“Deconstructing Efficiency of Mechanical Design in Bespoke Engineering”

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Date of Submission: 29/04/2024,

Words: 48,771

Abstract

This research investigates production efficiency improvements in the design phase of High-Value, Low-Volume, High-Variety (HVLVHV) machinery products rather than conventional mass-produced products with a low degree of variety. Achieving efficiency improvements in HVLVHV machinery products is challenging due to these products being labour-intensive and, as a generalisation, being designed or customised specifically for each customer.

The methodological choice for this research is concurrent mixed-method research, which utilises both quantitative and qualitative methods. This research comprises two distinct yet complimentary research strategies. The first strategy is action research, and this is implemented in a single case study company. The action research strategy is chosen because the research took place in the organisation within which the researcher works.

The key findings from this research are that the framework developed from this research has proven effective in improving production efficiency in the mechanical design phase of HVLVHV machinery products. This is attributed to the following efficiency improvement propositions being incorporated into the framework: These include adopting lean design principles, standardising the mechanical design process, utilising a modular design approach, fostering collaboration, and using design automation tools. It was not viable to incorporate embedding continuous improvement in the organisational culture into the framework as this needs to be driven by senior management.

This research has extended the application of Modularisation by applying Modularisation theory to improve production efficiencies in the mechanical design phase of the product lifecycle of HVLVHV machinery products. This research has highlighted the value of Modularisation when implemented into lower volume production during the design phase and, therefore, has extended the theory on this efficiency improvement tool. The main contribution to practice is the sharing of a fit-for-purpose Strategic Design Management framework integrated into the business management system. The framework operates at a level equivalent to achieving ISO 9001 certification and the results indicate the framework is effective in improving production efficiencies in terms of time, cost, and quality during the mechanical design phase of HVLVHV machinery products.

Acknowledgements

I would like to thank my supervisors, Martin Eley and Susan Sisay, for their support and guidance throughout my DBA studies.

Also, I would like to thank my fellow DBA students, who have shared the DBA journey with me and been a source of inspiration and encouragement.

Finally, I would like to thank my wife, Emma Jesic, for her unwavering patience and support. Without you at my side, then, I don’t believe I would have been able to complete this DBA and sustain my full-time job.

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Glossary of terms

Term or abbreviation	Definition
GDP	Gross Domestic Product
TPS	Toyota Production System
NVA	Non-Value Added
TFW	Thompson Friction Welding
FWT	Friction Welding Technologies
KPS	Kuka Production System
ERP	Enterprise Resource Planning
DFM	Design for Manufacture
DFA	Design for Assembly
ETO	Engineer to Order
MTS	Make to Stock
HVLVHV	High-Value, Low-Volume, and High-Variety

1. Introduction

1.1 Background

Modern-day manufacturing companies face many challenges. Some of these include competition for sales, which are potentially both national and global. This global economy has led to many in the manufacturing sector shifting their manufacturing abroad to countries with reduced labour costs. Although transferring the manufacture of goods abroad can work for a highly automated manufacturing process, it is more complicated for companies with more highly skilled, manually intensive production processes. This more traditional manufacturing style requires highly skilled staff, and these skills are not easily transferable. Sustaining competitiveness in this environment has forced many companies to rethink their processes and procedures to enable them to react to customer needs and manufacture products of a higher quality and reliability at a lower cost (Ocampo, et al., 2020).

Sorrell (2016) states that having slow growth influences a company’s ability to raise prices. Increasing your production output or growth enables a company to reduce its costs per unit thus increasing profit. As slow growth makes a business unable to increase prices it means that a company’s only way to increase profits is to decrease costs. Figure 1 shows the UK’s manufacturing output compared to the other countries in the top 10 manufacturing countries in the world. The UK is currently the ninth-largest manufacturer in the world by production. The Office for National Statistics (ONS, 2022) states that as of quarter 1, 2022, the UK manufacturing sector employed 2.7 million people. Make UK (2022) claim that as of 2022, it accounts for 51% of total UK exports, and the manufacturing sector's output totals £183bn. These figures highlight the importance of the UK’s manufacturing sector in terms of the economy and its high value around employment. Previously countries like the UK with skilled labour have been able to charge a premium for their exported products due to the quality of the produce. Developed countries like the UK need to sustain or improve the quality of their products to remain competitive against the emerging countries with lower costs, which have also been improving the quality of their products to that of a quality similar to the UK (Hassine and Mathieu, 2021).

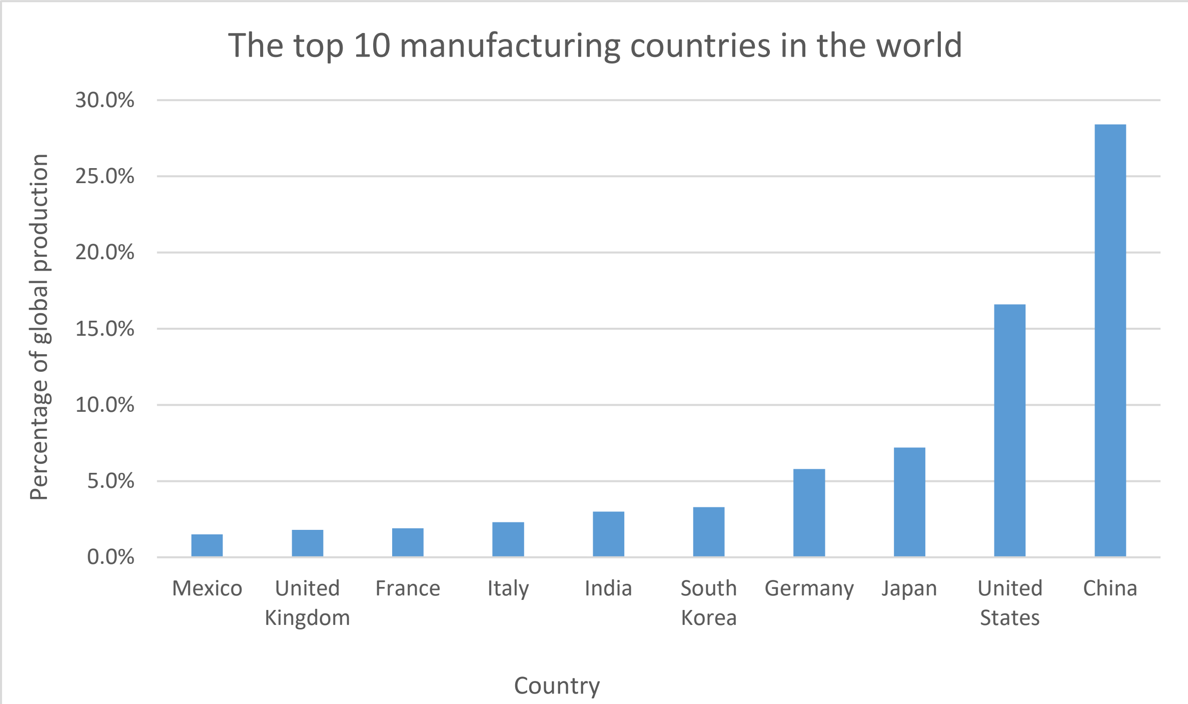

Figure 1, The top 10 manufacturing countries in the world. Source: (Khan et al., 2021)

In conclusion, this section describes some of the challenges the UK manufacturing sector faces due to the global economy. It also highlights some specific issues that companies with more highly skilled, manually intensive production processes face. The discussion also highlighted the importance of the UK's manufacturing sector in terms of the economy and its high value around employment. Therefore, any production efficiency improvements achieved during the mechanical design of bespoke products has the potential to significantly impact the UK economy. The next section will discuss the specific problem being investigated by this research in the manufacturing sector.

1.2 Problem Statement

The previous section discussed the UK manufacturing sector and the challenges faced by this industry generally and during the period of this thesis. This section will focus more on the specific problem faced by the manufacturing sector that this work will investigate. Specifically, how can production efficiencies be achieved in the design phase of low-volume, high-cost products with a high degree of variety?

Due to the need to reduce costs to increase profitability, companies have tried various tools and techniques to overcome the issue of manufacturing a high-quality product at a reduced cost. One company that has succeeded in this issue is Toyota, which has become the world's largest motor vehicle producer. One factor that has enabled Toyota to succeed is its development of the Toyota Production System (TPS). The TPS has evolved into a manufacturing style called Lean, and due to the success of Toyota and its management philosophy, many other companies have adopted its principles. The manufacturing style "Lean" is fundamentally a series of activities or solutions to eliminate waste, reduce non-value added (NVA) operations and improve the value-added (Wee and Wu, 2009).

Due to Toyota's long list of successes and quality achievements, companies within all industries, not just automotive, have been inspired to apply the TPS to their process models to improve (Proctor, 2016). However, as stated by Hines et al. (2004), the main weaknesses of Lean manufacturing are its automotive manufacturing-based view and limited appreciation of handling variability in demand. The implementation is entirely tool-focused and generally neglects the human aspects of the high-performance work system core to the Lean manufacturing approach. It is logical to assume that the focus on mass production is due to its origins, which derive from Toyota and the mass production of motor vehicles.

The example of Toyota has been given as this style of production is well known, but this research focuses on the opposite style of production to mass production. This research focuses on High-Value, Low-Volume, High-Variety (HVLVHV) machinery products. This manufacturing style is a vastly different process from Toyota's style of manufacture and is, more specifically, low-volume production with a high degree of variety in the products. Therefore, the tools utilised by Toyota may not be appropriate for this style of production. This difference is highlighted to show the specific niche sector to which this work is applied. It is more focused on bespoke manufacturing industries like Morgan automobiles, which have a more traditional craft style of manufacture. Mass production is a highly automated manufacturing process; HVLVHV machinery products generally have highly skilled labour-intensive production processes. Due to the highly skilled and labour-intensive production, achieving efficiency improvements in producing these products is extremely challenging. Additionally, these products are usually designed or customised specifically for each customer. Due to the variability in the designs, achieving efficiency improvements in designing these products is extremely challenging.

This research investigates production efficiency improvements in the design phase of HVLVHV machinery products rather than conventional mass-produced products with a low degree of variety. This section describes the problems faced in achieving efficiency improvements due to these products being labour-intensive and, as a generalisation, being designed or customised specifically for each customer. The next section will describe the boundaries of the research being undertaken.

1.3 Boundaries of the research

The previous section discussed how this research investigates production efficiency improvements in the design phase of labour-intensive HVLVHV machinery products rather than conventional mass-produced products with a low degree of variety. This section describes the boundaries of the research. All research undertaken will have limitations to its scope, but defining the boundaries of the research at this point will aid the reader by defining the limitations specific to this body of work.

The research conducted is limited to a single case study in a Western engineering company based in the United Kingdom (UK). The company is a medium-sized engineering company that manufactures HVLVHV machinery products. A medium-sized company is one that has less than 250 full-time equivalents (FTE) and has a turnover equal to or less than £50 million. The research is a longitudinal study that takes place over approximately a five-year period. The research focuses on improving production efficiency during the mechanical design phase in HVLVHV machinery products. This research focuses specifically on the discipline of mechanical design and, therefore, will not consider other disciplines like the electrical element of the machinery.

The data collected during the literature review focused on the specific words “Manufacturing”, “Design”, “Efficiency”, and “Jobbing Shop” or “HVLVHV” or “Jobbing Shop” as these represent critical components of the research. Additionally, the data collected within the case study company is specific to that organisation within the time frame of the research. As discussed previously, the research focuses on improving production efficiencies during the mechanical design element of HVLVHV machinery products. Any efficiency improvements seen are specific to the case study company and the action research participants (Discussed in 3.2.2 Strategy) being undertaken within the given timeframe. Additionally, the improvements achieved ought to be judged within this specific context, although they may be indicative of wider relevance.

The impact of the researcher being a manager within the case study company is reflected on during each cycle and observed when considering findings and implications. As this research is action research, there is potential for the results to have been impacted by the participants and the function of the researcher as a manager. The extent to which this circumstance has impacted the study could be verified with further research, but this is outside the boundaries of this study.

Smyth and Holian (1999) consider that an inside worker/researcher can enhance the research and, additionally, the organisation. Still, there is a risk of bias that immediately challenges the positivist stance that the researcher must maintain to remain objective. Donalson (2002) takes this perspective further and states that “self-report and mono-methods bias often threaten the validity of research conducted in a business setting and thus hinder the development of theories of organisational behaviour”. Mantzoukas (2005) argues that bias cannot sincerely be excluded from the research process regardless of paradigm and that the presupposition of excluding bias from research studies is based upon historical and ideological assumptions that, once pushed to their logical conclusion, do not hold ground.

When translating these findings into recommendations for this research, it is apparent that potential bias is unavoidable, but every effort should be implemented to alleviate it. Therefore, to mitigate this potential bias the researcher will undertake reflective practice during the research to assist in the recognition of any intrusive bias or personal interests and these should be identified and contested (Van Heugten, 2004). Additionally, utilising quantitative data where appropriate will ensure consistency and transparency.

This research investigates production efficiency improvements during the mechanical design phase of HVLVHV machinery products rather than conventional mass-produced products with a low degree of variety. This section discussed the boundaries of the research, the purpose being to aid the reader by defining the limitations specific to this body of work. The next section will describe the purpose of the research being undertaken.

1.4 Purpose

The purpose of this study is to develop a framework for improving production efficiency during the mechanical design phase of HVLVHV machinery products. Although this research will be situated in a single case study company, the aim is for the framework to be transferable to other manufacturers of HVLVHV machinery products. This research is in response to business sustainability challenges faced by the UK manufacturing sector, specifically manufacturers of HVLVHV machinery products.

This research comprises two distinct yet complimentary research strategies. The first strategy is action research, which is then implemented in a single case study company. It utilises a concurrent mixed-method approach, employing both quantitative and qualitative methods. Action research cycles were utilised, and three distinct work packages evolved to develop the framework. The first cycle tested several efficiency improvement tools to verify which tools were appropriate for implementation into the framework. Cycle two tested the efficiency improvement tools verified in cycle one on a complete machine. Cycle three was used to verify the transferability of the framework onto a different machine type, thus evidencing its potential transferability to other manufacturers of HVLVHV machinery products.

1.5 Research Aim

This work aims to develop a framework that is transferable to other manufacturers of machinery products of HVLVHV, which enables them to improve production efficiencies in the mechanical design phase of the product lifecycle.

1.6 Research Questions and Objectives

The research question was developed to assist in achieving the above research aim.

- How can production efficiencies be achieved during the mechanical design phase when dealing with HVLVHV machinery products?

The following research objectives underpin the above research aim and question:

- Undertake research to verify existing tools appropriate for improving production efficiencies in the mechanical design phase of HVLVHV machinery products.
- Develop a standard process for the mechanical design of HVLVHV machinery products.
- Develop action research cycles to verify appropriate tools for improving production efficiencies in the mechanical design phase of HVLVHV machinery products.
- Develop a framework for improving production efficiency in the mechanical design phase of HVLVHV machinery products.
- Confirm the transferability of the framework for improving production efficiency in the mechanical design phase of HVLVHV machinery products.

1.7 An Introduction to the Case Study Company

The following section introduces Kuka Systems UK, the case study company that is the focus of this research. They are a supplier of automated production solutions and robotic welding systems for use in various applications, including the aerospace and nuclear sectors (TWI, 2022). Kuka Systems UK also manufactures friction welding machines under the trading name Thompson Friction Welding (TFW). The parent company of Kuka Systems UK, Kuka AG, purchased TFW in 1993 (Machinery, 2009) and amalgamated it into Kuka Systems UK. TFW is, therefore, a trading name, and the parent company is Kuka. To aid clarity, for the remainder of this research, Kuka Systems UK will be referred to as TFW as the friction welding products are the specific focus of this research, and it's the TFW brand under which the products are sold. The justification for this is that the Rotary Friction Welding Machines (RFWM) produced are HVLVHV machinery products. These HVLVHV machinery products are the focus of the research rather than mass-produced machinery products. These products are, therefore, ideal candidates for being incorporated into this research.

TFW is a medium-sized manufacturing company that has been manufacturing friction welding machines for over 50 years. A medium-sized company is defined as one that has less than 250 employees and a turnover of under £50 million. The Welding Institute (TWI, 2022) states that over this period, TFW has produced around 700 machines and are pioneers in the development of friction welding. They manufacture RFWM, amongst other products in their portfolio. Friction welding is a solid-state joining process. The process involves one part to be welded being, rotated or oscillated at high speed and pressed against another stationary part. The resulting friction heats the pieces to a temperature they can join. At this point, the rotational or oscillating force is removed, and the two parts are pushed together whilst they cool.

TFW supplies machines to various industries, the customers purchase these machines to allow them to weld their components. Some of the components that customers may want to weld on the TFW machines include piston rods, drive shafts, drill pipes and trailer axles. As can be seen from the component list the main industries that TFW supplies to are commercial vehicle manufacturers and the oil and gas excavation industry.

TFW manufactures machines which have significant variety, as they are manufactured specifically to a customer's requirements. Due to the machines being bespoke, they are costly to produce, the volume of manufacture is low, and they are time-consuming to manufacture. In an ever-competitive market, customers are dictating that the machine price and lead time are reduced to that of TFW's direct competitors, who also manufacture bespoke machines. Several of these competitors are in countries with reduced labour and overhead costs, contributing factors enabling them to manufacture machines for a lower price than TFW can achieve. One example of such a company is Friction Welding Technologies (FWT), based in India. They are now manufacturing friction welders under licence for TFW's direct competitor Manufacturing Technology Inc (MTI). MTI is a global leader in joining and welding solutions and has been for the last nine decades (FWT, 2015).

FWT have an ever-increasing product range from a 5-tonne RFWM to a 60-tonne RFWM (FWT, 2019). Although their range of machines is not as broad as that produced by TFW, they offer a 60-tonne RFWM. When reviewing TFW machine sales, the 60-tonne RFWM produced by TFW is their best-selling machine. This means that FWT is a direct competitor for TFW when quoting a customer for this machine size. The manufacturing labour costs in India averaged £1.26 per hour in 2015 (The Economic Times, 2018), compared to an average of £14.38 per hour for manufacturing labour in the UK. This figure is based on the average weekly pay in the UK for labour in the manufacturing sector being £539 (ONS, 2021), and then working a typical UK average working period of 37.5 hours per week.

Although TFW manufactures various friction welding products the biggest selling products that they produce are RFWM. These products are high-value, high-variety products and a low volume are sold per annum. For many years, the most appropriate method for designing and manufacturing these products within TFW has been Engineer to Order (ETO). The production process of ETO means that once an order has been received, the design engineering process starts. Each customer order can be considered as an individual project with several activities like engineering and design, component manufacturing, assembly, and installation (Bertrandand and Muntslag, 1993). Engineer-to-order allows the product to be custom-made to the customer's exact specifications, but a consequence of this is long lead times. The lead time is measured from when the customer places an order to when it arrives at its manufacturing plant.

After agreeing to the research and an analysis of the process within TFW being undertaken, it revealed that the traditional approach to designing a new machine order for a customer involved the Lead Engineer looking at the last machine sold that welded a component similar to the new customer's components. This machine would then be used as the basis for the new order, but it would be modified and altered to the new customer's specifications. When discussing the opportunity for this research with the management team at TFW, they acknowledged that the company has used this process successfully in the past. Still, the industry is changing, and they are aware it is not viable to continue this way. To improve efficiency, they require a more efficient production process.

Internal calculations undertaken by the Head of Finance UK show that TFW currently loses up to 17% of an order's total value per month if the machine is on the shop floor past the forecast shipping date. The details of this calculation were quantified by the Head of Finance UK, who explained that when a machine is late to leave the factory, whilst here it occupies valuable floor space, where another machine could be built if the floor space were free. This is not a direct cost but an opportunity cost as it is dependent on their being an order to fill the space. This fact highlighted the importance of getting the machines out on time and emphasised the importance of efficiency improvements.

TFW has previously been able to sell its products at a premium due to their quality and reliability. This is evidenced by repeat orders from customers and their feedback. Using quality as its competitive advantage, TFW could charge a premium, and customers were willing to pay the additional amount. Recently, the price gap between TFW and its direct competitors has grown significantly, and the customers who were advocates of TFW are now questioning if the benefits warrant the increased cost. This has resulted in TFW needing to reduce the costs of manufacturing its products to remain competitive.

The purpose of this research is to find if production efficiencies be achieved during the mechanical design phase when dealing with HVLVHV machinery products. The case study company for this research is TFW as they manufacture the HVLVHV machinery products that are the focus of this research. The researcher undertaking this work is employed as a manager within the case study company as the Product Development and Mechanical Engineering manager. Figure 2 below shows a simplified version of the organisational chart to show a representation of the researcher's position within the organisation. The purpose of this diagram is to assist the reader by defining the positionality of the researcher within the organisation.

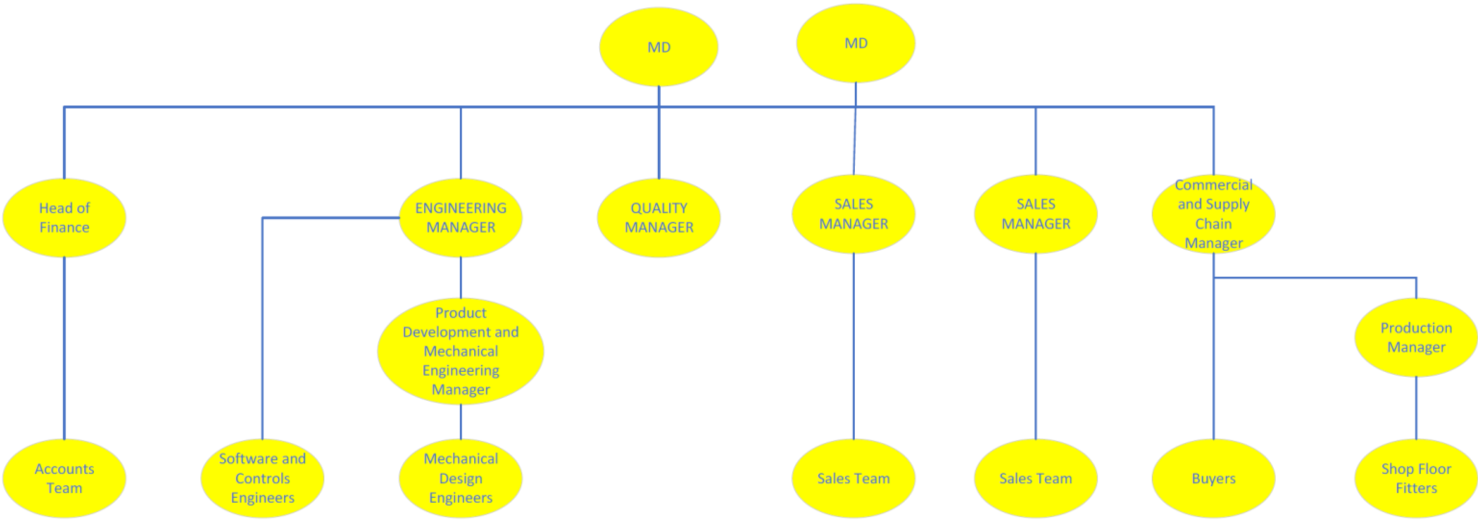

Figure 2, TFW, Simplified organisation chart

1.8 Timeline events

In the previous sections, the researcher explained the challenges the case study company faced as they aimed to achieve production efficiency improvements in the design phase of HVLVHV machinery products rather than conventional mass-produced products with a low degree of variety. This research took place between the period of 2018 and 2024. This timeframe included a global pandemic and a war in Ukraine, adding additional challenges to the manufacturing sector to those discussed earlier in the problem statement section. It is recognised that the war and pandemic are two specific challenges faced during this research period and are not typical challenges of the industry generally. However, they were additional challenges faced by the case study company during this period and therefore they should be identified.

The first of these two challenges came in 2019 when the COVID-19 pandemic occurred. Figure 3 below shows the catastrophic impact this had on the UK Gross Domestic Product (GDP) during the period from 2020 to 2022. Gross Domestic Product (GDP) is the total value of final products and services produced within the domestic territory of a country during a specific period (Aslamazishvili, 2021). Before the COVID-19 pandemic, the United Kingdom's (UK) Manufacturing sector was 10.3% of its Gross Domestic Product (GDP). Figure 3 shows the percentage difference from the end of 2019. The manufacturing sector's percentage of GDP contracted by 23.4% in the second quarter of 2020 (Oxford Economics, 2022).

For the case study company, COVID-19 resulted in a delay in new orders materialising and much of the staff working at home or being furloughed. This also resulted in product development being stopped, product development being the section of the case study company supporting the research. This had an impact on the progress of the research being undertaken but didn't have a direct impact on the results.

