	Yeah. No, I was trying to put the thing on from my point of view, I think it's very useful and very informative..You know, I wish you great success with it and really do hope that it's that it works. I would be interested in some of the reports and the papers that come out of it.
223.		AB-interviewer	Thank , thank you. Yeah, will do.
224.		IE-4	So I can disseminate them around the wider business and if there's anything else we can do in the future, let me know.

225.		AB-interviewer	OK.Yeah. OK. certainly, will do.No, no, no, thank you. Yeah, that is, that is true. That's that's really good. It's just we we we we just see the relevance of things or research we are doing that's that's great really examples. Hearing these feedback from practitioners is invaluable for me personally and knowing that the research we are conducting can become beneficial is very encouraging.
226.	Conclusion session	AB-interviewer	Absolutely.Excellent. Thank you. Yeah. Yeah. On that note. Yeah. I had a special slide for that too. Just to thank you for really. Do we do appreciate your time and dedication that you generously giving us today we, we and and also please be aware that just let me know at the end of this session, you can have free access to the research we are doing if you are interested and want to learn more about this. I'm more than happy to share them. You have our contacts and also e-mail and I shared on the first slide here. So please do keep in touch. Thank you so much for your time. Once again, if you have any more questions, please do stay after the session or if you want to discuss now. If not then thanks again, I will not hold you any longer.
227.		IE-4	I was just like, yeah.Hope everybody has a good weekend and. You don't. OK, stay safe. Alright, thanks all. Bye.
228.		AB-interviewer	Yes, yes. Please take care. Have a have a nice weekend, everyone. Thanks again. Bye. Thank you.
229.		IE-5	Yes, thank you. Bye, bye.
230.		AE-2	Myself. bye folks. Bye now. Bye. Thank you.