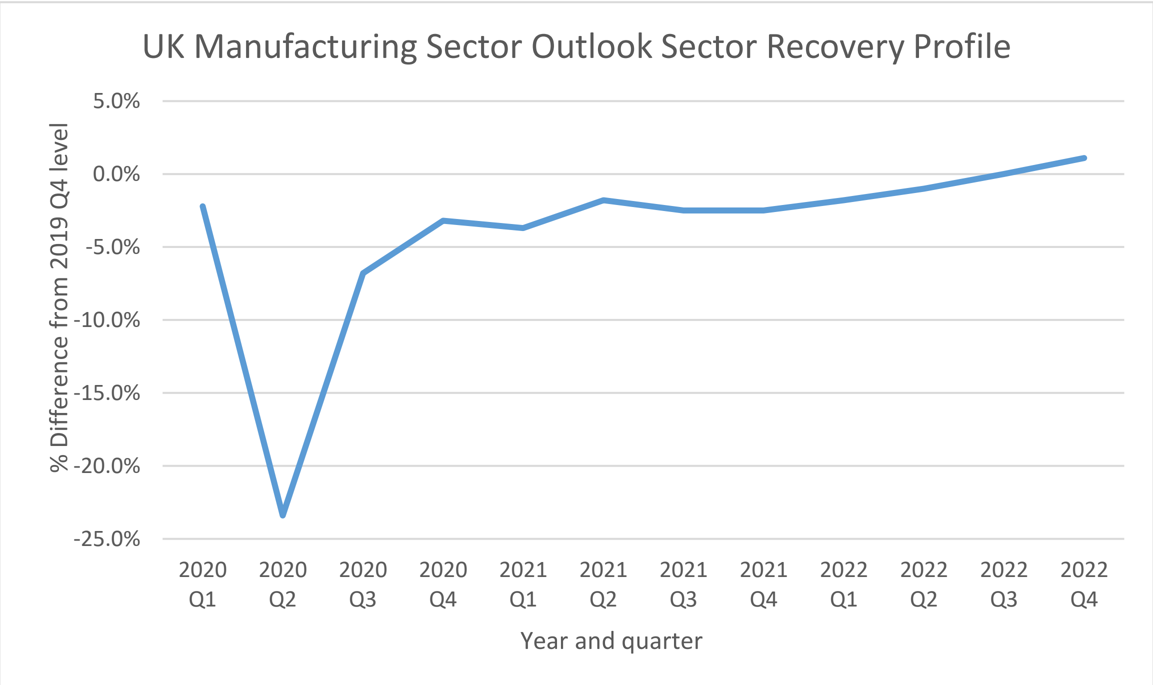

Figure 3, UK Manufacturing Sector Outlook Sector Recovery Profile (Oxford Economics, 2022)

During 2022, as the global economy was trying to recover from the COVID-19 pandemic, Russia invaded the country of Ukraine. Due to the country being at war, Ukraine could no longer produce steel. Moreover, the EU imposed sanctions on Russia in relation to its exports. These sanctions meant that they could no longer export their steel to countries belonging to the EU and the UK. Table 1 shows the quantity of Crude Steel produced by these and other countries. This had a significant impact on the global supply, meaning the price of steel increased from its already inflated prices from the COVID-19 Pandemic. The complete list of "Total Production of Crude Steel" can be found in Appendix 7.7.

Table 1, Global top 20 producers of Crude Steel

	Total Production of Crude Steel *										
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	China	577,070	638,743	701,968	731,040	822,000	822,306	803,825	807,609	870,855	928,264
2	India	63 527	68,976	73,471	77,264	81,299	87,292	89,026	95,477	101,455	109,272
3	Japan	87,534	109,599	107,601	107,232	110,595	110,666	105,134	104,775	104,661	104,319
4	United States	59,384	80,495	86,398	88,695	86,878	88,174	78,845	78,475	81,612	86,607
5	South Korea	48,572	58,914	68,519	69,073	66,061	71,543	69,670	68,576	71,030	72,464
6	Russia	60,011	66,942	68,852	70,209	69,008	71,461	70,898	70,453	71,491	72,042
7	Germany	32,670	43,830	44,284	42,661	42,645	42,943	42,676	42,080	43,297	42,435
8	Turkey	25,304	29,143	34,107	35,885	34,654	34,035	31,517	33,163	37,524	37,312
9	Brazil	26,506	32,948	35,220	34,524	34,163	33,897	33,258	31,642	34,778	35,407
10	Italy	19,848	25,750	28,735	27,252	24,093	23,714	22,018	23,373	24,068	24,532
11	Iran	10,908	11,995	13,197	14,463	15,422	16,331	16,146	17,895	21,236	24,520
12	Taiwan, China	15,814	19,755	20,178	20,664	22,282	23,221	21,392	21,751	22,438	23,240
13	Ukraine	29,855	33,432	35,332	32,975	32,771	27,170	22,968	24,218	21,417	21,100
14	Mexico	14,132	16,870	18,110	18,073	18,242	18,930	18,218	18,824	19,955	20,204
15	Viet Nam	2,700	4,314	4,900	5,298	5,474	5,847	5,647	7,811	11,473	15,471
16	France	12,840	15,414	15,780	15,609	15,685	16,143	14,984	14,413	15,505	15,387
17	Spain	14,358	16,343	15,504	13,639	14,252	14,249	14,845	13,616	14,441	14,320
18	Canada	9,292	13,009	12,891	13,507	12,417	12,730	12,473	12,646	13,208	13,443
19	Poland	7,128	7,993	8,779	8,366	7,950	8,558	9,198	9,001	10,332	10,167
20	Belgium	5,635	7,973	8,026	7,301	7,127	7,331	7,257	7,687	7,842	7,980

Russia is also one of the world's largest providers of crude oil, and sanctions on supplying oil increased fuel prices significantly. The cost of fuel significantly impacted the economy as the cost of goods includes the logistics for transportation. In brief, if fuel costs increase, then the cost of goods must increase to reflect this. This added additional pressure to the manufacturing sector as they now had the challenge of manufacturing their products with these inherited additional costs. In the UK, Steel had increased in cost by 25%, and as of July 2022, the cost of diesel increased by 32%.

There were also global supply chain issues caused in part by the pandemic. The pandemic resulted in people having to self-isolate, and others used this opportunity to change jobs. This lack of staff resulted in companies being unable to produce goods as effectively, and once made, there was a lack of transport services available to deliver them (Institute for Government, 2022). This was not a UK-specific issue, as this was a global problem. Therefore, many manufacturers faced these additional challenges.

All these factors were external to the company and as such are a variable that cannot be controlled. As the aforementioned factors all influenced both cost of materials and companies means and motivation for purchasing the machines. It also meant engaging the staff of the case study company to embark on new practices during a time of uncertainty in the market.

The case study company faced additional challenges throughout this period. During the phase from 2018 to 2024, the managing director of the case study company changed four times. This led to different organisational strategies being implemented in an attempt to address the global and industry challenges faced. In addition, each managing director had new ideas they wished to implement and a new direction to take the company. This included their views on the importance of the work being undertaken around product development and standardisation. Critically, this also meant that the staff had a lot of adjustments to deal with, and thus ran the risk of thinking that all changes during this time had the potential to be transient. This had a negative effect on staff engagement and "buy-in" to new concepts being introduced. It also meant that the staff were unsettled and potentially cynical of the stability of the company during this time. Additionally, the number of employees contracted from an estimated 120 to 60 as the business became refocused on its core product of friction welding machines. This would have also contributed to the disquiet.

This highlights the turbulence within the case study company during this period. This section has been included as it highlights the importance of this research in terms of the appropriateness of the timing of the research. Although the case study company going through a particularly challenging period during this time frame created challenges for the research. It also gave the researcher an ideal opportunity to have a potential impact within industry. This could be achieved by the research supporting the case study company in reducing the costs of manufacturing its products and therefore emerging from this turbulent period in a more competitive position.

1.9 Conclusion

This chapter describes some of the challenges the manufacturing sector faces due to the global economy. It also highlights some specific issues that companies with more highly skilled, manually intensive production processes face. Specifically, manufacturers of HVLVHV machinery products. It details the specific niche that this research investigates, that is how you gain production efficiency improvements in the mechanical design phase of HVLVHV rather than conventional mass-produced machinery products with a low degree of variety. The boundaries of the research were discussed, the purpose being to aid the reader by defining the limitations specific to this body of work. The aims and objectives were given, and the case study company was introduced. The following chapter will undertake a detailed review of the literature relevant to improving production efficiency in the mechanical design element of HVLVHV machinery products.

2. Literature Review

The following section aims to uncover relevant literature on potential methods for increasing production efficiency during the mechanical design phase of HVLVHV machinery products. A systematic literature review is utilised as the initial methodology for undertaking the investigation, as it gives a clear overview of relevant academic literature on the topic. This is followed by research on potential efficiency improvement tools that the researcher has been exposed to as a practitioner in industry. Combining the two research methodologies gives a holistic view of industry and academic tools and, therefore, a more complete review of the potential tools to be incorporated into the framework.

2.1 Systematic literature review

Introduction

This section aims to uncover relevant literature on potential methods for increasing production efficiency during the mechanical design phase of HVLVHV machinery products. There are various methods for this, but a Systematic Literature Review (SLR) results in a broad spectrum of literature being obtained. The findings from this review can then be refined, and the comprehensive data on the specific subject can be compiled. A SLR is a specific method that adopts a clear and detailed approach to the research, ensuring rigour and transparency are brought to the literature review process (Tranfield et al., 2003; Kitchenham and Charters, 2007).

When initiating this review, it was as unclear if any efficiency improvement frameworks or models already existed that would be appropriate for direct implementation. Should such a model or framework exist then it would save a considerable amount of time developing a new framework. Additionally, it would give the researcher an opportunity to test the framework or model in an industrial environment. The following literature review details the steps that were undertaken to research the current literature on potential methods for increasing production efficiency during the mechanical design phase of HVLVHV machinery products.

Method

The SLR is undertaken with the search protocol defined in Table 2. Due to the niche area in which this research is being undertaken, it is not confined to papers published between specific dates. The dates are left open to find the broadest amount of data and the papers were subsequently reviewed to ensure the findings are contemporary. Whilst there is no standard for what is deemed to be contemporary, it should be considered current enough for it to be relevant in modern engineering practice.

Table 2, Boolean Search String and Databases

Boolean Search String	(Manufacturing) and (Design) and (Efficiency) and (("jobbing shop") OR ("HVLVHV") OR (BESPOKE))
	1, Scopus
	2, Web of Science
	3, IEEE
	4, Science Direct

The specific words “Manufacturing”, “Design”, “Efficiency”, and “Jobbing shop” or “HVLVHV” or “Bespoke” represent critical components of the research and, therefore, were used as the search criterion. The criteria were also limited to academic journals written in English and published in recognised academic databases (i.e Scopus, Web of Science, IEEE and Science Direct). A computerised search was undertaken on the databases shown in Table 2, utilising the keywords “Manufacturing”, “Design”, “Efficiency”, and “Jobbing shop” or “HVLVHV” or “Bespoke” as the filter to limit it to documents containing these words. The search was refined further by surrounding the search terms with quotation marks. This told the database search that the words must appear as an exact phrase in the resultant documents. The source type of the files was filtered, and limited to ‘review articles’, ‘research articles’ and ‘conference papers’. The subject area of the search was limited to ‘Engineering’, ‘Business Management and ‘Accounting’, ‘Social Sciences’ and other subjects specific to the area of research. The search resulting from this criterion produced 1283 articles.

The results from each database were exported in a RIS Format file. Exporting the RIS file allowed the search results to be imported into a reference management tool. There are various software solutions for reference management, the one used for this research was Endnote. Importing the RIS Files containing the search results into Endnote allowed the results to be structured. The software highlighted duplicate files; these files were erased from the results, leaving 1244 articles. The title and abstract of the remaining 1244 articles were screened, and any that were not considered relevant to the research questions were removed; 26 papers remained for review. These 26 papers were read fully and 8 were found to contain data beneficial to the research. Figure 4 below shows a Prisma flow diagram detailing the steps undertaken whilst undertaking the literature review.

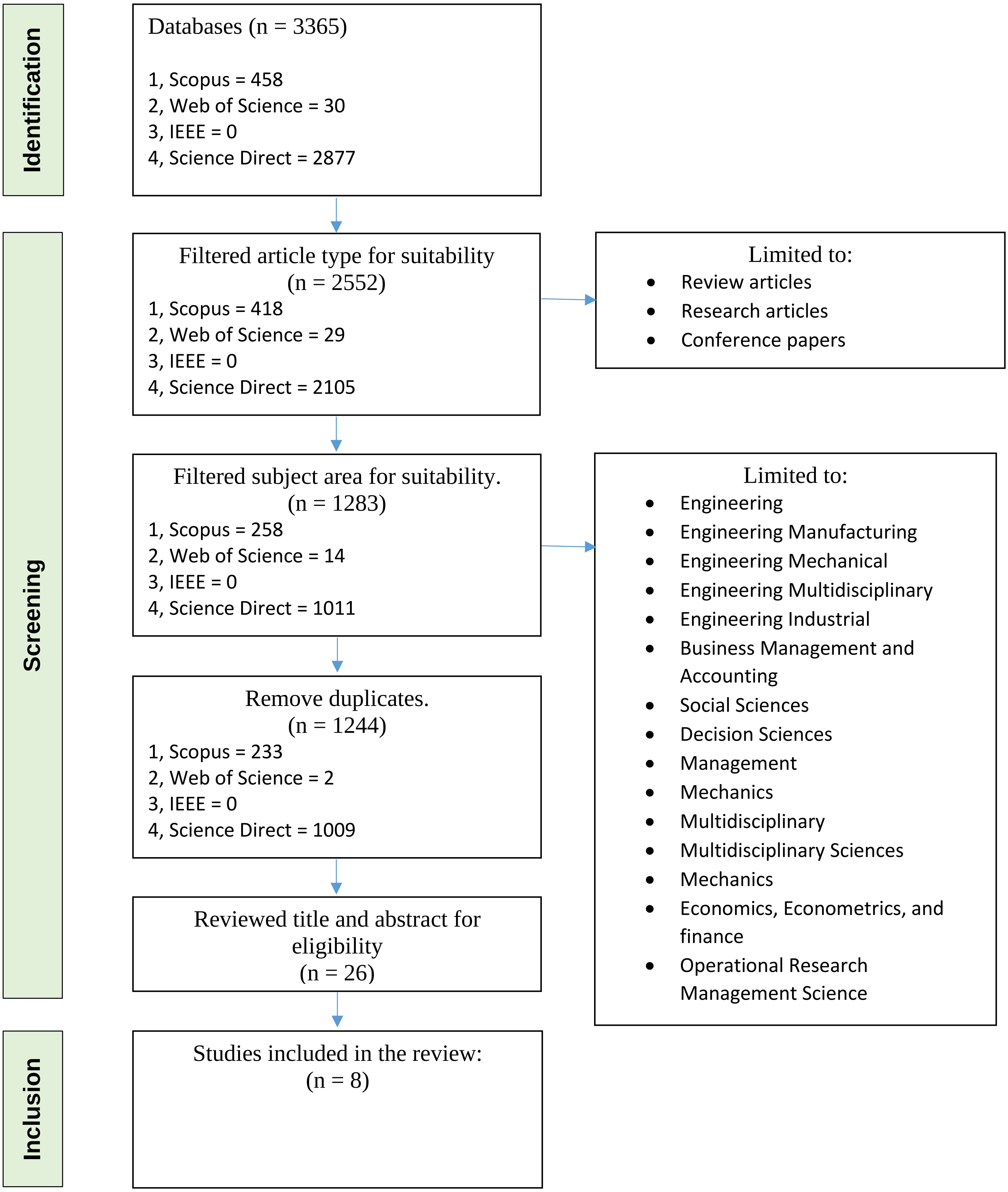

Figure 4, Search Strategy prisma flow diagram

Table 2, Systematic literature review findings

Systematic literature review findings					
No	Author	Title	Date	Type	Description
1	Gerschutz, B., Sauer, C., Kormann, A., Nicklas, S., Goetz, S., Roppel, M., Tremmel, S., Paetzold-Byhain, K and Wartzack, S.	Digital Engineering Methods in Practical Use during Mechatronic Design Process	2023	Journal Article	This work used a literature review to analyse the current state of research on the use of artificial intelligence, deep learning, digitalization, and Data Mining in product development, mainly in the mechanical and mechatronic domain.
2	Shi, J., Huang, F., Jia, F., Yang, Z and Rui, M.	Mass customization the role of consumer preference measurement, manufacturing flexibility and customer participation	2023	Journal Article	This paper explores the relationships between customer preference measurement accuracy, manufacturing flexibility, customer participation and customized product quality, inspired by module decomposition and integration theory.
3	Rankohi, S., Bourgault, M., Iordanova, I and Carbone, C.	Developing a Construction-Oriented DfMA Deployment Framework	2023	Journal Article	Following a design science research method, a systematic literature review is conducted to identify the construction-oriented DfMA implementation challenges. To address these challenges, a construction-oriented DfMA framework was theorized, verified in a project based context, and validated through focus group discussions with off-site construction industry experts.
4	Ndwiga, D., Ciera, L and Mokabi, G.	A conceptual appraisal towards the contextualization of product and process innovation in clothing manufacturing	2023	Journal Article	This research undertook a literature review which focussed on the context of innovation strategies in clothing manufacturing and the determinant factors indicating the acquisition and implementation of product and process-related innovation activities.

5	Dehe, B., Bamford, D and Kotcharin, S.	Bespoke benchmarking framework employed as vehicle and platform for open innovation – a healthcare infrastructure case	2022	Journal Article	This research reports on the development, testing and implementation of a bespoke benchmarking framework and assess its influence on the open innovation performance of new healthcare infrastructure. The research was developed from a series of 10 workshops. This investigation borrows a pragmatic paradigm and is inductive and qualitative by nature, but uses quantitative scoring within the benchmarking assessment.
6	Wang, C., Mao, Z., Su, H and Tian, Y.	Knowledge identification in medium sized enterprises under the context of quality improvement: An exploration in manufacturing companies in China	2020	Journal Article	The exploratory research reported by this paper has obtained and prioritised the up-to-date answers to what is and how to identify the knowledge most relevant to the medium sized enterprises, leading to the enrichment of the theoretical understanding of knowledge management approaches and practical guidance of their implementation in operations, under the context of quality improvement in medium sized enterprises.
7	Gao, S., Jin, R and Lu, W.	Design for manufacture and assembly in construction: a review	2019	Journal Article	This study reviews the processes and principles of Design for Manufacture and Assembly and explores the possible perspectives of Design for Manufacture and Assembly with a view to providing implications to the construction industry. This study suggests that development of design guidelines, forming multidisciplinary team, use of virtual design and construction systems and understanding the Lean principles are factors that could further enhance the successful application of Design for Manufacture and Assembly in construction.
8	Robinson, A., Gibb, A and Austin, S.	Standardisation of specification driven buildings with serial and repeat order designs	2012	Conference proceedings	This research, as part of an Engineering Doctorate study, examines repeat- and serial-order standardised buildings through multiple case studies where the reasons for their adoption are explored from various stakeholder perspectives. It tests existing theories. from literature on standardisation in design and construction efficiency, with an emphasis on specification driven ‘non-iconic’ buildings.

Further papers from snowballing technique					
9	O'Driscoll, M.	Design for manufacture	2002	Journal Article	This paper comprises an introduction to DFM, followed by a review of normal practices in industry, and finishing with an approach to implementing DFM in a manufacturing environment.
10	Dewhurst, N.	DFMA the product, then lean the process	2010	Conference proceedings	This paper explores the additional savings that could be unlocked when engineers combine an up front DFMA analysis of the product with Lean Manufacturing approaches to production. Combining these two techniques results in products that are "lean-from-the-start."
11	Emmatty, F, and Sarmah, S.	Modular product development through platform-based design and DFMA.	2012	Journal Article	This article presents a framework for modular product development by integrating function-based modular product architecture, platform-based design and design for manufacture and assembly. Application of the integrated framework is illustrated with a case study of the development of a watch mechanism. The illustration gives light to the stages of product development from conceptual evolution of the product to the detailed design.
12	Ashley, S.	Cutting costs and time with DFMA.	1995	Journal Article	This article presents the benefits of applying Design for Manufacturing and Assembly methodologies in early stages of product design and discusses how is can reduce the number of parts in a product and thus reduce the cost.

13	Boothroyd, G.	Product Design for manufacture and assembly.	1994	Journal Article	The paper first stresses the importance of taking careful account of manufacturing and assembly problems in the early stages of product design. Then, using a case study, the philosophy of the Design for Manufacture and Assembly (DFMA) methodology and its application are explained. The historical development of design-for-assembly and design-for- techniques in Japan, Europe and the USA is presented. A review of published case histories emphasizes the enormous advantages to be gained by adopting this relatively new approach as the major tool in concurrent and simultaneous engineering. Finally, a discussion of the various roadblocks affecting DFMA implementation is followed by a discussion of current developments, which include product design for disassembly, service and recycling.
14	Stoll, H.	Design for manufacture: An overview	1986	Journal Article	This article critically examines the broad range of activities which are embodied in the DFM approach. Discussion is divided into consideration of DFM principles and rules, quantitative evaluation methodologies, and computer-aided DFM. Underlying organization issues are also discussed.
15	Cillo, P., De Luca, L.M. and Troilo, G.	Market information approaches, product innovativeness, and firm performance: an empirical study in the fashion industry	2010	Journal Article	In this study the authors propose a distinction between two approaches to market information, rooted in the marked-based learning theory. The two approaches are conceptualized and operationalized on the basis of their differences along three processes: generation, dissemination and use of market information. Results suggest that the two approaches are complementary for firm performance, but have opposite effects on product innovativeness: while a forward-looking approach is positively related to product innovativeness, a retrospective approach seems to be negatively related. The results also shed light on how market information approaches and product innovativeness jointly affect firm performance.

16	Auken, V., Madrid-Guijarro, A., and Garcia-Pérez-de-Lema, D.	Innovation and Performance in Spanish Manufacturing SMEs	2008	Journal Article	Innovation facilitates how SMEs respond to market changes and maintain their competitive advantage. This paper analyses the relationship between the degree of innovation (measured as innovation in products, processes and administration systems) and performance among 1,091 Spanish manufacturing SMEs. The results show that innovation positively impacts SMEs performance in low and high technology industries. Innovation was more important to achieving a competitive advantage to high technology firms than low technology firms. These results support innovation as being important to a firm's sustainable competitive advantage.
17	Buergin, C.	Integrated Innovation Capability.	2006	Journal Article	The paper outlines a structure of a companys innovation capability integrated in its business environment. The structure is set up in different levels which affect a companys capability to innovate. As well as a basis of an instrument is described to measure and to lay the foundation for actions to improve the innovation capability.
18	OECD	Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data.	2018	Reference Guide	The Oslo Manual is the international reference guide for collecting and using data on innovation.
19	Wu, Q., Liao, K., Deng, X. and Marsillac, E.	Achieving automotive suppliers’ mass customization through modularity	2019	Journal Article	The purpose of this paper is to propose a sequential model reflecting the sequence of practices as well as an overview picture for a firm to achieve MC. The proposed model is tested with a data set collected from automotive suppliers in China and in the USA. Structural equation modeling is used to analyze the data and test the model. The results suggest that, for suppliers to achieve MC, postponement orientation and operational alignment are vital antecedents. The results also reveal the important responsibility and role of information sharing practices in coordinating suppliers’ modularity practices.

20	Holtewert, P. and Bauernhansl, T.	Choosing the Appropriate Methodology: Understanding Research Philosophy.	2016	Journal Article	This article proposes a new approach to increase the capacity flexibility in manufacturing systems. The core approach “Substitution of Product Functions” focuses on manufacturing two different variants of product components with the same product function simultaneously but two different product designs. One of the component designs needs a high process time with low variable costs, the other one a low process time with high variable costs. Thus, two product designs with differentiation in variable costs allow the use of the factor “manufacturing process time” as an additional control variable for increasing the capacity flexibility.
21	Aoki, M.	Modularization of industrial architecture: A theoretical introduction	2002	Book	The concept of "modularization" or "modularity," now catching on in economics and management describes the fundamental change to the industrial infrastructure that underlies the IT revolution. This book provides a summary of the debate among the world's leading theoreticians and practitioners on this topic to capture the nature of modularization and helps readers better understand the concepts.
22	Venkitachalam, K. and Busch, P.	Tacit knowledge: review and possible research directions	2012	Journal Article	The paper aims to propose directions for future research in this domain of discourse. It undertook a review of existing studies and highlights some gaps in the literature on the role of tacit knowledge, which is followed by questions for future research. From the research undertaken the authors believe that the proposed questions offer avenues for scholars to explore and develop greater understanding of the role of tacit know-how in certain knowledge management topics.
23	Gibb, A.	Standardisation and Preassembly – distinguishing myth from reality using case study research.	2000	Journal Article	Standardization and pre-assembly (S&P) are not new, but their application and their drivers, pragmatism and perception, need to be considered in the light of current technology and management practice. The CIRIA project, which forms the basis of this paper, aimed to produce a review of the subject and guidance for clients and project teams through a comprehensive literature review, expert work5 shops and case study research. The paper defines S&P, discusses past, present and future applications (providing case study evidence) and presents the key benefits and implications of the optimized use of standardization and pre-assembly.

24	Gibb, A.	Standardisation and Customisation in Construction – A Review of recent and current industry and research initiatives on standardisation and customisation in construction	2001	Report	This report was commissioned by the Technologies and Components Task Group of the Construction Research and Innovation Strategy Panel (CRISP). Its purpose is to identify, illustrate and where possible categorise recent and current initiatives on standardisation and customisation, particularly within UK construction.

Systematic literature review finding's introduction

From the literature review undertaken eight papers were found and these are detailed in Table 2. From these initial eight papers, a snowballing technique was used where the references from these papers were used to identify further relevant material. A further sixteen papers were identified, and they are also included in the table. From this literature, three main themes emerged that could potentially assist in achieving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products. The first theme to emerge was Design for manufacture (DFM) and Design for Assembly (DFA), the second theme was product and process development, and the third theme was modularisation and standardisation. The following section will discuss in more detail the findings on these three themes.

DFM and DFA

Two of the eight papers contain the main body of work concerning DFM and DFA. These papers comprise Developing a Construction-Oriented DfMA Deployment Framework (Rankohi et al., 2023) and Design for Manufacture and Assembly in Construction: a Review (Gao, Jin and Lu, 2019).

Rankohi et al., (2023) claim that design for manufacture and design for assembly began during World War two (1939 – 1945) when Ford and Chrysler developed design principles in their weapons production process. O'Driscoll (2002) claims that the concept dates back further to 1788 when a French musket manufacturer named LeBlanc devised interchangeable parts for muskets rather than the conventional bespoke parts.

Dewhurst (2010) notes that the design of the product itself ultimately defines the total cost. Utilising DFM & DFA during the design phase will assist in cost reduction as the full benefits of Lean production can be realised since potential manufacturing and assembly issues have already been resolved (Gao, Jin and Lu, 2019). Thus, incorporating DFM & DFA during the design phase avoids manufacturing and assembly issues in the latter stages of a manufacturing project (Emmatty and Sarmah, 2012).

Ashley (1995) describes how the team at Douglas Commercial Aircraft Co were taught DFM and DFA as a review method. The purpose of these reviews was to identify the optimal part design, material choice and assembly and fabrication operations to produce an efficient and cost-effective product. Boothroyd (1994) states that while the traditional viewpoint is that DFM and DFA are only worthwhile when the quantities to be manufactured are high, he argues that the philosophy is even more critical when the quantities are small. He argues this point as commonly, an initial design is not usually reconsidered for low-volume production.

Research undertaken by Stoll (1986 cited in Gao, Jin and Lu, 2019) found ten principles or rules for implementing DFM and DFA reviews. These include: (1) minimising the total number of parts, (2) developing a modular design, (3) using standard components, (4) designing parts to be multifunctional, (5) designing parts for multi-use, (6) designing parts for ease of fabrication, (7) avoiding separate fasteners, (8) minimising assembly directions, (9) maximising compliance (10) minimising handling. Boothroyd (1994) adds further clarity to the process by stating that DFA should always be the first consideration, leading to a simplification of the product structure. This is followed by a review of the materials and manufacturing processes with a perspective of being more efficient and reducing costs.

In conclusion to this section on DFA and DFM, Boothroyd (1994) uses an excellent metaphor for failing to include DFM and DFA in the design process. He refers to this action as being “over-the-wall”, meaning the design engineer throws the design over the wall to the manufacturing engineers, who then must deal with the various manufacturing issues as they were not involved earlier in the process. Similarly, the production engineers will have to deal with the various assembly issues as they were not involved earlier during the design phase.

Product and process development

The main body of work concerning product development is contained within three of the eight papers. These papers include Digital Engineering Methods in Practical Use during Mechatronic Design Processes (Gerschutz, et al., 2023). A conceptual appraisal towards the contextualisation of product and process innovation in clothing manufacturing (Ndwiga, Ciera, and Mokabi, 2023) and Bespoke benchmarking framework employed as a vehicle and platform for open innovation – a healthcare infrastructure case, (Dehe, Bamford and Kotcharin, 2022).

Cillo et al., (2010, cited in Ndwiga, Ciera, and Mokabi, 2023) describe product development as a degree of newness of a product as compared to previous products distributed by a firm based on their characteristics or intended use. Thus, they provide the customer with increased product differentiation, highlighting a firm's ability to respond to market changes. Product development not only allows a company to expedite its ability to respond to market changes and develop its competitive advantage (Auken, Madrid-Guijarro and Garcia-Pérez-de-Lema, 2008), it allows a firm to attain growth, achieve greater profitability and develop the appropriate innovation that the market demands to achieve a competitive advantage (Buergin, 2006).

The Oslo Manual describes itself as the foremost international source of guidelines for the collection and use of data on innovation activities (OECD, 2018). It takes the previous discussion on product development further, stating that product innovation can require a supporting business process innovation. Additionally, a business process innovation can significantly improve the quality of a product, resulting in a joint process and product improvement. Dehe, Bamford, and Kotcharin (2022) also promote using technical tools such as Plan-Do-Check-Act (PDCA) as a consistent approach to innovation problems to develop a culture of continuous improvement and capture knowledge.

Modularisation and standardisation

According to Wu et al. (2019), utilising modular theory empowers a manufacturer with manufacturing flexibility and the ability to adapt to small-batch and multi-variety customised production through module integration. Manufacturing flexibility refers to the capability of a manufacturer to adapt to both internal and external changes yet continue to produce products and volumes without compromising performance (Holtewert and Bauernhansl, 2016).

Aoki (2002) adds to this discussion, stating from a knowledge-based perspective that incorporating more decomposed modules into a design allows for more explicit knowledge to be transferred between modules, and tacit knowledge that would otherwise be hidden in each module is reduced. Tacit knowledge is difficult to express or extract, whereas explicit knowledge can be readily articulated or conceptualised (Venkitachalam and Busch, 2012). Gibb (2000) explains that using standardisation can be limiting for a designer. Using off-the-shelf solutions can limit innovation and result in less original designs. However, this can be overcome by incorporating standard items into standard modular components that allow for customisation (Gibb, 2001).

2.3 Systematic Literature Review Analysis

This section of the literature review involved a systematic literature review. The aim being to uncover relevant literature on potential methods for increasing production efficiency during the mechanical design phase of HVLVHV machinery products. The systematic literature review uncovered some very interesting literature that will be discussed shortly in the conclusion. It also identified what appears to be a gap in the literature concerning increasing production efficiency during the mechanical design phase of HVLVHV machinery products. The literature review focused on the specific keywords “Manufacturing”, “Design”, “Efficiency”, and “Jobbing shop” or “HVLVHV” or “Bespoke” as the filter to limit it to documents containing these words. None of the papers reviewed discussed improving production efficiency during the mechanical design phase of HVLVHV machinery products. Additionally, none of the papers covered mechanical design, as they were more focused towards clothing manufacturing and construction. The following section concludes the findings from this review.

2.4 Systematic Literature Review Conclusion

From the literature review undertaken, three main themes emerged that require investigation for their incorporation into the framework. The first theme to emerge was Design for manufacture (DFM) and Design for Assembly (DFA), the second theme was product and process development, and the third theme was modularisation and standardisation.

Dewhurst (2010) notes that the design of the product itself ultimately defines the total cost. Utilising DFM & DFA during the design phase assists in cost reduction as the full benefits of Lean production can be realised since potential manufacturing and assembly issues have already been resolved (Gao, Jin and Lu, 2019). Therefore, incorporating a DFM and a DFA review into the framework avoids manufacturing and assembly issues in the latter stages of a manufacturing project (Emmatty and Sarmah, 2012) and should, therefore, improve production efficiency.

A further argument for incorporating these tools is Boothroyd (1994), stating that while the traditional viewpoint is that DFM and DFA are only worthwhile when the quantities to be manufactured are high, they argue that the philosophy is even more critical when the quantities are small. The justification is that the initial design is not usually reconsidered for low-volume production. Therefore, DFM and DFA appear viable tools for implementation into the framework in the mechanical design of bespoke low-volume products. A further point noted by Boothroyd (1994) added further clarity to the process by stating that DFA should always be the first consideration, leading to a simplification of the product structure. This is followed by a review of the materials and manufacturing processes with a perspective of being more efficient and reducing costs. Therefore, the sequencing of the DFM and DFA reviews should be considered when implementing them into the framework.

When implementing the DFM and DFA reviews discussed previously, there will undoubtedly be changes implemented to the product. These changes along with others will fall under the guise of product development. Product development not only allows a company to expedite its ability to respond to market changes and develop its competitive advantage (Auken, Madrid-Guijarro and Garcia-Pérez-de-Lema, 2008), but it also allows a firm to attain growth, achieve greater profitability and develop the appropriate innovation that the market demands to achieve a competitive advantage (Buergin, 2006). Product development should be captured in the framework therefore as a method of improving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products.

The Oslo Manual (OECD, 2018) takes the previous discussion on product development further stating a product innovation can require a supporting business process innovation. Additionally, a business process innovation can significantly improve the quality of a product, resulting in a joint process and product improvement. The framework being developed derives from the process of the product passing through the Engineering department. Therefore, whilst implementing the product developments, process developments should also be undertaken to maximise the efficiency improvements. Additionally, as discussed by Dehe, Bamford, and Kotcharin (2022), using technical tools such as Plan-Do-Check-Act (PDCA) as a consistent approach to developing the framework will aid in developing a culture of continuous improvement and assist in capturing knowledge.

Wu et al., (2019) explain that utilising modular theory empowers a manufacturer with manufacturing flexibility and the ability to adapt to small-batch and multi-variety customised production through modules integration. Additionally, as discussed by Aoki (2002) from a knowledge-based perspective, incorporating more decomposed modules into a design allows for more explicit knowledge to be transferred between modules and tacit knowledge that would otherwise be hidden in each module is reduced. Gibb (2000) added to the argument for having a modular design rather than a standard design as they depicted using standardisation can be limiting for a designer. Using off-the-shelf solutions can limit innovation and result in less original designs. As explained by Gibb (2001), the benefits of using standard parts can still be seen by incorporating them into standard modular components that allow for customisation, and this will be the approach utilised for the framework.

In conclusion, none of the papers covered mechanical design, as they were more focused towards clothing manufacturing and construction. Therefore, from the research undertaken, the results indicate that there appears to be a gap in the literature on increasing production efficiency during the mechanical design phase of HVLVHV machinery products. This research, therefore, will populate the gap in the literature within this niche area.

2.5 Utilising Theory as a Practitioner

The previous section described the findings from undertaking a systematic literature review. A systematic literature review is utilised as it gives a clear overview of relevant academic literature on the topic. As the researcher is a practitioner in industry, it is common to be exposed to other tools that may benefit the framework and assist in improving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products. The following sections investigate the literature on potential tools for incorporation into the framework the researcher has been exposed to as a practitioner in industry.

2.5.1. Six Sigma

A potential method for improving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products is Six Sigma. Six Sigma is a popular contemporary process improvement practice developed from the Total Quality Management (TQM) philosophy to drive organisations towards efficiency and excellence (Assarlind et al., 2013). It can be considered both a business strategy and a science that aims to reduce manufacturing and service costs. It does this by significantly improving customer satisfaction and bottom-line savings by combining statistical and business process methodologies into an integrated model of the process, product, and service improvement (Singhet al., 2017). The fundamental principles of Six Sigma are to achieve stable and predictable process results (e.g., by reducing process variation), which are vital to a company’s success. This is achieved by measuring, analysing, improving, and controlling the manufacturing and business processes. In Six Sigma, this is known as DMAICR, and this is an adaptation of the Deming Wheel, plan, do, check, and act.

Six Sigma and process steps (DMAICR)

Define (D). Selection of appropriate projects, development of project plans and identification of the relevant process. The Supplier-Input-Process-Output-Customer (SIPOC) mapping exercise can be used effectively to describe the process.
Measure (M). Measurement of process variables through data quality checks, repeatability, and reproducibility (RAR) studies, and addressing process stability.
Analyse (A). Use of graphical techniques to analyse process behaviour.
Improve (I). Improvement of the existing process through experimentation and simulation techniques.
Control (C). Development of the Control plan for process improvement.
Reporting (R). Reporting of the benefits of the re-engineered process

(Senapi, 2004)

These quality improvement processes require commitment from the entire organisation and must be driven down from top-level management. It should be encompassed in the business strategy and be at the core of the management's vision for the company. The management team needs to select the right employees to train and then support these employees through both the implementation stages and the ensuing periods of effort necessary to succeed in Six Sigma implementations. Communication needs to be clear on what is required from the Six Sigma team, and this needs to be communicated to all employees. Without the informed support of all organisation members, the Six Sigma implementation will not be fully effective.

2.5.2. Lean

Lean is like Six Sigma in that its function is to streamline manufacturing and production processes. What differentiates Lean is that Lean is understood as a coherent system of practices focused on eliminating waste by concurrently reducing supplier, customer, and internal variability (Shah and Ward, 2007). Waste can come in many forms, ranging from excess inventory to excess capacity and variability in supply and processing time. The focus of Lean is cutting out these unnecessary and wasteful steps in creating a product so that only steps that directly add value to the product are taken.

Aziz and Hafez (2013) state the five fundamental principles of Lean thinking, which must be followed step by step to gain the maximum benefit of Lean success:

- Specify Value: Specify Value from the customer's own definition and needs and identify the value of activities which generate value for the end product.

- Identify the value stream: Identify the value stream by eliminating everything which does not generate value for the end product.

- Flow: Ensure a continuous flow in the process and value chain by focusing on the entire supply chain.

- Pull: Use pull in the production and construction process instead of push. This means producing exactly what the customer wants when the customer needs it and always preparing for changes made by the customer.

- Perfection: Aim at the perfect solution and continuous improvements. Deliver this solution to the specifications agreed upon with the customer within the agreed timeframe.

2.5.3. Total Quality Management (TQM)

Total Quality Management (TQM) is a management system built on the belief that long-term quality and success can be achieved if broad organisational efforts focus on this strategy. TQM is a long-term strategy and does not focus on short-term gains. TQM enjoyed widespread attention during the late 1980s and early 1990s before being overshadowed by ISO 9000, Lean manufacturing, and Six Sigma (Fragassa et al., 2014). To be successful TQM relies on the quality system being accepted into the culture and activities of the organisation.

Below are the eight principles of total quality management:

- Strategically based: TQ organisations have a strategic plan containing vision, mission, objectives, and activities. The strategic plan is designed to give a sustainable competitive advantage in the marketplace.

- Customer Focus: The customer is the driver internally and externally. Internal – Customer is the quality of the product. Externally – Customer is defined as the quality of people, processes, and the environment.

- Obsession with Quality: Because the customer is the driver, the organisation becomes obsessed with meeting or exceeding his expectations.

- Scientific approach: Employees are empowered. The scientific approach uses structured work and problem-solving.

- Long-term commitment: Organisations fail if they only implement quality changes in the short term.

- Teamwork: The best comparative efforts are within departments.

- Continual process employment: To improve quality, we must improve the system.

- Education and training: Needed to improve people continually.

(Goetsch and Davis, 2010)

2.5.4. ISO 9000

The ISO 9000 set of standards addresses all aspects of quality management. They provide guidance and tools for companies that want to ensure that their products and services constantly meet customer requirements and that quality is consistently improved (ISO, n.d.). ISO 9001:2015 sets out the criteria for a quality management system that helps companies become more efficient and improve customer satisfaction. A quality management system is a methodology for defining how an organisation can meet the requirements of its customers and other stakeholders affected by its work (ISO, 2015a). The ISO 9000 and ISO 9001 standards are based on the seven quality management principles (QMPs).

- Customer Focus

- Leadership

- Engagement of people

- Process approach

- Improvement

- Evidence-based decision making

- Relationship management

The QMPs can be used as a foundation to guide an organisation's performance improvement (ISO, 2015b).

2.5.5. Kotter’s 8-Step Change Model

Kotter (1996) recommends an eight-step model that aims to establish employee commitment and reduce scepticism:

- Establishing a sense of urgency.
- Creating a guiding coalition.
- Developing a Vision and Strategy.
- Communicating the change vision.
- Empowering broad-based action.
- Generating short-term wins.
- Consolidating gains and producing more change
- Anchoring new approaches in the culture.

Like any company implementing change, there are numerous challenges. According to Kotter's framework, planning changes should limit those obstacles, but the model is not detailed enough to provide help in all scenarios. For example, resistance to change and commitment to change are major aspects of change management and complementary components outside Kotter's model, such as Jaros's (2010) predictors to determine commitment to change, might be needed to address these (Appelbaum et al., 2012).

Utilising the above model and skills may result in engagement but will require the development of soft skills. Hard skills are academic and technical. Soft skills are the interpersonal and life skills that help leaders share their hard skills effectively. Soft skills are polite and pleasing ways of communicating with others to execute tasks effectively. They reach beyond team building and communication skills, considered a sub-set of soft skills (Rao, 2013).

2.5.6. The UWES questionnaire

Work engagement is defined as a positive, fulfilling, work-related state of mind that is characterized by vigour, dedication, and absorption (Schaufeli et al., 2002). However, work engagement isn't specifically a tool for improving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products. It can be argued that having an engaged workforce leads to more productive staff which leads to greater efficiency.

There are numerous methods for measuring employee engagement. Admasachew and Dawson (2010) describe a few, including the Maslach Burnout Inventory-General Survey (MBI-GS), the Job Demand-Resources (JD-R) model and the Utrecht Work Engagement Scale (UWES). After researching various methods, the UWES questionnaire was chosen for inclusion in the literature review as the reliability of the UWES, as well as the validity of the construct, had been demonstrated in the work environment and to a lesser degree in the academic environment (Guillen & Martinez-Alvarado, 2014).

2.6 Theory as a practitioner Literature review Analysis

The second part of the literature review introduces tools that the researcher has been exposed to as a practitioner in industry. These tools may be beneficial for the framework and assist in improving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products. These included:

- Six Sigma
- Lean
- Total Quality Management (TQM)
- Iso 9000
- Kotters 8-Step Change Model
- The Utrecht Work Engagement Scale (UWES) questionnaire

Six Sigma, Lean, TQM, and ISO 9000 are differing methodologies for undertaking business and process improvements. There are advantages and disadvantages to each of the methods, and these are discussed below.

There are many well-documented cases of success using “Six Sigma”, but these companies are usually industry pioneers like General Electric (GE) and Motorola. These are, in general, large corporate giants that implemented “Six Sigma” rather than small or medium-sized enterprises (SMEs). This is thought to be due to the large costs involved in implementing the program. One of the main costs is the Six Sigma training, which creates a barrier to spending and prevents the implementation of this improvement program. The four-year-old Six Sigma Academy in Scottsdale, Arizona, run by former Motorola quality experts Mikel Harry and Richard Schroeder, charges fees of approximately $1 million per corporate client (Senapti, 2004). Six Sigma, therefore, may not be appropriate for all companies due to the high costs involved in its implementation. Additionally, suppose a company chooses to train internal personnel in “Six Sigma”. In that case, their productivity will be delayed as they will have to be trained before they are proficient. There could also be challenges in who is selected for this training. This could lead to jealousy and discontent from personnel who are not selected. The central idea behind Six Sigma is that if you can measure how many "defects" you have in a process, you can systematically figure out how to eliminate them and get as close to "zero defects" as possible (GE, n.d.). Therefore, as it is intended for high production volumes, the process is not appropriate for bespoke manufacturing and will not be incorporated into the framework.

Lean is usually understood as a coherent system of practices focused on the elimination of waste by concurrently reducing supplier, customer, and internal variability (Shah and Ward, 2007). To be successfully implemented, Lean relies on a holistic approach, meaning all parts of the company engage in the process. It has also been found that deployment and sustaining improvements are major issues that can be overcome by building a sustainable infrastructure and making improvements to business processes (Snee, 2010). This could lead to a change in the organisation's culture as this new working methodology is implemented. Morgan (1997) recommends the use of attractor patterns as a creative metaphor for thinking about organizational change. Utilising this method is a powerful way for management to break the powerful hold of established attractors in favour of new ones.

Although specific Lean tools are not considered for implementation in the framework, Lean design principles will be incorporated. As discussed previously, utilising DFM & DFA during the design phase assists in cost reduction as the full benefits of Lean production can be realised since potential manufacturing and assembly issues have already been resolved. These manufacturing and assembly issues are a form of waste that is removed by the Lean design philosophy of considering them during the design phase.

Implementing a TQM continuous improvement program would rely on a cultural change in the organization. For organizational change to be a success, it cannot be rushed and takes time. Kotter (1996) recommends an eight-step model for organizational change that aims to establish employee commitment and reduce scepticism. Implementing TQM relies on management's total commitment to the cause and then mapping the critical processes through which the organization meets its customers' needs. TQM is closely linked to Porter's cost leadership strategy (Simani, 2017). Due to the dependence on cultural change and the total commitment of management, incorporating TQM into the framework was not deemed within the scope of this research.

ISO 9001, like the previous strategies, relies on top management committing to long-term change. Once management has chosen this strategy, the company quality management system will be revised or generated if none exists. It relies on the management team taking responsibility for the processes and procedures in their department. Many companies are ISO 9001 certified, so they should already be following this working methodology. As with TQM, due to the dependence on management, incorporating ISO 9001 into the framework was not deemed within the scope of this research.

Work engagement is defined as a positive, fulfilling, work-related state of mind that is characterized by vigour, dedication, and absorption (Schaufeli et al., 2002). Although work engagement isn't specifically a tool for improving production efficiencies, it can be argued that having an engaged workforce leads to more productive staff which leads to greater efficiency. After reviewing the various methods, the UWES questionnaire appeared most appropriate for this study.

2.7 Theory as a Practitioner Literature Review Conclusion

In conclusion, the investigation of literature investigating theory as a practitioner revealed some key tools that require incorporating into the framework for validation. The UWES questionnaire will be utilised to measure employee engagement. This will aid in gauging if good communication assists with employee engagement and potentially improves productivity. Finally, although specific Lean tools are not considered for implementation into the framework, Lean design principles will be incorporated.

2.8 Literature Review Conclusion

The first section of the literature review involved a systematic literature review. The aim is to uncover relevant literature on potential methods for increasing production efficiency during the mechanical design phase of HVLVHV machinery products. Due to a lack of literature and the weak generalisability of the findings, a second literature review was undertaken. The second part of the literature review investigated tools that the researcher has been exposed to as a practitioner in industry that may benefit the framework and assist in improving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products.

The concluding findings from the systematic literature review identified that none of the papers covered mechanical design and were more focused on clothing manufacturing and construction. This could be due to a lack of investment in research for HVLVHV machinery products as the volumes are so small in comparison to higher production areas, but evidencing this would require further investigation. As the results from the literature review indicated a lack of data on the research subject it identifies that this research is relevant both in terms of time but also importance. This is an opportunity to occupy what appears to be a gap in the literature.

The literature review identified several tools that had potential strengths for increasing production efficiency during the mechanical design phase of HVLVHV machinery products, and these will be taken forward and tested in the framework. These included DFM DFA, product and process development, including the tool PDCA, modularisation and standardisation.

The concluding findings from the investigation on literature investigating theory as a practitioner revealed some key tools that require incorporating into the framework for validation. The UWES questionnaire will be utilised to measure employee engagement. This will aid in gauging if good communication assists with employee engagement and potentially improves productivity. Finally, although specific Lean tools are not considered for implementation into the framework, Lean design principles will be incorporated.

Therefore, the findings from the literature review drive an approach to the investigation to verify the tools by implementing them into the framework. The framework will include DFM & DFA reviews during the design phase. The reviews will be sequenced, and DFA will be the first consideration. Product and process development will be captured in the framework to improve production efficiencies. Additionally, PDCA will be utilised as a consistent approach to developing the framework.

The framework will drive the use of standard modules that allow for customisation, and standard parts will be incorporated into the design where possible. The UWES questionnaire will be utilised to measure employee engagement. This will aid in gauging if good communication assists with employee engagement and potentially improves productivity. Finally, although specific Lean tools are not considered for implementation into the framework, Lean design principles will be incorporated.

In conclusion, from the research undertaken the results indicate that there appears to be a gap in the literature on increasing production efficiency during the mechanical design phase of HVLVHV machinery products. As this research will verify the validity of the tools for improving production efficiency in HVLVHV machinery by application in an industrial setting, it should populate the gap in the literature in this niche area. The following section describes the proposed research methods and techniques used to investigate the research question.

3. Methodology and research design

In the previous section, a literature review was undertaken to explore industry and academic tools that could be incorporated into the framework. The following section describes the proposed research methods and techniques used to investigate the research question:

“How can production efficiencies be achieved during the mechanical design phase when dealing with HVLVHV machinery products?”

It first describes the ontological, epistemological, and axiological approaches taken and details the justification for these choices. Once the philosophical approach is identified, the methodological choice will be discussed and acknowledged. This is then followed by an introduction to the proposed research strategy.

The section is structured using the research onion model developed by Saunders, Lewis and Thornhill (1997), see Figure 5. This model is used as a pictorial reference to guide the reader through the choices made concerning the various stages of the research methodology.

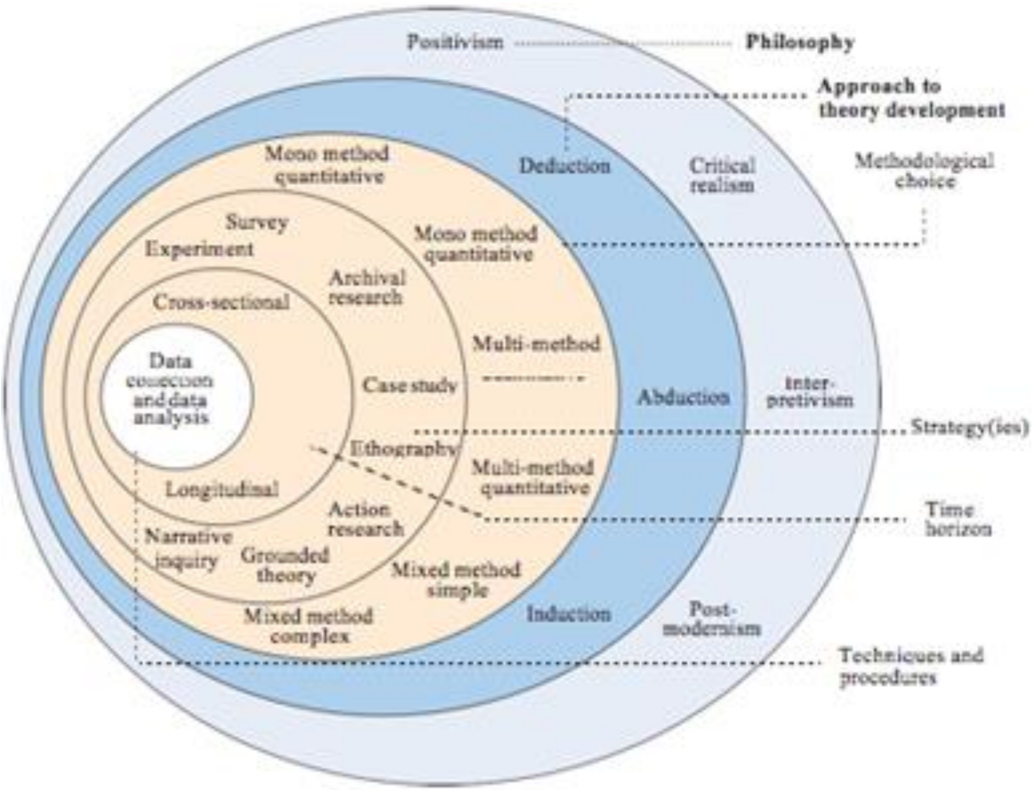

Figure 5, The research onion (Saunders, Lewis and Thornhill, 2016, p.164)

3.1 Philosophical approach

This research aims to answer the question: How can production efficiencies be achieved during the mechanical design phase when dealing with HVLVHV machinery products? While researching this question, various assumptions and beliefs will guide the researcher's behaviour (Jonker and Pennink, 2010). Saunders, Lewis, and Thornhill (2016) highlight the significance of critically examining the choice of a research paradigm at the outset of a study, as it profoundly shapes the approach to conducting social research. It shapes not only the research question and methodologies but also the philosophical and epistemological foundations of the study.

Table 3, Fundamental Beliefs of Research Paradigms in Social Sciences (Wahyuni, 2012)

	Research Paradigms			
Fundamental Beliefs	Positivism (Naïve realism)	Postpositivism (Critical Realism)	Interpretivism (Constructivism)	Pragmatism
Ontology: the position on the nature of reality.	External, objective and independent of social actors.	Objective. Exist independently of human thoughts and beliefs or knowledge of their existence, but is interpreted through social conditioning (critical realist).	Socially constructed, subjective, may change, multiple.	External, multiple, view chosen to best achieve an answer to the research question.
Epistemology: the view on what constitutes acceptable knowledge	Only observable phenomena can provide credible data, facts. Focus on causality and law-like generalisations, reducing phenomena to simplest elements.	Only observable phenomena can provide credible data, facts. Focus on explaining within a context or contexts.	Subjective meanings and social phenomena. Focus upon the details of situation, the reality behind these details, subjective meanings and motivating actions.	Either or both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research question. Focus on practical applied research, integrating different perspectives to help interpret the data.
Axiology: the role of values in research and the researcher's stance	Value-free and etic. Research is undertaken in a value-free way, the researcher is independent of the data and maintains an objective stance.	Value-laden and etic. Research is value laden; the researcher is biased by world views, cultural experiences and upbringing.	Value-bond and emic. Research is value bond, the researcher is part of what is being researched, cannot be separated and so will be subjective.	Value-bond and etic-emic. Values play a large role in interpreting the results, the researcher adopting both objective and subjective points of view.
Research Methodology: the model behind the research process	Quantitative	Quantitative or qualitative	Qualitative	Quantitative and qualitative (mixed or multimethod design)

Table 3 shows the assumptions and beliefs aligned to the differing paradigms. The foundation of all research is the ontological position on the nature of reality. For example, is the universe objective and independent of social actors or is reality subjective and perceived by the actor? The two extreme perspectives of ontology are positivism and interpretivism. Positivists believe the universe is objective and independent of social actors and the researcher's perspective or beliefs (Hudson and Ozanne, 1988). The opposing perspective to this paradigm is interpretivism. It has the core assumption that reality is socially constructed and a function of human imagination and experiences and is, therefore, a constructed interpretation (Joesbury, 2016).

The next layer down defines the epistemological assumptions, and this defines the researcher's perspective on what constitutes acceptable knowledge. Table 3 shows the two extremes of epistemology: positivism and interpretivism. Concerning epistemology, the positivist researcher believes that knowledge is observable and can be acquired through interactions with the world or experiments. The opposing epistemological stance to this is interpretivism, and this perspective believes that knowledge is subjective and focuses on research participants, their feelings, and patterns of behaviour.

The third layer down defines the axiological assumptions, and this defines the researcher's perspective on values and how they impact the research. These values could, for example, include biases and considering these could aid the researcher in their interpretation of data collected whilst undertaking the research. As can be seen from Table 3, the researcher's assumptions influence the research methodology. The researcher who favours a more objective, scientific approach would tend more towards a quantitative methodology. In contrast, the researcher who favours a more subjective approach, focusing on the research participants and behaviours, would tend more towards a qualitative methodology.

3.1.1 Ontological

Although it is recognised that there are several research philosophies, the research philosophy deemed most appropriate for undertaking this work is a pragmatic approach. The ontological position of pragmatism is one of multiple ontological positions. The ontological position shifts depending on the circumstances, and a pragmatic researcher can be both objective and subjective.

The reality cycle developed by Maarouf (2019, p. 7) is an excellent illustration of how this approach works, see Figure 6. They describe this cycle as being “based on the idea of the existence of one reality and multiple perceptions of this reality in the social actors' minds. According to the reality cycle, only one reality exists in a certain context at a certain point in time. Reality depends on the context to exist and continue existing, which means that changing the context changes the reality, and the existence of multiple contexts means the existence of multiple realities. In consequence, the reality cycle adopts a practical, pragmatic point of view assuming that reality is stable most of the time and changes periodically”.

Figure 6, The reality cycle (Maarouf, 2019, p.7)

The reality cycle assumption bestows the pragmatic researcher with the ability to switch between the two views of external reality and multiple perceptions of reality in social actors' minds and thus between the quantitative and qualitative research approaches and methods

(Maarouf, 2019). Therefore, combining both quantitative and qualitative data allows for the triangulation research method to be used. Utilising multiple data sets increases the credibility and validity of the research findings (Noble and Heale, 2019). Credibility refers to the trustworthiness of the research, while validity reflects how accurately the research represents the concept being investigated.

Additionally, the reality cycle assumption empowers the pragmatic researcher with the ability to adjust their view and perception whilst considering the organisational culture and additionally the departmental cultures embedded within organisations. Having this ability allows the researcher to assess the situation and adapt their style or approach depending on the circumstance and the participant in the research. Considering the complexity of dynamic social situations will aid the researcher in gaining access to data.

3.1.2 Epistemological

The epistemological assumptions define the researcher's perspective on what constitutes acceptable knowledge. The two extreme assumptions of epistemology are positivism and interpretivism. The positivist researcher believes that knowledge is observable and objective, they acquire knowledge by examining empirical evidence and hypothesis testing (Kaushik and Walsh, 2019). The interpretivism researcher believes that knowledge is subjective, and reality is too complex. The pragmatism approach to epistemology is that both observable and subjective meaning can provide acceptable knowledge. The pragmatism approach incorporates practical applied research, integrating the most appropriate epistemological approach to interpret the data and answer the research question. Pragmatists believe that the process of acquiring knowledge is a continuum rather than two opposing and mutually exclusive poles of either objectivity or subjectivity. Therefore, pragmatism is the chosen epistemological approach to this research as it allows the researcher to gain knowledge through practical applied research, integrating the most appropriate approach to answer the research question.

3.1.3 Axiological

The axiological stance of a researcher defines the role of values in research and the researcher's stance. The two extreme assumptions of the axiological stance are positivism and interpretivism. The positivist philosophical stance is characterised by a perspective which emphasises objectivity, quantifiability and the search for causal relationships. The axiological stance in this approach is often neutral or value-free, aiming to minimise the influence of personal biases or subjective interpretations in the pursuit of objective knowledge. The opposing view to this is interpretivism, where the researcher is part of the research and, therefore, cannot be objective. The axiological assumptions of pragmatism are value bound, where values play a large role in interpreting the results, with the research adopting both objective and subjective points of view.

Within the context of the case study company, there are differing values based on the theory that TFW has core business values that all personnel should hold in common. Additionally, the different departments within the business will have their own sets of standards or values based on their standpoints and needs (Johnson, 2009). As the researcher is a manager within the case study company, the core values and departmental values will be considered when interacting with these departments. Additionally, it is recognised that it is not viable to remain fully objective when interpreting the results of the research. Therefore, it is anticipated that the researcher will overcome this by focusing mainly on quantitative data and pre-defined metrics, thus making the results objective. Due to the axiological stance within the research adopting both objective and subjective points of view, pragmatism is deemed the most appropriate axiological stance for this research.

3.1.4 Inductive/deductive

Undertaking research where you are testing an existing theory is defined as deductive research. When research generates a new theory, it is defined as using an inductive approach. Undertaking the literature review did not yield a potential framework for incorporating into the research. Although a systematic literature review was undertaken, it did not identify an existing framework appropriate for implementation to improve production efficiency in the mechanical design element of HVLVHV machinery products. From the literature review undertaken, no framework appeared to exist, and therefore, the research will not be testing an existing theory, so this will not be deductive research.

Therefore, the research focuses on developing a new framework that drives the use of standard modules that allow for customisation and standard parts incorporated into the design where possible. Additionally, although specific Lean tools are not implemented into the framework, Lean design principles are incorporated. The output from this research is a framework that can be implemented in other areas of TFW's product portfolio and the broader industry that specifically manufactures HVLVHV machinery products. Therefore, as the researcher is generating new theories, knowledge, and applications for practice, they will be using an inductive approach.

3.1.5 Philosophical Doctoral Journey

When starting on the Doctorate in Business Administration journey, the researcher was a manager at an engineering company, this being the case study company TFW. The researcher was considerably more biased towards the left side of their brain, being analytical and orderly. Neglecting the right-hand side of the brain and the creativity and emotion. The following section describes the researcher's philosophical stance at the start of the research rather than the previous section, which describes the researcher's philosophical stance towards the end of the doctorate. This section has been included to highlight the impact the doctoral journey has had on the researcher and to highlight how they have changed as an individual.

Burrell and Morgan's (1979) book "Social Paradigms and Organisational Analysis" attempts to organise the predominant approaches to the study of organisations. They conclude that the various schools of thought reside in four paradigms (Lane, 1999). Positioning yourself on this model and developing a philosophical perspective requires that the researcher make several core assumptions concerning two dimensions: the nature of society and the nature of science (Burrell and Morgan, 1979).

The first axis, the 'Nature of Social Science', involves either a subjective or an objective approach to research, and these two major philosophical approaches are depicted by several core assumptions concerning ontology (reality), epistemology (knowledge), human nature (pre-determined or not), and methodology (Holden and Lynch, 2004). Philosophers often use Ontology as a synonym of 'metaphysics' (literally: 'What comes after physics'), a term used by early students of Aristotle to refer to what Aristotle called himself 'first philosophy' (Gruber, 2007). Ontology refers to our assumptions about how we see the world, e.g., does the world consist mostly of social order or constant change? An objectivist view of ontology assumes that social and natural reality have an independent existence prior to human cognition, whereas a subjectivist ontology assumes that what we take as reality is an output of the human cognitive process (Johnson and Duberley, 2000).

Coghlan and Brannick (2005) state that the most appropriate view of ontology for action research is an objective stance or positivism. Positivism was created in the mid-19th Century by Auguste Comte, who established the positivist approach to social science. Positivists argue that the explanation of sociology is the same as that of natural science (Gunbayi and Sorm, 2018). This directly opposes the stance of Baskerville (1999), who argues that the subjective viewpoint follows from the allowance for social intervention in the research setting. Therefore, when being subjective, the researcher intervenes and becomes part of the study, *i.e.* one of the study subjects. This causes a moral dilemma for the researcher as the work being undertaken is intended to be objective and, therefore, should not be influenced. However, it is recognised that as a researcher, it is incredibly challenging to remain genuinely objective, and this is acknowledged. Additionally, as the researcher's background is working as a Mechanical Design Engineer, the positivist approach is more akin to the natural sciences and, therefore, comparable to the way they are used to working.

Epistemology concerns the study of the nature of knowledge: "How do we begin to understand phenomena and communicate it?" It concerns "the nature, validity, and limits of inquiry" (Rosenau, 1992). Much of the research produced on organisational science assumes that reality is objective and 'out there' waiting to be discovered and that this knowledge can be identified and communicated to others (Holden and Lynch, 2004). The researcher's current school of thought is in the positivist epistemology. The data collected for the thesis is mainly quantitative data and is collected systematically. The results are believed to be objective, and this is achieved by utilising quantitative data and pre-defined metrics. As a positivist, the researcher adopts a methodological approach towards reflexivity and concentrates on improving methods and their application within the organisation (Johnson and Duberley, 2000).

Burrell and Morgan (1979) discuss the "Human Nature" assumption as having two extremes: voluntarism and determinism. Determinists adhere to the position that man is completely determined by the situation or environment around him (Burrell and Morgan, 1979). The voluntarist approach ascribes a much more creative, free-will approach to humans, treating them as agents able to create their environment through their thoughts and actions (Lane, 2001). The "Human Nature" approach to Burrell and Morgan's (1979) model is particularly interesting. The researcher holds the belief that society is under the impression that they have free will, but the concept of free will in the general population is an illusion. Society generally can go where they want, not being confined to a building or walled in, thus giving the impression of freedom. This became even more apparent with the imposed lockdown secondary to the Covid-19 pandemic. The population was thanked for their compliance, but the lockdown was enforced by the government, which thus demonstrated that they had the power to remove the liberties of otherwise law-abiding citizens. Therefore, freedom only exists within the boundaries of rules imposed by the State. Another example of this lack of freedom is found when an individual browses the internet; the searches that an individual makes are tracked and encoded, interpreted into patterns that are either acceptable or unacceptable. If you set off enough markers by going to certain sites or using certain words, you could be placed on a government "watchlist" (Crain, n.d.). Therefore, the determinist's position that man is completely determined by the situation or environment around him is more aligned with the researcher's beliefs.

When it comes to the methodological debate in Burrell and Morgan's (1979) model, there are two opposing concepts: the Ideographic and the nomothetic. The Ideographic approach is "based on the view that one can only understand the social world by obtaining first-hand knowledge of the subject under investigation. It thus places considerable stress upon getting close to one's subject and emphasises the analysis of the subjective accounts which one generates by "getting inside" situations and involving oneself in the everyday flow of life - the detailed analysis of the insights generated by such encounters with one's subject and the insights revealed in impressionistic accounts found in diaries, biographies, and journalistic records" (Burrell and Morgan, 1979, p.6). According to Burrell and Morgan (1979) the nomothetic approach to methodology is "basing research upon systematic protocol and technique". It is epitomised in the approach and methods employed in the natural sciences. It is preoccupied with the construction of scientific tests and the use of quantitative techniques for the analysis of data. Surveys, questionnaires, personality tests and standardised research instruments of all kinds are prominent among the tools which comprise nomothetic methodology" (Burrell and Morgan, 1979, pp.6-7). The nomothetic approach to the methodology is more aligned with the research that the researcher will undertake as the data will be mainly quantitative data sourced in a very structured and systematic way.

The vertical axis on Burrell and Morgan's (1979) model positions the researcher in relation to the theory of Society. This axis has two extremes: the society of regulation (Order) and the sociology of radical Change (Conflict). The society of regulation is concerned with the status quo and social order; society is viewed as unified and cohesive. On the other hand, the society of radical change is viewed as in structural conflict, modes of domination and structural contradiction, which its theorists see as characterising modern society (Burrell and Morgan, 1979). These contrasting views are the basis of opposing schools of thought; a rational view of society is the basis of modernism, whereas a radical change perspective underlies postmodernism (Holden and Lynch, 2004). On the axis of the theory of society, the researcher is more aligned with the radical change (conflict) perspective. It relates to understanding structural contradictions and emancipating man from these constraining structures, the concern here being what is possible rather than what is the present situation (Cerin, 2003).

This approach to researching organisational change and management is far more appropriate than adhering to the status quo and is far more aligned with the researcher's personal beliefs on how one should live life. As the researcher came from a poor, underprivileged background and was forced to work hard to change their socioeconomic status, they can relate to struggle and not accepting the situation one is currently in.

Undertaking the assumptions outlined in Burrell and Morgan's (1979) model and positioning themself in relation to the two dimensions of the nature of society and the nature of science, it appears that with the researcher's current beliefs, they fall into the radical structuralist paradigm. The radical structuralist paradigm approaches issues from an objective standpoint. This view is concerned with structure, structural relationships and with the certainty that as all things have a structural relationship within society, then all things can be explained in a logical way. This view is closely aligned with that of the functionalist (Burke, 2007). Burrell and Morgan (1979) explain that the radical structuralist paradigm comprises three fundamental approaches: Russian social theory, contemporary Mediterranean Marxism and conflict theory. Of these approaches, the one that appears to align most closely with the researcher's current way of thinking is contemporary Mediterranean Marxism. Contemporary Mediterranean Marxism lies between extremist Russian social theory and the more subjective critical theory. According to Burrell and Morgan (1979), conflict theory is the sociological expression of "radical Weberianism"; it focuses on bureaucracy, authority and the corporatist role of the state and is distinguished from the other two by Weber's orientation to capitalism. Conflict theory and Mediterranean Marxism are said to be the closest to radical organisation theory (Kamoche, 2019).

According to Burrell and Morgan (1979), contemporary Mediterranean Marxism is split into two different schools that are based on a common set of approaches. These are Althusser and Colleti's approaches. Of the two, the researcher finds themself more aligned to the work of Colleti as Althusser totally rejects empiricism and is, therefore, not a true positivist. The Islamic philosopher Avicenna, born in 980, refined the concept of tabula rasa or empiricism (Roslender, 2016). He maintained that the "human mind at birth is rather like a Blank Sheet, that is actualised via education" and that knowledge is come upon through "empirical familiarity with objects in this world from which one outlines universal concepts" which is developed through a "deducting method of reasoning; observations lead to prepositional statements, which when compounded lead to further synopsis" (Avicenna, 1954, p. 249). As the researcher has a strong belief in empiricism, they can't align with Althusser's work. Additionally, the researcher agrees with Colleti's belief that Marxism is a science based on the method of hypothesis testing in the search for causal laws.

In conclusion, this section's inclusion is intended to highlight the researcher's philosophical stance at the start of the research to enable comparison to the researcher's philosophical stance towards the end of the doctorate. There are several reasons that the researcher believes that this change in their philosophical stance has taken place. Undertaking the doctorate has been challenging for the researcher and forced them to undertake personal growth. This personal development has been beneficial but has been enforced by undertaking the research and the challenges this entails. Undertaking the research has exposed the researcher to new ideas and perspectives, leading to a reassessment of philosophical beliefs. Additionally, the research has also demanded rigorous critical thinking, which has made the researcher critically evaluate the researcher's philosophical beliefs. This change in the researcher's philosophical stance highlights the impact the doctoral journey has had on the researcher and how they have evolved as an individual.

3.2 Methodological Choice

3.2.1 Quantitative/Qualitative

The proposed methodological choice for this research is concurrent mixed-method research, which utilises both quantitative and qualitative methods. The justification for using quantitative and qualitative data collection and analysis techniques is to validate the findings by having corroborative evidence derived from different methods or, more often, to explain or complement results from one method by using another (Bryman, 2006; Greene et al., 1989). Saunders et al. (2016) describe this method as a sequential explanatory research design, first utilising the quantitative method for analysing the data, followed by the qualitative method. Using this approach as the methodological choice for the research enables the researcher to validate the quantitative data. Quantitative data is robust, reliable, and usually, generalisable, and qualitative data can produce, for example, rich detailed process data based on the participant's knowledge and experience (Verhoef and Casebeer, 1997).

An example of how this approach may work in practice can be envisioned by compiling quantitative information on the time it takes an individual to assemble an assembly. The time data would be captured with route cards and then validated with an interview. Undertaking the interview would validate if there were unnecessary delays in the assembly. These unforeseen delays would impact the data and could be missed if the researcher were utilising a single process to gather data. If the person assembling the assembly had been delayed for a few hours as the crane was unavailable, it could lead to delays. These delays would not necessarily be transparent in the quantitative time data, which could jeopardise the validity of the data without the validation of qualitative data in the form of the interview. This example highlights the justification for the use of concurrent mixed-method research as the proposed methodological choice for this research.

3.2.2 Strategy

This research comprises two distinct yet complimentary research strategies. The first strategy is action research, and this is implemented in a single case study company. The action research strategy is chosen because the research took place in the organisation within which the researcher works. Saunders et al. (2016) describe action research as an emergent and iterative process of inquiry designed to develop solutions to real organisations' problems through a participative and collaborative approach, which uses different forms of knowledge and will have implications for participants and the organisation beyond the research project. As action research is collaborative, the members of the system being studied participate actively in the cyclical process. This contrasts with traditional research, where members are objects of the study (Coghlan and Brannick, 2005). The project was not instigated as a pure participatory action research project. Instead, it was conceived as an action research project that promoted participation.

Action research is deemed an appropriate tool for undertaking the research project from a theoretical perspective. Not only does it empower employees through collaborative work, but it empowers them to sustain the planned changes that will be taking place (Somekh, 2006). Applying action research in a real-world organisation will be challenging and require adaptation. The purpose of action research is to promote learning within the organisation. This learning is done by identifying a problem, planning action, taking action, and evaluating action; this is known as Kolb's (1984) action research cycle (Coghlan and Brannick, 2005). Action research has a second form of the action research cycle, known as the reflection cycle. This form of research is an iterative, cyclical process of reflecting on practice, taking action, reflecting, and taking further action. Therefore, the research takes shape while it is being performed. Additionally, a greater understanding of each cycle is achieved, which points towards improved practice (Riel and Rowell, 2016). One of the significant challenges when undertaking action research is to engage in making the action happen and then standing back from the action and reflecting on it as it happens to contribute theory to the body of knowledge (Coghlan and Brannick, 2005).

A case study is an investigative study on a person, group, or unit to generalise over several units (Gustafsson, 2017). A single case study was undertaken in this research, and the investigation is based on a single organisation. The benefit of undertaking a single case study is the quantity of data obtained. It would not be viable to get the same amount of data in multiple organisations in the same time frame. However, Mariotto, Zanni and Moraes (2014) warn that undertaking a case study whilst embracing a positivist mindset leaves the researcher open to criticism as it is perceived to be impossible to make controlled observations in the case study. This issue could be perceived as being more challenging as the researcher works as a manager in the company where the research takes place. Lee (1989) adds a further point to the discussion by questioning the viability of making controlled deductions with qualitative data whilst undertaking a case study. It was anticipated that the researcher would overcome this by focusing mainly on quantitative data and pre-defined metrics, leading to the results being objective. Mathematical analysis for the data's quantitative element should allow for logical deductions due to the implemented mathematical rules and control measures.

As the research being undertaken is action research, it follows an interpretation of the action research cycle. The research is split into three cycles, and each cycle is split into four phases as per the action research model. These phases are plan, do, check, and act. This strategy was recommended by Dehe, Bamford, and Kotcharin (2022) in the literature review. Dehe, Bamford, and Kotcharin (2022) claim that using tools such as Plan-Do-Check-Act (PDCA) as a consistent approach to developing the framework could aid in developing a culture of continuous improvement and assist in capturing knowledge. The Plan, Do, Check, and Act model is a Lean tool for implementing change and was therefore deemed appropriate for inclusion in the action research cycle.

Action research is iterative, using repeated cycles, comprising planning, doing, observing, and reflecting (MacColl et al., 2005). Figure 7 shows the action research cycle developed for this specific research.

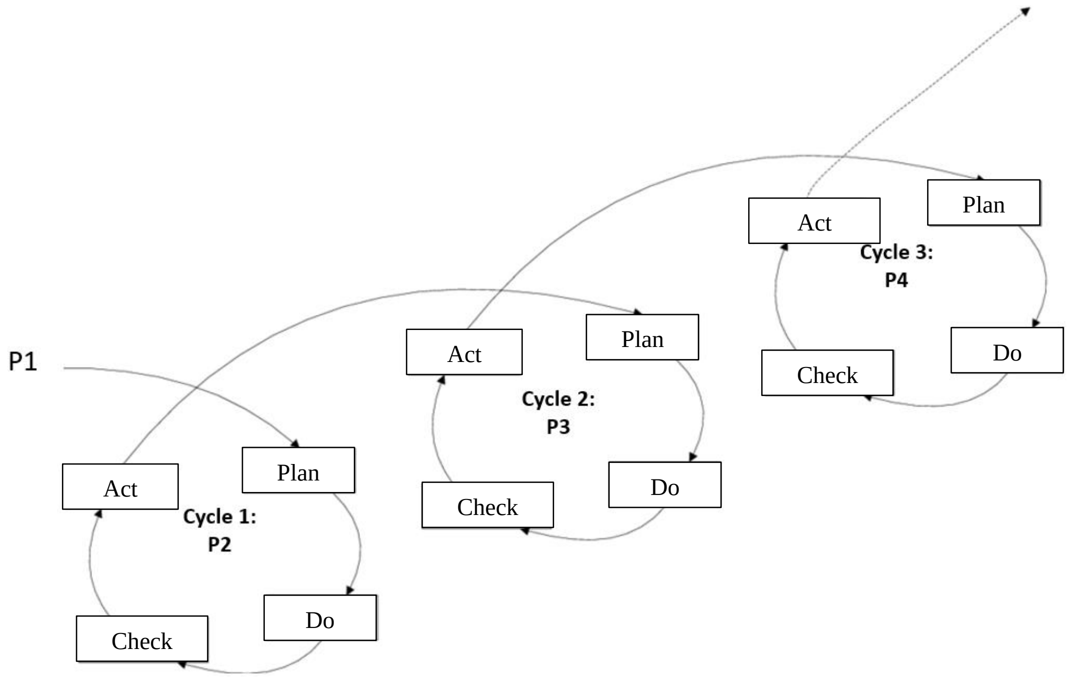

Figure 7, Developed from Spiral of Action Research Cycles (Coghlan and Brannick, 2005, p.22)

Each cycle has an individual purpose, and these are expanded on below:

<u>Cycle One</u>

The purpose of cycle one is to test several tools for improving production efficiencies in the mechanical design phase of the product lifecycle discovered whilst undertaking the literature review. This cycle verifies which tools are appropriate for implementation into the framework. It also serves to select appropriate data collection methods and determines the success criteria. For cycle one, the tools are implemented on a single module of the machine. Therefore, the output from this cycle is a framework proven on a single module with verified tools for improving production efficiencies in the mechanical design phase of the product lifecycle incorporated into its design.

Cycle Two

The purpose of cycle two is to test the framework developed in cycle one on a complete machine rather than just a single module. This cycle uses the same machine type from which the module selected for cycle one came but implements the framework on the remainder of the machine. This cycle verifies if the framework developed in cycle one is appropriate for implementation on a complete machine and is effective in improving production efficiencies in the mechanical design phase of the product lifecycle. The output from this cycle is an updated framework proven on a single machine with verified tools for improving production efficiencies in the mechanical design phase of the product lifecycle incorporated into its design.

Cycle Three

The purpose of cycle three is to verify the transferability of the framework onto a different machine type. Therefore, the framework is applied to another machine in the case study company's machine portfolio for cycle three, but it is a different product type. Undertaking this cycle verifies the appropriateness of the framework developed in cycle two for implementation on a completely different machine type. It also verifies its effectiveness in improving production efficiencies in the mechanical design phase of the product lifecycle. The output from this cycle is an updated framework with proven transferability and verified tools for improving production efficiencies in the mechanical design phase of the product lifecycle.

3.3 Research Plan

The following section outlines the research plan, which details the steps and data collection methods to assist the researcher in achieving the research objectives. Several distinct work packages form part of the research plan, and these are defined in Figure 8 below. These work packages are driven by the research question and the work required to try to resolve it. For each cycle, the research is split into two sections: the proposed method detailing what is planned and the implementation detailing what occurred.

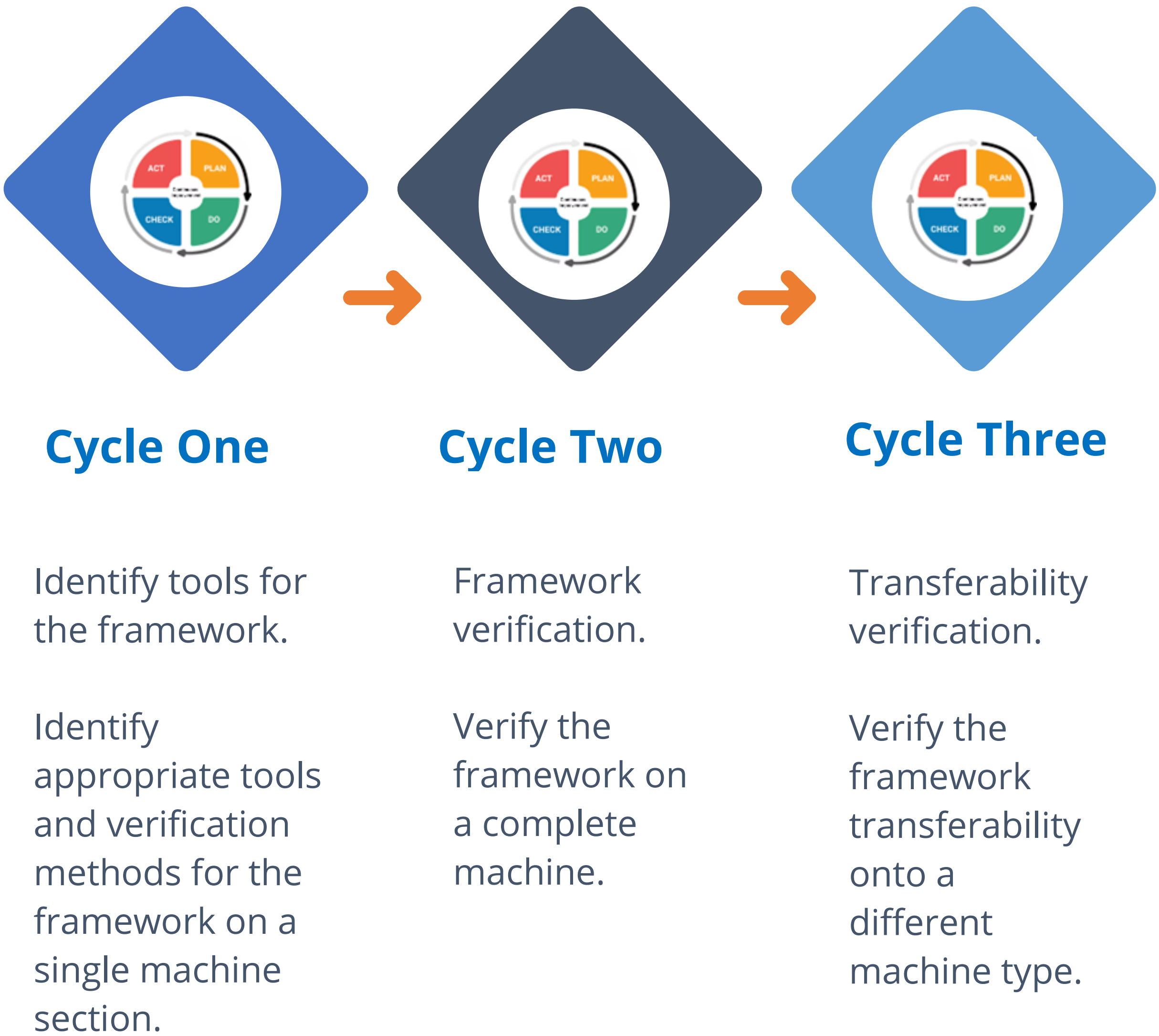

Figure 8, Diagrammatic representation of the research plan.

3.3.1 Cycle One – Proposed method

The purpose of cycle one is to test several tools for improving production efficiencies in the mechanical design phase of the product lifecycle discovered whilst undertaking the literature review. This cycle verifies which tools are appropriate for implementation into the framework. It also serves to select appropriate data collection methods and determines the success criteria. For cycle one, the tools are implemented on a single module of the machine. Therefore, the output from this cycle is a framework proven on a single module with verified tools for improving production efficiencies in the mechanical design phase of the product lifecycle incorporated into its design.

Method

Machine selection

For cycle one, a machine is selected from the TFW range of friction welding machines. Utilising quantitative sales figures as the primary factor for machine choice means that the most significant selling machine is used. Undertaking the production efficiency improvements on the most significant selling machine ensures that the maximum impact is derived from the work undertaken. By selecting the machine that is proven to be the highest-selling machine, the business achieves maximum impact in terms of production efficiency improvements incorporated into the framework due to the greater product numbers.

VSM - Machine module selection

Once the proposed machine is selected for processing through the framework, a meeting takes place with the senior management team and other key personnel. During this meeting, the attendees will establish the selected RFW machine product lifecycle process, from order procurement to delivery. This process entails utilising a Lean tool by undertaking a process flow diagram. Generating a process flow diagram requires the team to apply estimated times for each stage of the product lifecycle. The process of generating the process flow diagram baselines the current production approach for the selected RFW machine and assists in identifying steps that appear to have excessive delays where production efficiencies can be gained. The justification for undertaking this process is that cycle one of the research focuses on a single machine module. The single machine module selected for cycle one is one of the machine modules with perceived greater delays in its production. Using a module with greater production delays enhances the benefit of the research for the company but additionally expands the potential impact from the cycle for the researcher.

The diagram generated is known as a process flow diagram, although Bicheno and Holweg (2016) designate this type of high-level chart as a brown paper chart. A process flow diagram is a graphical representation of any manufacturing process or an assembly operation. It contains the sequence of all operations in the order in which they are performed and includes inspections, time allowances and materials used in any business process – from the arrival of raw material to the final product (Yerasi, 2011). Although there are numerous techniques for undertaking this task, the researcher utilises this method as it is known that the management team have used this method previously. Utilising a methodology that the management team knows means they are familiar with its implementation, thereby facilitating application and impact. Undertaking this stage baselines the current process in the production of the RFW Machine, also known as the as-is state. It is acknowledged that this research focuses on improving production efficiency in the mechanical design element of HVLVHV machinery products and that undertaking this process may identify potential production efficiency improvements outside the scope of this research. Undertaking this process still adds value to the business, and the research only focuses on the production efficiency in the mechanical design element of HVLVHV machinery. Additionally, a further benefit is described in the literature review by Kotter (1996) in his eight-step model. Engaging with the management team at this early stage of the research should establish management commitment, reduce scepticism, and create a guiding coalition. These are contributing factors that impact the success of action research in a case study company.

Product improvement forum

As the RFW machine type and selected module for implementation into cycle one are now defined, the next body of work is undertaking semi-structured interviews with the shop floor fitters to identify the potential product, DFA, followed by DFM improvements that can be implemented on the selected machine module. As highlighted by Gao, Jin and Lu (2019), utilising DFA & DFM during the design phase assists in cost reduction as the full benefits of

Lean production can be realised since potential manufacturing and assembly issues have already been resolved before they go into manufacture.

Semi-structured interviews are chosen as they offer a good balance between structure and flexibility. Using this form of interview allows the shop floor fitters to communicate their ideas and thoughts and express themselves in their own words. This was the preferred choice over other methods like a focus group for example. Recent research has shown that larger group settings like a focus group can limit innovation as the stronger personalities tend to take the lead and individuals are more likely to give answers that have social approval rather than their true beliefs (Ananian, 2024). Using the semi-structured interview approach allows each of the individuals to have their say. This adds validity and authenticity to the data, leading to rich qualitative data. For the first set of semi-structured interviews, the Shop Floor Supervisor is approached and asked if he and some of his personnel can suggest any potential product, DFA, followed by DFM improvements for the chosen machine module. The Shop Floor Supervisor is asked to pick the personnel to participate based on experience and availability at the time of the meeting.

Communication strategy

Previous research undertaken by the researcher whilst undertaking a Master's Degree in Business Administration (MBA) highlighted the importance of communication when undertaking any change strategy. An example of this is emphasised in research conducted by Lodgaard et al. (2016). They state that poor communication is one of the fundamental reasons for the failure of Lean implementation strategies. Although this research does not focus on implementing Lean, it incorporates Lean design principles into the framework. Additionally, the fact that it concerns implementing change highlights the importance of appropriate communication.

Kumar et al. (2014) stressed that poor communication can lead to anxiety in workers and a lack of awareness of the purpose of the change, thus resulting in resistance to change (Lodgaard et al. 2016). Therefore, good communication by both the researcher and the management team is critical to overcoming these potential issues and additionally aids employee engagement. Due to the importance of communication and its potential impact on the framework, it was decided that a formal communication strategy would form an integral part of cycle one of this research.

For cycle one, two forms of communication are utilised within the business, and these form the communication strategy assessed by the researcher. The first is an open-door improvement forum, and the second is Town Hall Meetings. The open-door improvement forum involves TFW employees coming forward with business improvement suggestions. For this cycle, the open-door policy will be adopted over two days. This policy enables employees to come in at their convenience, sit down with the researcher, and present their business improvement suggestions.

The second communication strategy comprises town hall meetings presented by the business' managing director (MD). As a key driver and stakeholder in this research, this is a way for the MD to connect with the employees and show commitment to this research. All the staff are requested to get together in a meeting room. The managing director then presents information on the company's performance and any other positive news that could potentially boost employee morale. This boost in morale could have an impact on employee engagement and, therefore, the production efficiency improvements during the mechanical design phase of HVLVHV machinery products.

UWES

Much of the production efficiency improvement tools incorporated into the framework require engagement with the Mechanical Fitters. The Mechanical Fitters are, after all, the experts who assemble the machines. As highlighted by Kumar et al., (2014) and Lodgaard et al. (2016), it is critical that they feel involved in the process, and the management team communicating effectively with them is deemed crucial to this. Work engagement is defined as a positive, fulfilling, work-related state of mind that is characterized by vigour, dedication, and absorption (Schaufeli et al. 2002). There are numerous methods for measuring employee engagement, but research undertaken during the literature review identified the UWES questionnaire as being appropriate for this study. The justification is that as this questionnaire is proven reliable and effective in the industrial setting, it is deemed appropriate for the research (see Appendix 7.5).

The case study company devised Town Hall Meetings as a strategy to give the MD the opportunity to inform the employees of business results, important company initiatives, and personnel changes and answer any questions. Due to the potential effect that this information can have on employee engagement, the researcher decided that undertaking a questionnaire on either side of this meeting is an ideal opportunity to test the appropriateness of the UWES questionnaire and the process and procedure for undertaking it.

Data Capture Sheets

For cycle one, a focus group with the Mechanical Fitters is required. This focus group serves the purpose of generating a document mapping the current assembly process of the chosen machine module. The purpose of this document is to map the steps required to assemble the module and the time required for each step. This document captures how they assemble the module before any DFA changes occur, the ‘As-Is’.

There are various names for this document, but for consistency in this research, the document will be referred to as a manual data capture sheet. The data capture sheet documents the assembly process for the module and the estimated time it takes to assemble it. This baselines the current assembly process and allows the identification of any improvements in assembly time. The University of Strathclyde (n.d.) explain that manual data capture sheets ensure that improvements can be evidenced in scenarios where no automated data sources are available. Therefore, this process avoids relying on the subjective opinions of those involved in the process or rough estimates to demonstrate the initiative's success.

To generate the manual data capture sheet, semi-structured expert interviews are undertaken with the Mechanical Fitters who have built the machines. A semi-structured approach is used, and the structure is to assist the participant with drawings of the individual parts and the general arrangement drawing but implement some flexibility to the interview. This gives the participant freedom to think and reflect, providing a more detailed and accurate reproduction of the build process. The drawings are used as visual stimuli to assist the participant in remembering the assembled parts, and the general arrangement drawings show the assembly methodology.

Once the DFA improvements are implemented, a further focus group with the Mechanical Fitters is required. This focus group serves the purpose of generating a document mapping how they assemble the module with the improvements implemented. The changes implemented into this module are the output from the product improvement forum. The data capture sheet documents the assembly process for the updated module and the estimated time it takes to assemble it. Undertaking this work allows for a comparison between the ‘As-Is’ previous time to build and the ‘To-Be’ future state with the improvements incorporated and the new time to assemble the module captured. This method of capturing the quantitative data of time is chosen as it's a recognised process for capturing assembly time in industry, and additionally, it adds value to the case study company. Having this data captured enables them to quote the build time more accurately and additionally capture best practices.

Machine module costs

The case study company uses Enterprise Resource Planning (ERP) software to organise procurement of the parts and modules that make up their machinery. ERP Systems are increasingly important in modern business because of their ability to integrate the flow of material, finance, and information and to support organizational strategies (Yusuf et al., 2004, Yao and He, 2000 cited in Chun-Chin et al., 2005). The ERP software is used to collate quantitative data on the cost of the machine parts and modules before any changes occur. The collated data is then exported to Microsoft Excel, thus allowing the investigation to ascertain the overall cost of the machine module.

Once the machine module modifications have been undertaken, the parts are issued to purchasing for procurement. The ERP software is then used to collate quantitative data on the cost of the updated machine parts. The collated data is then exported to Microsoft Excel, thus allowing the investigation to ascertain the overall cost of the new module. Undertaking this work allows a comparison to be undertaken between the 'As-Is' previous cost to buy and the 'To-Be' future state with the improvements incorporated and the new cost to procure the module. This method of capturing the quantitative cost data was chosen as it's data that the case study company has already captured, and therefore, the data is readily available for analysis.

P10 Design Procedure

The P10 Design procedure is the standard process that the engineering team work to within the case study company. This document is critical to this research as this procedure is the foundation of the framework developed from this work and additionally forms the output of this research. The original P10 procedure is shown in Appendix 7.1.

This research aims to verify the production efficiency improvement tools uncovered whilst undertaking the literature review and incorporate them into the framework. The framework developed, therefore, will improve production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products. As discussed, the framework is based on the original P10 procedure and evolves from learning discovered whilst undertaking the research.

The P10 document that forms the foundation of the framework plays a significant part in the ISO 9001 certification that the case study company has been certified to. ISO 9001:2015 sets out the criteria for a quality management system that assists companies in continuously improving and cultivating customer satisfaction. As the P10 document forms the basis of the way the mechanical design engineering team currently works, and the purpose of cycle one is to test tools for improving efficiency, cycle one of this research will follow this procedure and any production efficiency improvements identified are documented. The production efficiency improvements identified are then implemented into the framework for cycle two of the research.

3.3.2 Cycle One – Implementation

The purpose of cycle one is to test several tools for improving production efficiencies in the mechanical design phase of the product lifecycle that were discovered whilst undertaking the literature review. This cycle verifies which tools are appropriate for implementation into the framework. It also serves to select appropriate data collection methods and determines the success criteria. For cycle one, the tools are implemented on a single module of the machine. The following sections describe how this cycle was implemented and the steps that were undertaken.

Machine selection

One of the fundamental points to implementing the research was to understand the market demand to help the researcher understand the correct machine to utilise as the initial focus for the framework implementation. An initial assessment was undertaken with the Head of the Business Unit for Advanced Welding Solutions (AWS). As the Head of the Business Unit, they are responsible for developing and growing the customer base, so they are ideally positioned with professional experience and expertise to know the market requirements and the most appropriate machine to begin the production efficiency improvements.

Due to limitations on resources and time, it is not viable to undertake the production efficiency improvements on all the machines, so a cluster sampling method was used. A weighted scale was employed, incorporating both potential sales and previous sales figures. The output score from this work was then added to each of the machine types. The highest-scoring machine type was then proposed to the researcher as the appropriate machine for development work. Utilising quantitative sales figures as the primary factor for machine choice ensured that the maximum impact was derived from the work undertaken and minimised potential bias. The precise sales data is not included as the sales factors are commercially sensitive and are not directly relevant to the focus subject of this research.

The output from the above work was that the TFW5 D AX FWM scored as the most appropriate machine for processing through the framework to begin implementing the production efficiency improvements. The Head of the Business Unit for AWS explained that although the TFW3 variant is TFW’s biggest selling machine, there was a potential for a higher volume of TFW5 D AX machine sales in the following 12-month period, and as this is practice-based research, potential impact is a strong driver. This data was presented to the management team, which undertook the final vote on the initial machine choice for the study and accepted the researcher’s proposal.

The TFW range of FWM’s comprises the machines shown in Figure 9. Alternative machines have been manufactured throughout TFW's years of production, but these would be outside the standard scope of supply. Although the phrase standard scope of supply has been used, each machine manufactured from the below range would be considered a unique one-off manufactured for a specific customer.

D = Double Head			
60t		TFW3 PR	Piston rod machines
150t		TFW5 PR	
60t		TFW3 DP	Piston rod machines
150t		TFW5 DP	
60t		TFW3 AX	Axle machines
150t		TFW5 AX	
150t		TFW5 D AX	
15t		TFW1 D	

Figure 9, TFW Machine range

As can be seen from Figure 9, TFW has numerous machines that could have been incorporated into the research.

Process Flow Diagram - Machine module selection

Once the machine had been selected for processing through the framework, an assessment was undertaken with the senior management team and other key personnel to establish the company's existing RFW machine product lifecycle process from order procurement to delivery for the selected product. This process entailed utilising a Lean tool by undertaking a process flow diagram. Generating the process flow diagram required the team to apply estimated times to each stage of the product lifecycle. This baselined the current approach to producing the selected RFW machine and assisted in identifying the steps that appear to have excessive delays where potential production efficiencies could be achieved.

The diagram generated from this work is known as a process flow diagram, although Bicheno and Holweg (2016) designate this type of high-level chart as a brown paper chart. A process flow diagram is a graphical representation of any manufacturing process or an assembly operation. It contains the sequence of all operations in the order in which they are performed and includes inspections, time allowances and materials used in any business process – from the arrival of raw material to the final product (Yerasi, 2011). Although there are numerous techniques for undertaking this task, this method was chosen because the organisation's management has used it previously and is familiar with its implementation, facilitating application and impact. Undertaking this stage baselined the current process in the production of the RFW Machine, see Figure 10.

Undertaking this work highlighted machine modules with a longer processing time. Further work was then done to identify the waste causing this delay. Filho et al. (2017) and Nor and Rasi (2017) state that there are seven well-known wastes in Lean, including overproduction, unnecessary transportation, inventory, motion, defects, over-processing and waiting. Any machine modules that stood out as having significantly more time to process than the others were highlighted as having the potential to be processed through the framework as a priority. The data sourced from this task comprised both quantitative and qualitative data and identified the specific module of the machine to be processed through the framework for cycle one. The work highlighted that the module known as the head assembly (402-A) took significant time to produce and that there were definite opportunities for producing it more efficiently. Therefore, it was decided that the head module would be processed through the framework for cycle one.

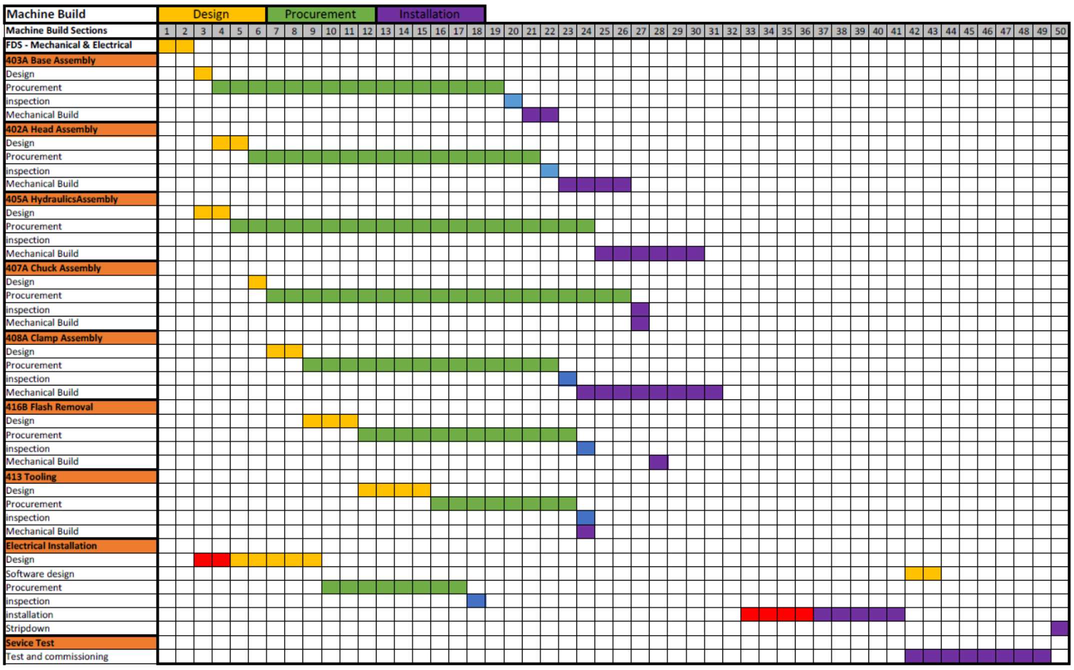

Figure 10, TFW5 D AX Process Flow Diagram in Microsoft Excel

Figure 10 shows the output from generating the process flow diagram transferred to Microsoft Excel. Microsoft Excel was used to aid clarity in communicating to the business the durations for each stage of producing the TFW5 D AX product. This diagram has three main designations: design, procurement, and installation. The installation section includes the machine's build at the case study company’s facility.

The purpose of this research is to explore whether production efficiencies can be achieved during the mechanical design phase when dealing with HVLVHV machinery products. The process flow diagram shows three main designations, and they all have the potential for production efficiency improvements.

The orange design phase, for example, shows the modules being issued to procurement individually and sequentially, which takes an extended period. Therefore, it can be concluded that there is potential for efficiency improvement in issuing modules. The green procurement phase shows that each module cannot be procured until the design department issues it. Therefore, the process of issuing the modules from design is impacting procurement. Additionally, the procurement phase is by far the largest portion of the product's production time. Again, there is potential for efficiency improvement in the procurement of modules. Finally, the purple phase is the installation and build phase of the machine. Again, the process of sequentially issuing the modules from the design department is impacting the build. Additionally, some of the modules appear to be taking a disproportionate amount of time to assemble, so there is potential room for efficiency improvements in this phase also.

<u>Product improvement forum</u>

Once the machine type (TFW5 AX) and machine module (402-A) had been chosen for processing through the framework, meetings were held with the shop floor fitters to identify the potential product, DFA, followed by DFM improvements that can be implemented on the selected machine module. For this first cycle, the Shop Floor Supervisor was approached and asked if he and some of his personnel could suggest DFA, followed by DFM for the chosen machine module. The Shop Floor Supervisor picked the personnel to participate based on experience and availability at the meeting time. Four shop floor personnel, including the supervisor, supported this meeting, equating to 67% of the potential participants. The suggested improvements they put forward were tabulated in Microsoft Excel to enable the viability of each suggestion to be investigated. Cycle one focused on one specific machine module, and the improvements suggested for that module were incorporated during that cycle.

Kuo et al. (2001) state that the implementation of DFA and DFM can lead to enormous benefits, including simplifying products, reducing assembly, and manufacturing costs, improving quality, and reducing time to market. Therefore, utilising these improvement methods should reduce the cost of manufacturing and assembling the chosen machine module. As highlighted by Gao, Jin and Lu (2019), utilising DFA & DFM during the design phase assists in cost reduction as the full benefits of Lean production can be realised since potential manufacturing and assembly issues have already been resolved before they go into manufacture. Therefore, it was beneficial for the company to capture these improvements now as the later in the product development cycle that changes are made, the more expensive they become. Research undertaken by Hamada (1996) reported that work done at Richo costs $35 to fix a design defect during the design stage compared to $690 in field service. Thus, highlighting the importance of showing due diligence and capturing any changes upfront. Additionally, by engaging with the Mechanical Fitters, they should feel part of the process and, therefore, put up less resistance to potential future business changes resulting from this research, thereby increasing the potential impact of its application.

Two separate semi-structured interviews were held with the shop floor Mechanical Fitters that assemble the machines. In total, 26 potential improvements were highlighted that could be implemented into the module of the selected machine.

Communication strategy

Previous research highlighted the importance of communication when undertaking any change strategy. Therefore, for cycle one, there were two forms of communication implemented within the business: the first was an open-door improvement forum, and the second was Town Hall Meetings. The open-door improvement forum allowed TFW employees the opportunity to come forward with business improvement suggestions. The structure enabled employees to come in at their convenience, sit down with the researcher, and present their business improvement suggestions. This forum was conducted over a two-day period.

The second communication strategy was implemented, this comprised of town hall meetings presented by the managing director of the business. As a key driver and stakeholder in this research, this was a way for the MD to connect with the employees and show commitment to this research. All staff that were on site were requested to get together in a meeting room. The managing director then undertook a presentation sharing information on the company's performance and any other relevant positive news that could potentially boost morale. This boost in morale could have an impact on employee engagement and, therefore, the production efficiency improvements during the mechanical design phase of HVLVHV machinery products.

UWES

The researcher selected the UWES questionnaire as the process to measure employee engagement, as described in section 3.2.1. In total, there were eight employees selected to undertake the UWES questionnaire. The chosen employees were the employees who had engaged with the researcher in the open-door forum. Two questionnaires were undertaken on either side of the "Town Hall Meeting". The questionnaire was self-guided as it has instructions on how to populate the document within the questionnaire.

The quantitative data from the UWES questionnaire was analysed to ascertain how effective the questionnaire was in evaluating employee engagement with the process. It was scored using the Mean (M), standard error (SE) and standard deviation (SD) as detailed in the UWES questionnaire Manual (Schaufeli & Bakker, 2004, p.34). Using this proven methodology and process ensured a greater probability of consistency in the results and enabled the opportunity to undertake a comparison with international norms if required. Undertaking this task would define the appropriateness of the UWES questionnaire for the case study company as a tool to evaluate employee engagement and is relevant to the framework as engaged employees should perform more efficiently.

When analysing the results from the UWES questionnaire, the employees' names were replaced with letters to ensure confidentiality. The results were split into the three constituting dimensions of work engagement: vigour, dedication, and absorption. The mean of each table is shown below, along with the standard error and the standard deviation. The mean is the average of the results, and the Standard Deviation indicates how far the individual responses to the question vary or "deviate" from the mean. The Standard Error is an indication of the reliability of the mean. A small Standard Error is an indication that the sample mean is a more accurate reflection of the actual mean (Datastar, 2017).

Data Capture Sheets

After the questionnaire had been circulated, a focus group with the Mechanical Fitters took place. This focus group served the purpose of generating a document mapping how they currently assemble the chosen machine module out of the many that make up the machine before any changes occur. A data capture sheet was generated for the selected module, and each step of assembling the chosen module is detailed (see Appendix 7.6). This data capture sheet identified all the process steps and an estimated time to undertake each step. Therefore, a data capture sheet was generated for the module before any changes were undertaken. Then, a further data capture sheet was generated after the proposed improvements.

Machine module costs

For cycle one, the ERP software was used to collate quantitative data on the cost of the machine parts and module before any changes occurred. The collated data was then exported to Microsoft Excel, thus allowing an investigation to ascertain the overall cost of the module.

Once the machine module modifications had been undertaken, the parts were issued to purchasing for procurement. The ERP software was then used to collate quantitative data on the cost of the updated machine parts. The collated data was then exported to Microsoft Excel, thus allowing an investigation to ascertain the overall cost of the new module.

P10 Design Procedure

As discussed previously, the P10 Design procedure is the standard process that the engineering team works to within the case study company. This document is the basis of how the mechanical design engineering team works and cycles; one’s purpose is to test tools to improve efficiency. Therefore, cycle one of this research followed this procedure, and any verified production efficiency improvements were documented. The verified production efficiency improvements are then implemented into the framework for cycle two of the research, and this framework is what the engineering team works to rather than the P10 document.

3.3.3 Cycle Two – Proposed method

The purpose of cycle two is to test the framework developed in cycle one on a complete machine. The proposal is to use the machine module selected for cycle one and implement the framework on the remainder of the machine. This should verify if the framework developed for cycle, one is appropriate for implementation on a complete machine and is effective in improving efficiency in the mechanical design of HVLVHV machinery products.

Product improvement forum

Once cycle one is complete, the plan is to undertake semi-structured interviews with the shop floor Mechanical Fitters to identify the potential product, DFA, followed by DFM improvements that can be implemented on the remaining machine modules for the selected machine type. The proposed process for undertaking these semi-structured interviews is to approach the Shop Floor Supervisor and ask if he and some of his personnel could suggest improvements for the additional machine modules not captured in cycle one. The Shop Floor Supervisor will be asked to pick the personnel to participate based on experience and availability at the time of the meeting.

Data Capture Sheets

There is a requirement for further focus groups to take place in cycle two with the Mechanical Fitters. These focus groups serve the purpose of generating manual data capture sheets mapping how they currently assemble the remainder of the machine modules. These documents will capture how they assemble the machine modules prior to any changes taking place, the ‘As-Is’. The data capture sheet will document the assembly process for the remaining machine modules and the estimated time it takes to assemble them. This should baseline the current assembly process for the complete machine and allow any improvements in assembly time to be identified. To generate the manual data capture sheets, the proposed method is to undertake semi-structured expert interviews with the Mechanical Fitters who have built the machines. The proposed structure for the semi-structured approach is to assist the participant with drawings of the individual parts and the general arrangement drawing.

Additionally, some flexibility will be implemented in the interview to give the participant freedom to think and reflect, providing a more detailed and accurate reproduction of the build process. The drawings will be used as a visual stimulus to assist the participant in remembering the assembled parts, and the general arrangement drawings will show the assembly methodology.

Once the machine improvements have been implemented on the remainder of the machine modules, further focus groups will be required with the Mechanical Fitters. These focus groups will serve the purpose of generating documents mapping how they will assemble the remainder of the machine modules with the improvements implemented. The changes that will be implemented into the machine modules are the output from the planned product improvement forum. The data capture sheets will document the assembly process for the updated machine modules and the estimated time it takes to assemble them. Undertaking this work will allow a comparison to be undertaken between the 'As-Is' previous time to build the machine and the 'To-Be' future state with the improvements incorporated with the new time to build the machine.

Machine module costs

The case study company uses ERP software to organise the procurement of the parts and assemblies that make up their machinery. The ERP software will be used to collate quantitative data on the cost of the machine parts and assemblies prior to any changes taking place. The collated data will then be exported to Microsoft Excel, thus allowing an investigation to ascertain the overall cost of the overall machine modules.

Once the machine module's modifications have been undertaken, the parts will be issued to purchasing for procurement. The ERP software will then be used to collate quantitative data on the cost of the updated machine modules. The collated data will then be exported to Microsoft Excel, thus allowing an investigation to ascertain the overall cost of the newly updated modules and, therefore, the machine. Undertaking this work will allow a comparison to be undertaken between the 'As-Is' previous cost to buy and the 'To-Be' future state with the improvements incorporated and the new cost to procure the machine.

Triangulation method – Semi-structured expert interviews

Much of the data collected during cycle two is quantitative data concerning the cost and time to produce the product. The researcher is aware that additional factors may impact production efficiencies in the mechanical design phase of the product lifecycle, which may be missed by focusing solely on this data. Therefore, semi-structured expert interviews will be undertaken with the Procurement and Production Manager and the Purchasing Manager. These two individuals are responsible for procuring products and bringing them into the company to be assembled. Therefore, they are ideally placed to discuss any additional factors impacting production efficiencies in the mechanical design phase of the product lifecycle that have not been captured in the research thus far.

A semi-structured approach will be used, and the planned structure is to assist the participant with general arrangement drawings of the three selected modules, the head module (402-A), base module (403-A) and the clamp module (408-A) for the TFW5 machine to stimulate conversation but implement some flexibility to the interview. This should give the participant freedom to think and reflect, providing a more detailed and accurate reproduction of the procurement process. A one-hour meeting will be allocated as the duration for this discussion, and further meetings can take place if required.

Cycle Two Framework

The P10 Design procedure is the standard process that the engineering team works to within the case study company for cycle one. The framework used for cycle two is a development of this process, but with the production efficiency improvements verified in cycle one implemented into the framework. Any potential production efficiency improvements discovered during cycle two will be documented and implemented into the framework for cycle three of the research.

3.3.4 Cycle Two – Implementation

The purpose of cycle two is to test the framework developed in cycle one on a complete machine. The proposal is to use the machine modules selected for cycle one and implement the framework on the remainder of the machine. This should verify if the framework developed in cycle one is appropriate for implementation on a complete machine and is effective in improving efficiency in the mechanical design of HVLVHV machinery products.

Product improvement forum

During cycle one, the shop floor supervisor was approached, and an improvement forum was undertaken with the shop floor mechanical fitters. One of the changes suggested during this meeting was a fundamental change to the structure of the machine. This change involved changing from bespoke manufactured rails to standard ones that can be readily purchased. This change was not viable during the first cycle due to the inherent risk of doing this change on a live customer order and the additional time constraints imposed by this. When it came to the implementation stage of stage two, the case study company identified numerous benefits to undertaking this change, so it was decided that this would be the fundamental change to the machine design for the second phase of the research.

Due to this being such a significant change to the machine's design, no further improvement forums were held with the shop floor Mechanical Fitters. There was an inherent risk of implementing a major change, so keeping the changes to a minimum would help identify the cause of any issues that become apparent when setting up the machine for commissioning.

Data Capture Sheets

For the second cycle of the research, it was decided that although all the machine modules would have the data capture sheets generated, only three of them would be considered as a focus for this research. One of these modules had already been generated during cycle one, this being the head module (402-A). The two additional modules that had data capture sheets generated were the base module (403-A) and the clamp module (408-A). Two factors instigated this decision: firstly, issues in gaining access to shop floor Mechanical Fitters and the time it took to generate the data capture sheet for cycle one. Secondly, these are the only modules that were affected by the modification, and therefore, the cost and build time of the other modules were unchanged.

An expert interview was held with one of the shop floor Mechanical Fitters to generate a manual data capture sheet for the Clamp and the Base before any changes took place. Another expert then validated the data capture sheet from the shop floor to ensure its accuracy. The data capture sheet for the head assembly had already been generated during the first cycle. Therefore, there was no requirement to repeat this work.

During the first cycle, the data capture sheets reflecting the modifications to the machine were generated by the shop floor Mechanical Fitters. For cycle two, it was decided that the Mechanical Design Engineer undertaking the design modifications would generate the manual data capture sheets after the changes. This was beneficial on two counts. Firstly, the Mechanical Design Engineer undertaking the design had intricate knowledge of how it works and how it is assembled. Secondly, it avoided the issues found with access to shop floor Mechanical Fitters.

Machine modules cost

As discussed previously in the first cycle, TFW uses ERP software to organise the procurement of its product parts and modules. The ERP software was used to collate quantitative data on the cost of the machine parts before any changes occurred. As the data for the head assembly had already been collated for the first cycle, no further work was required to collate the costs before any changes took place. However, the clamp and base assembly required collating.

Once the machine parts had been modified and the drawings updated, they were issued for quotation and procurement. The case study company’s internal procedure for getting drawings manufactured is to add them to the company’s ERP system. The ERP software was then used to collate quantitative data on the cost of the machine parts after the changes had taken place. This data was then exported to Microsoft Excel, which enabled the overall cost of the specific modules to be ascertained.

Triangulation method – Semi-structured expert interviews

Semi-structured expert interviews were undertaken with the Procurement and Production Manager and the Purchasing Manager to capture additional factors impacting production efficiencies in the mechanical design phase of the product lifecycle that may be missed by focusing solely on the quantitative data captured thus far in cycle two.

A semi-structured approach was used, and general arrangement drawings of the three selected modules, the head module (402-A), base module (403-A) and the clamp module (408-A) for the TFW5 machine were used to stimulate conversation but implemented some flexibility in the interview. This gave the participants the freedom to think and reflect and provide a more detailed and accurate idea of the procurement process and the efficiency improvements they had identified. A one-hour and thirty-minute meeting took place, which proved sufficient to capture the required data. The researcher captured the data during this meeting by manually taking notes.

Cycle Two Framework

As discussed previously, The P10 Design procedure is the standard process that the engineering team work to within the case study company for cycle one. The framework implemented in cycle two is a development of this process, with the production efficiency improvements verified in cycle one incorporated into the framework. Any potential production efficiency improvements discovered during cycle two are documented and implemented into the framework for cycle three of the research.

3.3.5 Cycle Three - Proposed method

The purpose of cycle three is to verify the transferability of the framework onto a different machine type. The framework developed in cycle two was implemented on a complete machine. For cycle three, the proposal is to use another machine in the TFW portfolio but a different machine type. Undertaking this cycle will verify if the framework developed in cycle two is transferable and appropriate for implementation on a completely different machine type. Additionally, it will verify if it is effective in improving efficiency in the mechanical design of HVLVHV machinery products.

Shop floor - Product improvement forum

Once cycle two is complete, the plan is to undertake semi-structured interviews with the shop floor Mechanical Fitters to identify potential product improvements that can be implemented on the new machine type. For cycle three's set of semi-structured interviews, the plan is to approach the Shop Floor Supervisor and ask if he and some of his Mechanical Fitters could suggest improvements for the new machine type. The Shop Floor Supervisor will be asked to pick the personnel to participate based on experience and availability at the time of the meeting.

Mechanical Design Engineering team - Product improvement forum

Once cycle two is complete, the plan is to undertake semi-structured interviews with the mechanical design engineering team to identify potential product improvements that can be implemented on the new machine type. For cycle three's set of semi-structured interviews, the plan is to hold a meeting with the mechanical design engineering personnel and request that they suggest improvements for the new machine type. Due to the team being small, it is viable for all personnel to be involved in this meeting.

Standardise the machine modules before implementing changes

For cycle three, the order of development should be to standardise the machine modules and then implement any product, DFA, followed by DFM changes. Standardising the product first creates a baseline prior to implementing the changes. This is important due to the number of changes and potential variations between modules. Additionally, using design automation tools can increase the efficiency of this process. An example is using the original part design three-dimensional (3D) computer-aided design (CAD) for the Finite Element Analysis (FEA) as the previous design that is the basis for the new design is proven by being used in service. Therefore, starting with the standard design gives you a proven design and a basis for deflection and stress comparison, among other requirements.

Develop a design specification

For cycle three, a design specification will be generated for the machine, which will be the output of the work undertaken. Reich (1995) describes a design specification as describing a desired function and constraints. This document will contain a description of the product and serve as a guideline for the design engineers to ensure the final product meets the desired objectives. Having a clearly defined specification that the company has agreed on is crucial to prevent delays from happening in cycle three.

Undertake a design for assembly review

A proposal for cycle three is to incorporate a standalone DFA review into the framework. In terms of identifying potential improvements related to DFA, it is proposed that meeting with the Mechanical Fitters on the shop floor would be beneficial. These personnel assemble the machines and can identify possible improvements due to their familiarity with the machines. When implementing DFA, a designer will consider the manufacturing constraints and materials of the part in the design stage. Kuo et al. (2001) state that the implementation of DFA can lead to enormous benefits, including simplifying products, reducing assembly costs, improving quality, and reducing time to market. Therefore, utilising this improvement method should reduce the cost of manufacturing the chosen machine.

Undertake a design for manufacture review

A proposal for cycle three is to incorporate a standalone DFM review into the framework. In terms of identifying potential improvements related to DFM, meeting with the Mechanical Fitters on the shop floor and the Procurement Manager would be beneficial. The shop floor personnel assemble the machines and can identify possible improvements due to their familiarity with the machines. The procurement manager is constantly in talks with suppliers who manufacture the TFW products, so he has a wealth of knowledge of how the parts are manufactured. When implementing DFM, a designer will consider the manufacturing constraints and materials of the part in the design stage. Kuo et al., (2001) state that the implementation of DFM can lead to enormous benefits, including simplifying products, reducing manufacturing costs, improving quality, and reducing time to market. Therefore, utilising this improvement method should reduce the cost of manufacturing the chosen machine.

Data Capture Sheets

There is a requirement for further focus groups to take place in cycle three with the Mechanical Fitters. These focus groups serve the purpose of generating manual data capture sheets mapping how they currently assemble the machine modules. For the third cycle of the research, it was decided that although all machine modules would have the data capture sheets generated, only three would be focused on. These focus modules were as in cycle two: the head (402-A), base (403-A) and clamp (408-A) modules of the machine. Therefore, only these modules would have data capture sheets generated. This decision was made due to the time it took to generate the data capture sheets and the difficulties in getting access to personnel with sufficient experience to generate the documentation.

These documents will capture how they assemble the machine modules prior to any changes taking place, the ‘As-Is’. The data capture sheet will document the assembly process for the machine module and the estimated time it takes to assemble them. This should baseline the three modules' current assembly process and allow any assembly time improvements to be identified. To generate the manual data capture sheets, the plan is to undertake semi-structured expert interviews with the Mechanical Fitters who have built the machines. A semi-structured approach will be used, and the planned structure is to assist the participant with general arrangement drawings of the three selected modules: the head module (402-A), base module (403-A) and the clamp module (408-A) for the TFW3 machine to stimulate conversation but implement some flexibility to the interview. This should give the participant freedom to think and reflect, providing a more detailed and accurate reproduction of the build process. The drawings will be used as a visual stimulus to assist the participant in remembering the assembled parts, and the general arrangement drawings will show the assembly methodology.

Once the machine improvements have been implemented on the machine modules, further focus groups will be required with the Mechanical Fitters. These focus groups will serve the purpose of generating documents mapping how they will assemble the machine modules with the improvements implemented. The changes that will be implemented into the machine modules are the output from the planned product improvement forums and the DFM and DFA reviews. The data capture sheets will document the assembly process for the updated machine modules and the estimated time it takes to assemble them. Undertaking this work will allow a comparison to be undertaken between the 'As-Is' previous time to build the machine and the 'To-Be' future state with the improvements incorporated in the updated time to build the modules.

Machine modules costs

The case study company uses ERP software to procure the parts and assemblies that make up their machinery. The ERP software will be used to collate quantitative data on the cost of the machine parts and modules before any changes occur. The collated data will then be exported to Microsoft Excel, thus allowing an investigation to ascertain the overall cost of the overall machine modules.

Once the machine modules modifications have been undertaken, the parts will be issued to purchasing for procurement. The ERP software will then be used to collate quantitative data on the cost of the updated machine modules. The collated data will then be exported to Microsoft Excel, thus allowing an investigation to ascertain the overall cost of the new modules and, therefore, the machine. Undertaking this work will allow a comparison to be undertaken between the 'As-Is' previous cost to buy and the 'To-Be' future state with the improvements incorporated and the new cost to procure the machine.

Cycle Three framework

The proposed framework to be implemented in cycle three is a development of the framework implemented in cycle two. This new framework has any verified production efficiency improvements discovered during cycle two implemented into the framework for cycle three of the research.

3.3.6 Cycle Three – Implementation

The purpose of cycle three was to verify the transferability of the framework onto a different machine type. During cycle two, the framework was implemented on a complete machine, the TFW5DE. For cycle three, the framework was implemented on another machine in the TFW portfolio, TFW3. The TFW3 range of machines comprises two different types of machines of the same capacity. The TFW3 range is defined by the components that they weld, the variants being Piston Rods and Drill Pipes. The component type being welded defines the make-up of the machine, and the machine's make-up for each variant is significantly different. This information is relevant as it impacts the approach for undertaking the development of the framework for this range of machines.

Shop floor product improvement forum

As was done in previous cycles, the Shop Floor Supervisor was approached, and an improvement forum was undertaken with the shop floor Mechanical Fitters. The meeting included the shop floor supervisor and one of his personnel, a mechanical fitter. Two representatives from the product development team chaired the forum. The forum was recorded to ensure that all comments were captured. This minimised the requirement for notetaking and lapses in attention from what the shop floor personnel were saying.

Before the meeting, a presentation was generated showing a screenshot of each assembly that existed for TFW3, including a three-dimensional CAD model. This presentation also included any points raised by the shop floor in the company’s improvement capturing scheme. This scheme comprises an opportunity for an improvement document to be maintained by the manufacturing engineer, where shop-floor improvement suggestions are documented. The shop floor personnel propose these improvement suggestions during a machine build. The hope was that including these in the presentation would show the shop floor personnel that the points they had raised to date were noted, which would improve their engagement in the process. The attendees were shown the presentation, one module at a time, and asked what improvements could be applied to each module. The meeting lasted for 56 minutes.

Mechanical Design Engineering team product improvement forum

Once the presentation with the shop floor personnel had been completed, the improvements that they had suggested were added to the presentation. This presentation was then shown to personnel from the mechanical design engineering team to see if they had any additional improvements to add. Due to COVID-19, this presentation was shown over Microsoft Teams, and the meeting was recorded. One benefit of the meeting being over teams and recorded was that it minimised the requirement for notetaking and lapses in attention to what the Mechanical Design Engineers were saying. The improvement forum with the mechanical design engineering team comprised the researcher leading the meeting and eight Mechanical Design Engineers. The meeting lasted 2 hours and 30 minutes.

The recording was manually transcribed, and all points raised for each machine module were added to a Microsoft Excel document to allow for easy interrogation. The machine improvement data collected for cycle three comprised the product improvements from the shop floor improvement forum, the mechanical design engineering improvement forum and the improvements captured in the Opportunity for Improvement (OFI) document. As mentioned previously in the shop floor product improvement section, the OFI document is maintained by the Manufacturing Engineer, where improvement suggestions from the shop floor during machine builds are documented. Table 4 shows the number of improvements suggested by each source.

Table 4, Cycle 3 – Improvement suggestions table

Source	Improvements
Shop Floor Improvement forum	34
Mechanical Engineering Improvement forum	97
Opportunities For Improvement document	5
Total	136

<u>Standardise the machine modules before implementing changes</u>

For cycle three, it was decided that the order of development should be to standardise the machine modules and then implement any changes or suggested improvements. Standardising the product first creates a baseline prior to implementing the changes.

Firstly, the new standard modules were modelled in 3D using the AutoCAD Inventor CAD Software. There are significant benefits of having 3D CAD models and using design automation tools, which will be expanded in the discussion section 4.1.3. This step was important for the case study company as the original drawings used as the design template didn't incorporate 3D CAD models in their development. The 3D parts were then detailed using AutoCAD Inventor CAD Software, and drawings were created to manufacture the parts.

The detailed 2D drawings were generated according to the latest drawings standard BS 8888:2020 as per the work instructions developed for the framework. This standard ensures that the drawings are generated in a universal way that all manufacturers can understand. Additionally, it ensures that the drawings are generated accurately, negating the chance of misinterpretation (British Standards Institute (BSI), 2020). Apprentice engineers were utilised for this step as it reduced the impact on the business in terms of the cost of undertaking the work. More importantly, it was a development opportunity for the apprentices within the company to learn about British standards, various parts of the machine and how they are assembled.

The modules that had been generated during cycle three were selected from various machine orders over the last ten years. Although the designs were similar for each type of machine over this period, there were minor differences that would be easy to overlook. Therefore, the final step of collating the CAD data prior to any changes was to check that the selected modules for each type of machine fit together without any misalignment or errors. Once this work has been undertaken, the process of implementing the suggested improvements could begin, and a baseline for each module would be created.

Develop a design specification

As mentioned during the planning stage for cycle three, a specification contains a description of the product and serves as a guideline for the design engineers to ensure the final product meets the desired objectives. For this document to be generated, the researcher had to plan the machine modules that would be the basis of the two machines that make up the TFW3 range. Table 5 shows the selection process undertaken. Firstly, a list of all the TFW3 machines sold was compiled. This data was sourced from the company's machine list, a Microsoft Excel document showing all machines sold, the size of the machine, the component types and the data of sale. This Excel document has filters applied that enabled the researcher to filter out a 10-year period and the TFW3 machine type. Over this period, ten drill pipe machines and 12 piston rod machines have been sold. The period of mid-2009 to mid-2019 was chosen as this was pre-COVID-19. Being pre-COVID would be reflective of normal operating conditions, and therefore the pandemic would not influence the results. Additionally, machines older than ten years are considered outdated from a machine design perspective and were therefore not included in the results.

Table 5, TFW3 - Machine Module Selection Process

STEP	ACTION
1	List all Piston Rod (PR) and Drill Pipe (DP) machines sold in the last ten years.
2	List all modules used for each machine.
3	List all General arrangements used for each module.
4	List the specifications for each module.
5	Identify duplicate GA's and remove them.
6	Identify special 1-off modules and remove them.
7	Identify the GA as the master design for each module.
8	Model the selected modules according to the new drawing office standard.
9	Detail the module to BS 8888.
10	Check that the modules fit together and update the model and drawings as required.

Once the machine list had been generated, the modules that make up each machine specific to the customer's order were listed. This data was sourced from the company's ERP System. TFW uses ERP software to procure its product's parts and modules. Using this software to list all the modules for each type of machine was deemed appropriate, as the Bills of Materials (BOM) are listed to enable procurement of the parts. In total, thirty different modules were used for the ten drill pipe machines and thirty different modules were used for the twelve piston rod machines. Each individual machine had an average of seventeen modules used for the piston rod machines and twenty for the drill pipe.

Once the modules used for each machine had been listed, the General Arrangement (GA) drawings were listed for each module. In total, there were one hundred and seventy-five different GA drawings for the piston rod machines. There were two hundred and thirteen different GA drawings for the drill pipe machines.

The next step was to list the specifications for each GA. This stage was necessary as adding this data would ensure that the machine could achieve the broadest specifications whilst still serving as a guideline for the design engineers to ensure the final product meets the desired objectives; see Table 6 for an example of the database. Selecting the modules that had the best performance would ensure this was the case. An example is the clamp module for the piston rod machine; the largest component this can hold could be ø140mm or a diameter of ø160mm. Going for the larger diameter would ensure that the largest range of components possible could be welded on the machine. However, consideration needed to be given to ensure that the other modules on the machine could also achieve this larger diameter. Not checking that all the relevant modules could achieve this larger diameter could result in additional unnecessary costs being incorporated into the machine. This assumption is based on incorporating the design of a larger diameter part into the module. However, the module cannot function at this larger size because the remainder of the machine is not compatible. As a result, it will cost more to manufacture due to the unnecessary additional material in the design.

Table 6, TFW3 - Machine Database Comparison example

				T70	T70
				Mar-13	Mar-18
				Drill Rods & Drill Pipe	Drill Rods
1	402A	HEAD ASSEMBLY	Front Bearing Bore (mm)	Ø190.5	Ø190.5
			Pulley Ratio	43 : 60	43 : 60
			Belt	Eagle Pd	Eagle Pd
			Brake	Yes	Yes
			Forge Cylinder Stroke (mm)	670	600
			Motor Type	AC	AC
			Motor Ref	E1088-00035	E1088-00143
			Motor kW	150 kW	125 kW
			GA Sheet 1	T70592-02-A SHT1	T70619-02-A
			GA Sheet 2	T70592-02-A SHT2	
2	402-B	PNEUMATICS		T70592-02-B	T70619-02-B
3	402-E	HEAD LINEAR TRANSDUCER		T70592-02-E	T70558-02-E
4	403-A	BASE ASSEMBLY	Reference	T70592-03-A001	T70580-03-A001
			Length (mm)	4095	3795
5	404-A	BACKSTOP ASSY FIXED BASE MOUNTED			T70619-04-E
6	404-C	TIE BAR ASSEMBLY			T70619-04-A
	404-D	ROLLER STEADY POSITIONER			
7	404-G	BACKSTOP ASSEMBLY MANUAL			
8	404-H	AUTOMATIC BACKSTOP, TIE-BAR MOUNTED		T70592-04-D SHT1	
				T70592-04-D SHT2	
9	405-A	HYDRAULICS		T70592-05-A	T70619-05-A
10	405-C	HYDRAULICS INSTALLATION			T70619-05-C
11	406-A	HEAD LUBRICATION		T70592-06-A	T70556-06-A
12	406-B	SLIDE LUBRICATION (SELF CENTRE CLAMP)		T70592-06-B	
13	406-C	ROLLER STEADY LUBRICATION		T70592-06-C	
14	406-D	MANUAL LUBRICATION		T70592-06-D	T70619-06-D
15	406-E	SLIDE LUBRICATION (FORGE CLAMP)			T70574-06-B
16	407-A	3 JAW SFRONT OPERATED SPRING CHUCK			T70619-06-D
	407-B	2 JAW DRAWBAR CHUCK			
			FULLY OPEN PER JAW		
			@ GRIP PER JAW		
	407-D	COLLET CHUCK			
17	407-E	3 JAW FRONT OPERATED HYDRAULIC CHUCK			
16	407-G	3 JAW DRAWBAR OPERATED CHUCK		T70592-07-C	T70619-07-C
18	407-S	CHUCK SWITCHING			T70619-07-S
19	408-A	SELF CENTRING CLAMP		T70592-08-A	
20	408-B	CLAMP POSITIONER		T70592-08-B	
21	408-C	MACHINE MOUNTED ROLLER STEADY			T70619-08-C
			MAX DIAMETER (mm)		150
			MIN DIAMETER (mm)		20
22	408-E	FORGE CLAMP			041-08-E
23	408-S	ROLLER STEADY - FIXED TO TIEBAR			T70619-08-G
			MAX DIAMETER (mm)		140
			MIN DIAMETER (mm)		
24	408-K	ROLLER STEADY - STATIC FREE STANDING		T70592-08-F	
25	408-L	MANUAL ROLLER STEADY TIEBAR MOUNTED		T70592-08-C	T70619-08-F
			MAX DIAMETER (mm)		140
			MIN DIAMETER (mm)		

The next step was to identify which modules were considered special and were, therefore, not to be included in the modular machine options. The defining feature of these modules that identified them as special was that they had been used only once or twice in the ten-year period. Therefore, they were not considered standard options that are regularly sold to customers. Although from a percentage of machines sold perspective, discarding modules that have been used twice may seem excessive. The driving factor for this was the requirement for standardisation of commonly used modules and cost reductions. Essentially, all modules that can be incorporated into the base machine add cost to this machine, so the number of modules must be reduced to the minimum whilst still achieving the customer's desired objectives. Once these had been removed, the GAs that would be the master design for each module were selected. In total, there were now twenty-nine modules for the piston rod machine and twenty-seven for the drill pipe machine. Two of these modules were universal, meaning that they could be used on both types of machines.

Undertake the DFA & DFM reviews

At this point in cycle three, there was a significant change in strategy concerning the work being undertaken in comparison to previous cycles. Two members of the senior management team, the Quality Manager and the Commercial and Supply Chain Manager, could see the benefit of the work being undertaken and were keen to drive it forward. Several of the TFW5 machines developed in cycle two had been sold, and senior management began to see the benefit of having standard modules. Due to the sales quantities being achieved, the Commercial and Supply Chain Manager was required to procure the same module multiple times. This allowed for the purchase of multiples of the same part in one order rather than the parts being ordered as individual parts as they had been in the past. Thus, the saving potential and benefit of purchasing parts in bulk were revealed, which will be expanded on in the discussion section 4.1.3. Due to the results being seen within the business, the managers wanted to expedite the research and, therefore, decided to dedicate resources to the process. Additionally, the shop floor personnel could see the improvements they had suggested captured in the new modules being issued for manufacture. This reinvigorated interest in the project and resulted in a multi-functional team. Each group member had individual tasks related to developing the standard modules.

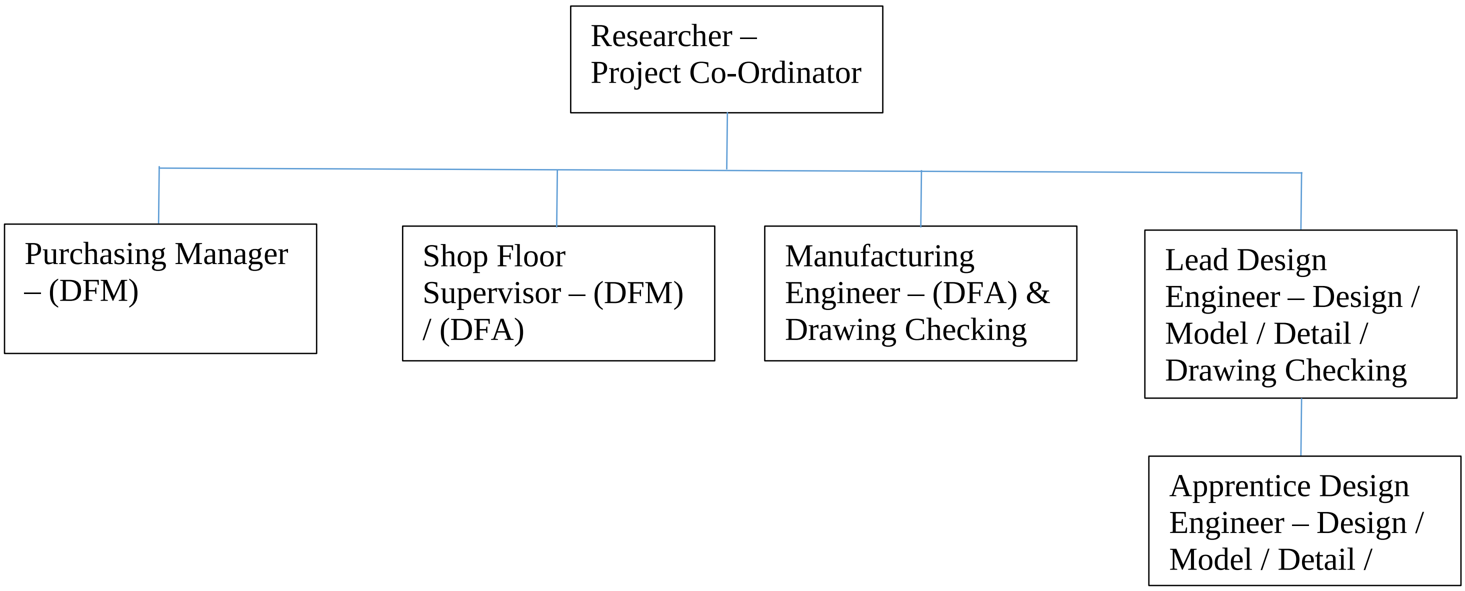

Figure 11, Cycle 3 – Standardisation team

Figure 11 shows the team that collaborated to move the project forward and the tasks assigned to each of them. Additionally, each module developed for cycle three was supported by this team in following the steps outlined in Figure 12. This is a simplification of the framework being adhered to by the mechanical engineering department and is shown for clarity. The framework that the mechanical design engineering team were working on was developed from the learning undertaken in previous cycles.

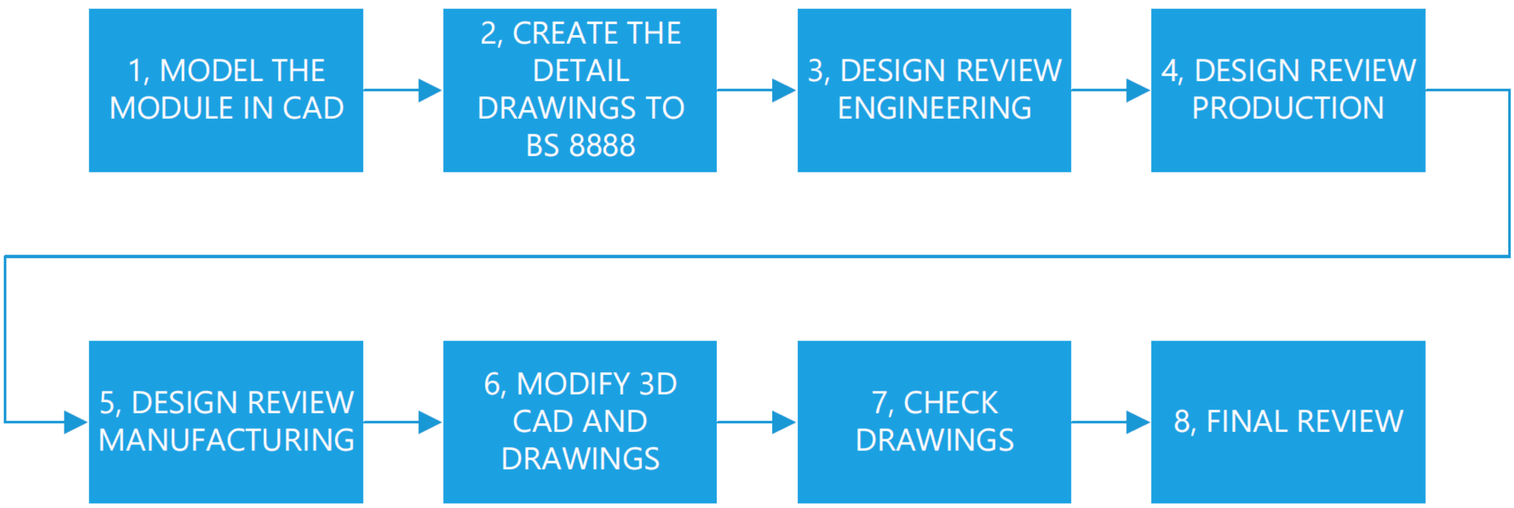

Figure 12, Cycle Three – Simplified framework for clarity

The machine modules to be reviewed were prioritised depending on their complexity and the percentage of the machine that they take up in terms of cost. A meeting was called by the apprentice who had generated the module, and the review participants were the team from Figure 11. The CAD drawings were sent to the Purchasing Manager, the Shop Floor Supervisor, and the Manufacturing Engineer in advance of the meeting to allow them to consider any DFA and DFM issues or improvements. This allowed them the opportunity to review the drawings and mark up any suggested improvements or errors identified in advance of the reviews. It was important to keep the meeting as concise as possible as there was a meaningful cost to the business for the time in this meeting due to the personnel involved.

Asking the apprentice to call the meeting and document the changes was a further learning opportunity and gave them exposure to other departments within the business. All potential changes were documented between the meeting minutes taken during the meeting and the marked-up drawings sent before the meeting. Each of the potential changes was discussed individually, and a decision was made within the meeting as to whether the changes would be implemented. Undertaking the decision-making process with all personnel involved led to a guiding coalition and additionally assisted with their engagement in the process. Had the decisions on what changes were implemented been made independently of the reviews, it could have led to issues with the personnel who suggested the changes. As the researcher was accountable for the delivery of the project, they had the final say in the inclusion of changes, and this caused no issues during the research.

The drawings were updated, incorporating the DFA and DFM agreed changes suggested in the reviews before undergoing a final check by the Manufacturing Engineer. Utilising a different engineer to check from the one who undertook the changes is necessary as this process forms part of the QMS.

Data Capture Sheets

For the third cycle of the research, it was decided that only the machine's Head, Base and Clamp modules would have data capture sheets generated. This decision was made due to issues in gaining access to shop floor Mechanical Fitters and the time it took to generate the data capture sheets. This could be considered a limitation of the research and will be expanded on in section 5.4. An expert interview was held with the Manufacturing Engineer to generate a manual data capture sheet for the head module (402-A), the base module (403-A) and the clamp module (408-A). Another expert from the shop floor then validated the data capture sheet to ensure its accuracy.

Once the machine improvements had been implemented on the machine modules, there was a requirement for further focus groups to take place with the Manufacturing Engineer & Mechanical Fitters. These focus groups served the purpose of generating documents mapping how they assemble the machine modules with the improvements implemented. The changes that were implemented into the machine modules were the output from the product improvement forums and the DFM and DFA reviews. The data capture sheets document the assembly process for the updated machine modules and the estimated time it takes to assemble them. Undertaking this work allowed a comparison to be undertaken between the ‘As-Is’ previous time to build the machine and the ‘To-Be’ future state with the improvements incorporated and the new time to build the modules.

Machine sections cost

The ERP software used by the case study company to procure its purchased parts was utilised by the researcher to get the quantitative data for the cost of the modules before any changes were undertaken. The data was then exported to Microsoft Excel, which enabled the overall cost of each module to be ascertained. Each part in the module had its own row, and the cost was allocated to the part in a cell in that row. Analysis of the data highlighted that it had been several years since many of the parts were last purchased. Therefore, their cost was not directly comparable to any new prices sourced due to inflation. Therefore, the part cost was adjusted by 3% per annum from the date of procurement to 2021. This increase reflected inflation; the figure is shown in the next column.

As mentioned previously, whilst researching global inflation for inclusion, there were variations in the data being found depending on the source; from the data compiled, 3% was found to be a reflective average. Global inflation was used to reflect inflation on the price increase. The parts and materials used to manufacture the machines are sourced globally and therefore impacted by this phenomenon. Undertaking this modification to the data presented the current cost of the parts in 2021 before any modification was implemented.

Once the machine parts had been modified and the drawings updated, they were issued for quotation and procurement. The case study company’s internal procedure for getting drawings manufactured is to add them to the company’s ERP system. The ERP software was then used to collate quantitative data on the cost of the machine parts after the changes had taken place. This data was then exported to Microsoft Excel, which enabled the overall cost of the modules to be ascertained. This allowed for a direct comparison of the cost of all the parts after the changes were undertaken to show if the improvements had reduced the manufacturing cost. The sum of the cost column was also calculated, giving the overall cost of the specific modules of the machine.

Cycle Three framework

The framework implemented in cycle three is a development of the framework implemented in cycle two, with the production efficiency improvements verified in cycle two incorporated into the framework. The production efficiency improvements discovered during cycle three were captured and implemented into the framework, and this framework is the output of this research.

Research Plan conclusion

The section outlined the research plan, which details the steps and data collection methods to assist the researcher in achieving the research objectives. Three distinct work packages form part of the research plan, and these are split into two sections: the proposed method detailing what is planned and the implementation and finally what actually happened. The following section details the findings from implementing the research plan.

4. Analysis & Findings

The purpose of this research is to develop a framework to assist companies in improving production efficiencies in the mechanical design of HVLVHV machinery products. The following section details the findings from implementing the research plan.

4.1 Analysis, Findings and Discussion

The following section deconstructs the findings and discussion for the three cycles investigated through the research.

4.1.1 Analysis, Findings and Discussion Cycle 1

The purpose of cycle one is to test several tools for improving production efficiencies in the mechanical design phase of the product lifecycle that were found whilst undertaking the literature review. This cycle verifies which tools are appropriate for implementation into the framework. It also served to verify appropriate data collection methods and determine the criteria for success. For cycle one, the tools are implemented on a single module of the machine. The following sections describe the analysis, findings, and discussion from undertaking this cycle.

For cycle one, the following efficiency improvement tools were implemented for verification:

- Communication – UWES Questionnaire
- Product improvement forum – DFA / DFM Review
- Data Capture Sheets - Time
- Machine module costs - Cost

Communication Strategy & UWES

The purpose of this research was to explore whether production efficiencies can be achieved during the mechanical design phase when dealing with HVLVHV machinery products. One potential facet of this is employee engagement, which is relevant to the framework as engaged employees should perform more efficiently. A potential tool for measuring employee engagement is the UWES questionnaire. The purpose of implementing the questionnaire in cycle one was to test the appropriateness of the UWES questionnaire as a tool for assessing employee engagement.

Table 7 shows the first set of results from the UWES questionnaire, which was taken before the MD undertook the Town Hall Meeting. The employees' names have been replaced with letters to ensure confidentiality, and the results have been split into the three constituting dimensions of work engagement: vigour, dedication, and absorption. The mean of each table is shown below, along with the standard error and the standard deviation. The mean is the average of the results, and the standard deviation indicates how far the individual responses to the question vary or "deviate" from the mean. The standard error is an indication of the reliability of the mean. A small standard error is an indication that the sample mean is a more accurate reflection of the actual mean (Datastar, 2017).

Table 7, UWES Questionnaire 1 results

	Vigor						
Question	1	4	8	12	15	17	
A	3	2	2	3	5	5	3.33
B	5	4	5	5	5	4	4.67
C	3	3	3	3	2	4	3.00
D	5	4	4	4	4	4	4.17
E	3	3	3	5	6	6	4.33
F	4	3	3	4	4	4	3.67
G	6	6	6	6	6	6	6.00
H	2	3	4	4	4	4	3.50

Mean	4.08
Std Errors	0.34
Standard Deviation	0.95

Dedication					
2	5	7	10	13	
2	5	2	5	5	3.80
4	5	4	6	4	4.60
3	4	3	4	3	3.40
5	4	7	5	4	5.00
2	3	3	5	5	3.60
5	5	5	6	6	5.40
6	6	6	6	6	6.00
3	3	3	5	3	3.40

Mean	4.40
Std Errors	0.35
Standard Deviation	1.00

Absorbtion						
3	6	9	11	14	16	
3	2	3	3	2	1	2.33
5	4	5	4	4	2	4.00
3	3	4	4	3	2	3.17
5	4	4	5	4	4	4.33
3	5	3	5	5	3	4.00
3	4	4	4	4	3	3.67
6	5	6	6	3	1	4.50
5	3	4	4	4	2	3.67

Mean	3.71
Std Errors	0.25
Standard Deviation	0.69

Table 8 shows the second set of results from the UWES questionnaire, which was taken after the MD had undertaken the Town Hall Meeting. What is apparent from these results is there is very little difference between this and the first set of results. A T-test was used to validate if there was a significant difference between the two sets of results, and this proved that the difference was statistically insignificant. This result is not surprising due to the short period of time between the two questionnaires being undertaken.

Table 8. UWES Questionnaire 2 results

	Vigor						
Question	1	4	8	12	15	17	
A	2	2	2	3	5	6	3.33
B	5	4	4	4	4	4	4.17
C	3	3	3	3	3	3	3.00
D	5	4	3	3	4	5	4.00
E	3	5	5	6	6	6	5.17
F	4	3	5	3	4	4	3.83
G	6	6	5	6	6	6	5.83
H	3	2	2	3	3	4	2.83

Dedication					
2	5	7	10	13	
3	4	2	5	5	3.80
4	5	5	5	4	4.60
3	3	3	4	3	3.20
5	4	4	5	4	4.40
3	5	5	6	6	5.00
4	2	4	6	5	4.20
6	6	6	6	6	6.00
3	3	3	4	2	3.00

Absorbtion						
3	6	9	11	14	16	
3	2	3	3	2	1	2.33
5	3	4	4	3	2	3.50
3	3	4	3	3	3	3.17
5	4	4	4	4	3	4.00
5	5	5	6	5	3	4.83
3	2	4	6	2	3	3.33
6	4	6	6	4	2	4.67
4	4	5	2	4	2	3.50

Mean	4.02
Std Errors	0.37
Standard Deviation	1.04
T_Test	0.90

Mean	4.28
Std Errors	0.34
Standard Deviation	0.97
T_Test	0.803

Mean	3.67
Std Errors	0.29
Standard Deviation	0.82
T_Test	0.914

As both questionnaires were taken in the same week, this is thought to be the reason that there is a negligible difference in the results. Analysis of the results shows that although the results were not valuable in showing differentiation in employee engagement, the process and methodology were proven to be sound. As this was the purpose of this research stage, this outcome can be deemed a success. The initial objective of the first cycle was to test the appropriateness of the UWES questionnaire as a tool to evaluate employee engagement. Examining the results has proven that the UWES questionnaire is an appropriate tool for analysing employee engagement, and the process has also been proven viable.

Although the Town Hall meeting was a success, the researcher reflected on what had been communicated and identified missed opportunities to aid engagement. As will be expanded on later in this section, an area that proved to have not been communicated effectively was the shop floor. The personnel here were frustrated at not seeing the changes they had suggested implemented. The Town Hall meeting was an ideal opportunity to precisely lay out the stages and avoid the frustration that stemmed from the shop floor not having a clear understanding of the process. Due to the lack of time and explanation given to the subject, the vision for the future state of the business was not displayed in a format where it would get engagement. It was more of a statement in a presentation than a vision to generate excitement and support. Therefore, I feel this was a missed opportunity as it could have had a more significant impact and potentially gained additional support had it been presented in a different format. Stajkovic et al. (2019) found that primed goals are proven to enhance performance in an organisation, thus showing that it could have potentially increased engagement if the presentation had been framed differently.

Additionally, although a sense of urgency was created with the management team and the other personnel involved in the first cycle, it was not communicated in the town hall meetings and, therefore, the entire business. Reflecting on this, it was another missed opportunity as the business, in its entirety, could have been told that the company had identified an opportunity to improve its production efficiencies. Sharing the information during this meeting may have improved the engagement from differing facets of the business at the latter stages of the project, where sustaining engagement becomes more challenging.

Product Improvement Forum, Data Capture Sheets & Machine module costs

Table 9. Results of Product Improvements

Results		
P1 - Original Machine		
1	Cost of all parts	£91,118.94
2	Time to assemble	202.8 Hrs
3	Cost to assemble @ £36.25	£7,351.50
4	P1 total cost	£98,470.44
P2 - 25 Separate modifications		
1	Cost of all parts	£88,769.17 (Saving £2,349.77)
2	Time to assemble	131.7 Hrs (Saving 71.1. Hrs)
3	Cost to assemble @ £36.25	£4,774.13 (Saving = £2577.38)
4	P2 total cost	£93,543.30
Time savings per head = 71.1 hrs		
Time savings Per Machine = 142.2 hrs		
Total cost Saving Per Head = £4,927.14		
Cost savings Per Machine = £9854.28		
Percentage saving = 5%		

The purpose of cycle one was to test several tools for improving production efficiencies in the mechanical design phase of the product lifecycle that were found whilst undertaking the literature review. Table 9 shows the results of the product improvement forums where the DRA and DFM improvements were captured. In total, twenty-five modifications were undertaken on the module selected for cycle one, designated as P2. Once these modifications were undertaken, new quotes were sourced for the parts. Additionally, a new data capture sheet was generated with the updated estimated time to assemble the module. Undertaking this work resulted in a 5% reduction in the production cost of the module. This saving comprises both the cost to produce the parts and the time to assemble them. This figure was generated by generating a data capture sheet to capture time and analysing the company’s ERP system to capture costs.

Utilising the quantitative data from the company's ERP software and the data capture sheet enabled a direct comparison of the machine section before and after the changes. This data was compiled in two forms, one being cost from the ERP system and the other being time from the data capture sheet. Using these two cost and time metrics through all stages of the framework's development will ensure consistency and transparency. Additionally, to avoid potential bias by the researcher, the data was independently verified to confirm the accuracy of the findings. The engineering manager undertook this verification within the case study company, and he had no specific allegiance to the research and, therefore, should remain objective. This cycle has proven that adopting the Lean design principles of DRA and DFM reviews and the process and methodology for capturing the results is sound. Therefore, this production efficiency tool can be implemented in the framework and used on further cycles.

Efficiency improvement proposition 1: Adopting Lean design principles will improve production efficiencies in the mechanical design of HVLVHV machinery products.

Reflections

The following sections utilise reflection to question what steps were undertaken and whether there is a better, more efficient way of doing them. It also aids the researchers' learning as it challenges the researcher's assumptions of professional knowledge and their own response to the situations that arose during this cycle. It utilises the PDCA cycle to give a consistent approach to the research problem and aid reflection, which is shown in the cycle one framework section below.

VSM - Machine module selection

During cycle one, the value stream map was completed, and the data was compiled in Microsoft Excel to analyse the results more effectively. The quantitative time per process highlighted that procurement took a considerable amount of time and caused a substantial portion of the delays that the case study company saw in the lead time of their products. This is significant as it highlighted that using standard modules in the makeup of the products could reduce the lead time of machine orders. By standardising the modules, they have the option of stocking parts and, therefore, reducing or removing the procurement phase of the process. Although this may appear at odds with Lean principles, utilising a make-to-stock methodology acts like a Kanban inventory system. The process will pull the materials through to production as required, and a signal will then be triggered to replenish the stock. The process of generating the value stream map highlighted delays in the process, and therefore, it was clear to the management team the potential benefits of undertaking this research and business improvement initiative.

At the start of cycle one, the management team proved their intention to engage in the research as they signed a Project Charter to say that they had aligned with the project. The project charter detailed the issue being addressed, the project's scope, the people involved, projected times, milestones, and potential risks. As all facets of the management team had been engaged in this project, it ensured that all business functions were involved and had been communicated with regarding the project's requirements. The purpose of this charter was to detail the team that would support the project and ensure its success. The result of this was that support could be sought from all areas within the business if required. All participants appeared very optimistic about the project, and no objections were raised; therefore, the researcher was optimistic that all personnel could see the benefits of undertaking the work.

Unfortunately, as further meetings took place, it became apparent that there appeared to be two distinct groups of managers. One group of managers was genuinely engaged, and the other group of managers participated to the minimum and only in the meeting setting. Having historical knowledge of the management team personally assisted the researcher in differentiating between the ones who were genuinely engaged and those who were participating to the minimum. This was important for the researcher as it highlighted the personnel who would engage in the change initiative and assist the researcher in driving it to completion. At this early stage of the project, it was quite clear that the trio of key management team members not engaged either didn’t fully understand or wholly agree with the proposed improvement proposal. One team member struggled to see standardisation's benefits and how it would work in our industry. It was hard not to take the unengaged manager's negativity towards the project personally as the researcher was so espoused in the project. Instead, the researcher chose to take solace in the fact that most of the management team agreed with the proposed project plan. Reflecting on the points made by the individual who didn’t see the benefits of standardisation, there is a possibility that they felt that their method of working was being questioned as they are a vital member of the team that delivers the existing machines.

Additionally, as this individual had worked at the company for many years when the strategy changed, and the company intended to work differently, it is a fundamental change to the way the business works, and as a rule, people generally don't like change. The other two members of the management team who didn't appear fully engaged in the project explained that they thought it would be more beneficial for the business to design a new type of machine. This was discussed, and the engaged managers argued that this doesn't address the issues concerning improving the efficiency of producing the FWM's. Even when it had been concluded that the business was not going to design a new type of machine, it was apparent that this was still the direction the less engaged managers wanted to follow.

This diversity in opinions is a normal part of any project, and there will always be certain personnel who don't truly engage. As the researcher is the project lead, the fundamental objective was to provide conditions in which the "Critical Mass" of individuals will be accumulated and directed towards achieving the collective goal (Marwell and Oliver, 1993). The researcher believes that this was achieved, and the divide is a natural consequence that can be attributed to any project.

Cycle one - Framework

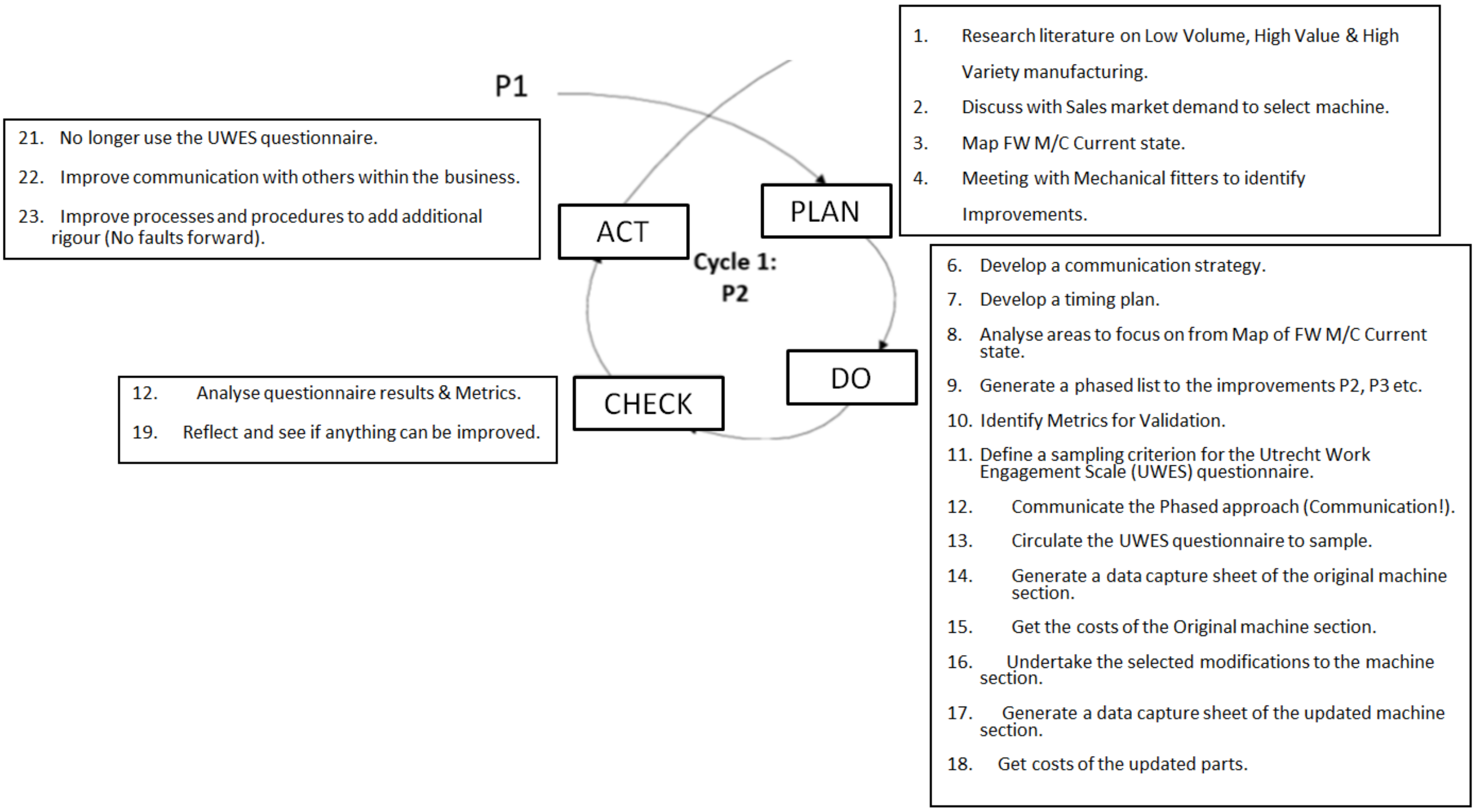

Figure 13, HVLVHV design process efficiency model: Cycle 1

As discussed previously in the proposed method for cycle one, the P10 Design procedure was the standard process that the engineering team worked to within the case study company. This process formed the basis of how the mechanical design engineering team worked daily; therefore, cycle one of this research followed this procedure.

No longer use UWES questionnaire

Figure 13 shows the HVLVHV design process efficiency model of the work undertaken for the first cycle of the research. Although the process proved to be a success, several primary learning points were taken from this cycle into cycle two. Firstly, the UWES questionnaire was no longer part of the research. Although the questionnaire and process of measuring employee engagement were found to be valuable tools, the impact on this specific research compared to the work required to undertake the questionnaire and survey analysis made it impracticable for implementation into the framework.

Improve communication

A further learning point that caused the researcher some anxiety came from the shop floor personnel. They were very vocal about their frustration that the changes they had suggested in the improvement forum had not been implemented in the following machine that came to the shop floor for assembly. This wasn't very clear to the researcher as this was not viable, and it highlighted that the shop floor personnel hadn’t truly understood the plan that had been communicated to them. Due to the time, it takes for a machine to be produced in the case study company, as highlighted in Figure 10, the next machine that comes to the shop floor for assembly will have been issued for manufacture months in advance, and therefore, it is not viable for the changes they suggested to have been implemented.

The researcher believed that the plan had been communicated clearly to them during the improvement forum, but it was evident that this was not the case. This learning point was noted to improve communication in the following cycles. Additionally, the researcher received positive feedback concerning regular updates from the management team and the remainder of the business. Kotter (1984) highlighted in his 8-step change model that it is important to celebrate any short-term wins, so continuing this communication is essential, particularly concerning the management team, as they are the sponsors for this research.

Improve processes and procedures

During the period of undertaking cycle one, the management team picked up on a philosophy that originated with Toyota and was encapsulated in their vision. The Philosophy was “No Faults Forward”, and the management team appeared to embrace this concept. It was hoped that the management team's persistent repetition of this phrase would emphasise the importance of this point to personnel and embed it within the organisation's culture. The researcher recognised that a change in organisational culture takes time. It was also recognised that for this change to succeed within the mechanical design team, it would need to be embedded into their work procedures. Therefore, the researcher decided that the additional rigour required to adhere to this philosophy would be fundamental to the framework developed by this research. To achieve this, for cycle two of the research, new procedures and work instructions that underpin the framework were created to add additional rigour to the next iteration of the framework, see section 7.2. This framework clearly shows the development undertaken when compared to the original in section 7.1. This development of the framework through each cycle is a natural occurrence. Bicheno & Holweg (2016) quantify this as they explain that a standard reflects the current and safest known way, but it’s not fixed in stone forever. The standard at each cycle moves to an improved standard. This improvement constitutes part of the plan, do, check, act cycle discussed in the literature review.

By standardising the processes and work instructions that underpin the framework, unnecessary steps were eliminated, and the process optimised for efficiency. Additionally, creating new procedures and work instructions for subroutines in the design process was streamlined, and further waste was removed. This work was undertaken during cycle 1, and the framework developed see section 7.2 is used as a template for cycle two and optimised further.

Efficiency improvement proposition 2: Standardising the mechanical design process will improve production efficiencies in the mechanical design of HVLVHV machinery products.

4.1.2 Analysis, Findings and Discussion Cycle 2

The previous section discussed the findings for cycle 1; this section will discuss the data analysis findings for cycle 2 of the research. This work aimed to develop a framework to assist companies in improving production efficiency in the mechanical design of HVLVHV machinery products. As Ackoff (1994) discussed, a system's performance is not dependent on the performance of its parts. Although the performance of parts is important, the most important aspect of a part's performance is how it interacts with other parts to affect the system's overall performance. It was important to remember this when analysing the results for cycle 2, as a holistic review of the results and consideration of the transfer of information was required. The production efficiencies of various departments needed to be considered for cycle two, not just the mechanical design department singularly.

For cycle two, the following efficiency improvement tools were implemented for verification:

- Machine module costs – Cost
- Data Capture Sheets – Time
- Product improvement forum – DFA / DFM Review

Table 10. Results of Product Improvements P2 – P3

Results			
P2 Machine (2nd Cycle) (2019)			
			3% inflation per annum
1	Cost of all parts for the three modules (P2)	£319,235.72	£338,677.18
2	Time to assemble the three modules (P2)	686.11	686.11
3	Cost to assemble the three modules @ £36.25 (P2)	£24,871.49	£24,871.49
4	Total Cost (Part cost & time cost) (P2)	£344,107.21	£363,548.66
P3 Machine (3rd Cycle) (2021)			
1	Cost of all parts for the three modules (P3)	£355,414.34	
2	Time to assemble the three modules (P3)	464	
3	Cost to assemble the three modules @ £36.25 (3)	£16,820.00	
4	Total Cost (Part cost & time cost) (P3)	£372,234.34	
Time savings (P2 - P3)		222.11	
Total cost Increase (Part cost & time cost) (P2 - P3)		£8,685.68	
Percentage saving time (P2 - P3)		32.37%	
Percentage part Increase cost (P2 - P3)		4.94%	
Percentage Increase total cost (Part cost & time cost) (P2 - P3)		2.39%	

Machine module costs - Cost

As discussed in the previous section, 3.3.4, the fundamental change for this cycle was changing from bespoke manufactured rails to standard ones. Changing from the bespoke manufactured rails to the standard ones increased the cost of the parts by 4.9%, although it reduced the build time by 32.4%. This reduction in build time is very significant as it leads to the potential for increased productivity and, therefore, turnover. This will be expanded on later in this section. Amongst the findings in this section, additional factors positively impacted the company's production efficiency. This was validated by undertaking expert interviews with the

Procurement and Production Manager and the Purchasing Manager to capture qualitative data that wasn't immediately apparent from the quantitative results. The findings from these interviews are discussed in the section below, and the format is discussed in section 3.3.3.

Table 10 shows the results of the product improvements for cycle two. The three main modules of the machine were selected: the head (402-A), the base (403-A), and the clamp (408-A). The first cost shown in row one of P2 shows the cumulative cost of all parts for the three modules in 2019 when the modules were previously manufactured. This cost was adjusted by 3% per annum for the two years between 2019 & 2021 to reflect inflation, and this figure is shown in the next column. While researching global inflation for inclusion during this period, there were variations in the data being found depending on the source, for example, Statista (2021), Macrotrends (2021), and OECD (2021). From the data found, 3% was considered a reflective average for this data and was therefore used for the adjustment per annum for the period of 2019 to 2021. Global inflation was used for the price increase to reflect inflation as the parts and materials used to manufacture the machines are sourced globally and are therefore impacted by this. It was not viable to trace the parts individually to their source of procurement and calculate the individual inflation rates as this data is not available, so the average was considered appropriate for inclusion. Undertaking this alteration enabled a direct comparison of the cost of manufacturing the parts for the three modules between the two variants of the machine (P2 and P3), which were manufactured in different years.

Undertaking a direct cost comparison with the machine manufactured in 2019 was complicated further due to several factors. Firstly, the price of steel can fluctuate weekly, and this affects the cost of the manufactured parts from suppliers. This situation was made worse due to Covid-19 and the running down of supplier's stock during this period. As the global economy began to recover, the case study company's procurement department found that the cost of goods had increased due to the reduced stock that companies were holding, leading to increased demand.

The first additional saving that is not reflected in Table 10 that became apparent during the interview with the Procurement and Production Manager and the Purchasing Manager was during the inspection phase. When goods are manufactured, the company's policy is that they are inspected to ensure they have been manufactured in line with the drawing. As the new rails added during this cycle are standard items, this step was not required as standard items are found to be extremely repeatable. This saves the company significant time and cost as inspection is highly time-consuming. This time was quantified with the support of the inspection department. The inspection Engineer timed each of the steps required to inspect the manufactured slideways used before the standard rail solution was added to the design to replace them.

Table 11. Slideways inspection time

Number	QTY	Inspection Time	Total Time (Mins)
T706---03-A002	2	210	420
T706---03-A004	2	180	360
T706---03-A005	1	115	115
T706---03-A006	1	95	95
		Total	990

Table 11 shows the time required to inspect the six slideways that were replaced by the standard rail solution that didn't require inspection. As can be seen from the table, it took 990 minutes to inspect the slideways. There was obviously a significant cost to this time, as, at £36.25 per hour, this equated to £598.13. This is a direct cost to the business and would need to be added to the cost of the machine. This could lead to the case study company being less competitive as this additional cost being multiplied across many parts could contribute to a TFW machine costing more than its competitors. Additionally, undertaking this rail inspection has added a two-day delay to the build. This is significant as the Head of Finance within the business states that every month that can be taken off the machine build saves the business 17% of an order's total value.

One also needs to consider that the rail parts are a few of the machine's many requiring inspection. Therefore, the more parts of the machine that were replaced with standard solutions, the shorter the time it took to build the machine. Additionally, standard parts are generally faster to procure than bespoke items manufactured to order. Therefore, the reduction in time from the place of order to assembly is twofold. This real-world example clearly shows the profitability benefits that the company capitalised on by incorporating standard products into the modules rather than manufactured items. Additionally, this point highlighted the business impact in terms of efficiency improvements that can be seen by incorporating improvements early in the design phase. Another factor considered when developing the standard modules was the opportunity for the purchasing department to buy the products in bulk, reducing their cost further.

Table 12. Machine Variants and Sales

YEAR	TOTAL MACHINES SOLD	MACHINE VARIANT										
		TFW1	TFW1D	TFW2	TFW3	TFW4	TFW5	TFW5D	TFW6	TFW7	TFW8	TFW9
2019	4				2		1	1				
2018	6	1	1		1		2	1				
2017	9	1	4		2		1	1				
2016	6	1	2		1			2				
2015	6		1		2		2				1	
2014	5	1			3			1				
2013	8		1		4			1			1	1
2012	8				3			4		1		
2011	7				1		4	1		1		
2010	8				4		1	1		2		
TOTAL	67	4	9	0	23	0	11	13	0	4	2	1

KEY
D; Double ended

Table 12 shows the different variations of friction welding machines sold by TFW and the quantity sold for each type from 2010 to 2019. This period was selected as COVID-19 impacted 2020 sales, so they do not reflect an average year. TFW currently sell, on average, seven machines per year. Additionally, based on these ten years, a maximum of five of these would be one type of machine per year.

Table 13. Cost and Quantity Comparison

QTY	Part No.	Description	Charge No.	Price	Date
6	T7C -02-A001	BALLSPLINE ADAPTOR	T7 3-402-A	£962.00	2016
1	T7C -02-A001	BALLSPLINE ADAPTOR	T7 3-402-A	£2,096.00	2019

Table 13 shows the benefit of purchasing parts in bulk. In 2016, six Ball spline Adapters were ordered from a supplier. Due to the quantity, the cost was £962.00 per part. The same item was ordered in 2019, and due to only a single item being ordered, the cost was £2096.00. Even considering inflation, the bulk order still costs £1,051.20, which is essentially half the cost of a single item. Thus, strengthening the argument for having standard modules and enabling procurement to order larger quantities of the parts.

Data Capture Sheets - Time

Row two of Table 10 shows the cumulative time to assemble each of the three modules summed to give a total assembly time for the three modules. Row three of the table gives the total cost to assemble the three modules. This was calculated by multiplying the time from row two by £36.25. This is the hourly cost to the business per hour for each of the shop floor Mechanical Fitters who assemble the machines. This cost was sourced from the Head of Finance within the business. Row four of the table gives the total cost per variant of the machine, including the cost of all the parts for the three modules and the cost of the time it takes to assemble the three modules. As can be seen, undertaking the DFA reviews has reduced the build time for these three modules by 32%.

This is crucial as a reduction in the machine's lead time can directly impact potential customers. Data from the Sales and customer service team shows that in the past, customers have looked for alternative suppliers of the machines as they have offered a shorter lead time than the case study company, which was a direct factor in their purchase decision. This means that the case study company can forecast build times more accurately, capture best practices in terms of build, and potentially reduce the build time further. Data shared by the production manager put previous estimates for build time in the region of ± 40 – 50% accurate. This is thought to have improved to ± 5% by incorporating the data capture sheets generated during this cycle.

Product improvement forum - DFA / DFM Review

The improvements undertaken on the P3 variant of the machine focused on the manufactured rails that are attached to the base, which enable the head and clamp to move. The original rails were bespoke manufactured items. The machine was redesigned to allow the fitment of standard rails that could be purchased off the shelf from suppliers. These are generally referred to as commercial off-the-shelf or COTS in industry. Due to the complexity of this modification, there were very minimal additional modifications to the machine, so keeping the changes to a minimum would help identify the cause of any issues that become apparent when setting up the machine for commissioning.

Purchasing standard rails rather than the ones that TFW designed in their own office has increased the part cost of the modules by 4.9%. However, the time needed to build the machine decreased by 32.4%. Therefore, when considering the reduction in build time, the actual cost of the modules has only increased by 2.4%. Utilising the part cost data singularly without considering other facets of the business could give the impression that the improvement strategy had failed. Therefore, an expert interview was undertaken with the Head of Procurement and Production to get a more holistic view of the changes' impact. The information obtained from this interview is included in the following Conclusions and Recommendations section.

Reflections

The following sections utilise reflection to question what steps were undertaken and whether there is a better, more efficient way of doing them. It also aids the researchers' learning as it challenges the researcher's assumptions of professional knowledge and their own response to the situations that arose during this cycle. It utilises the PDCA cycle to give a consistent approach to the research problem and aid reflection, as shown in the section below.

Cycle 2 - Framework

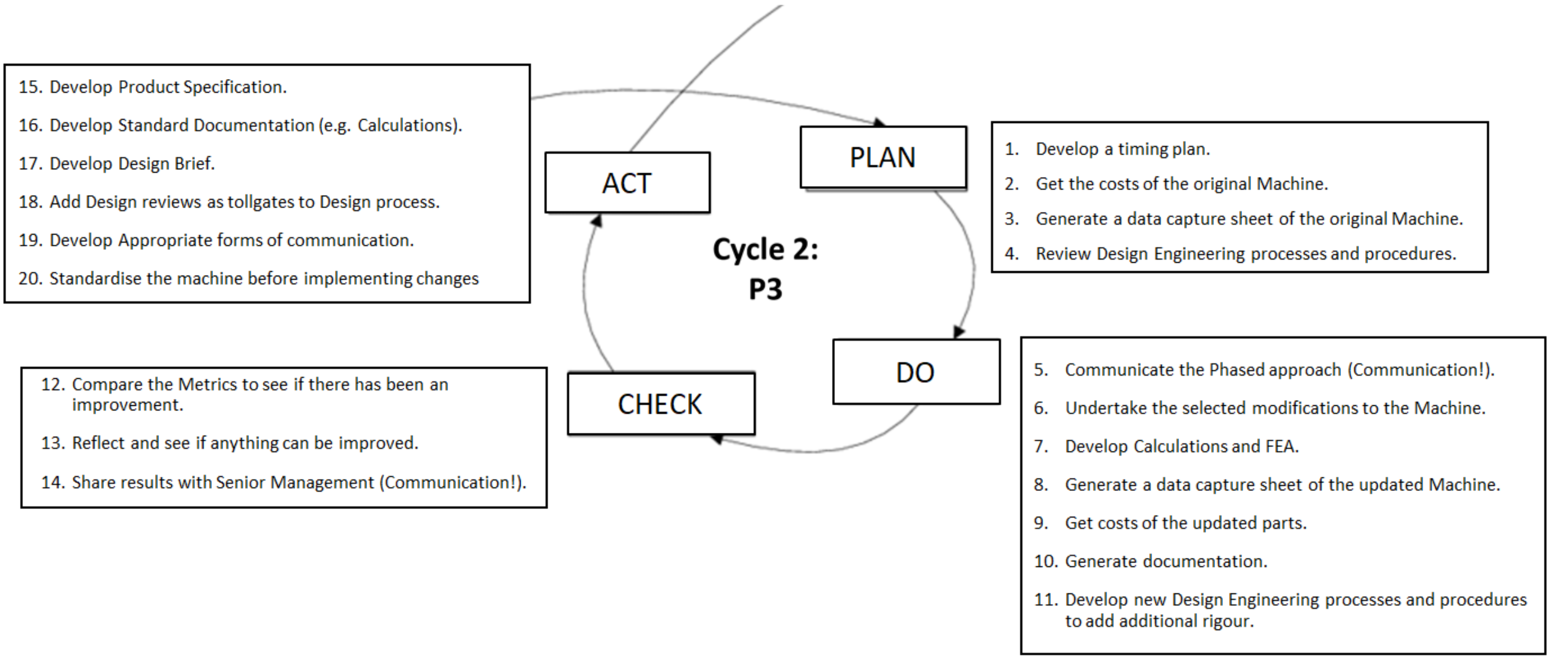

Figure 14, HVLVHV design process efficiency model: Cycle 2

Figure 14 shows the HVLVHV design process efficiency model of the work undertaken for cycle two of the research, this cycle focussing on the TFW5DE machine. This cycle proved to be a success, and several primary learning points were taken from this cycle into the next cycle, that being cycle 3 of the research.

Develop Product Specification & Design Brief

The first primary learning point being taken forward to the next cycle was the requirement for a clearly defined specification. The lack of a clear specification for cycle two caused several issues and made designing the product difficult due to the lack of information. For the next cycle, a specification will be generated prior to any design work taking place, and this will be reflected in the HVLVHV design process efficiency model. However, having the specification document for reference during cycle two would have solved many of the issues in terms of a lack of information. The consensus amongst the product development team was that there could still be ambiguity, and an additional document was required. Therefore, a template "Design Brief" document was created that contained additional, more detailed information than a traditional specification. The requirement to generate this documentation was added to the framework to ensure that these production efficiency improvements are captured; this output framework for cycle two can be seen in Appendix 7.3.

Aligned with the requirement for a clearly defined specification, cycle two highlighted issues concerning empirical data. Empirical data is information obtained through observation or experimentation. Without this data, the product development team had no evidence to show why the machines had been designed in their current format. An example is that there were no calculations or FEA analyses to quantify why the machine bed plates were the thickness they were. Additionally, when developing the various standard modules for the machines, there are points where decisions must be made. Examples are which variant of the product should be used or if this feature can be removed. Making these decisions is far easier if the person making the decision has empirical data to assist in the decision-making process. This resulted in significant delays as the team was forced to resort to first principles and analyse and investigate all decisions with little or no supporting data. The team developed numerous calculations and FEA processes during this period to verify the decisions they made during the design's progression.

The most significant example of this was the machine bed. The one used as the basis for the design was found to be failing under analysis at a capacity far lower than its original rating. The bed design was traced back to 1986 but may have been designed before then. The design was found to be failing at the welds that hold the bed together. The traditional method for analysing this bed when it was designed would have been to undertake various hand calculations. These are believed to have not included the welds as this would have been extremely complex or impossible to calculate with hand calculations. Utilising modern simulation techniques and FEA, the bed could be analysed with greater accuracy and include the welds in the analysis. Utilising this method led to a much more accurate analysis and highlighted the weakness in the welds in the original design.

Although the original intention for this machine was to comprise a new standard modular design, product development was stopped due to COVID-19. The impact of this is that rather than the product development team working in isolation on development machines, they worked on live orders. Additionally, as the new machine was designed for cycle two, the capacity was equal to the one required by the customer, so this machine was selected as the basis for their machine. The outcome was that rather than the specification being defined by the business, it was defined by the customers' requirements. This led to additional work as once the customer order had concluded, the machine had to be changed. This change made the machine align with the general market requirements rather than this one specific customer.

An example of the customer requirements driving the specification was the machine bed. The new bed was designed to withstand 150 tonnes of forge force rather than the 125 tonnes that the original bed was designed to withstand. This increase in capacity will open the product to a wider range of customers but brought about some dissatisfaction, as will be expanded on below. Firstly, as this product incorporated a brand-new feature in the rails, the team would have liked to have experimented with the new design. Due to the restrictions imposed by COVID-19 and the time limitations imposed by it being a live order for a customer, this was not viable. The result was that the team was not afforded the benefit of proving the design by testing. Therefore, the calculations and FEA undertaken by the team had to be double-checked. The product development team used the opportunity whilst undertaking the work to develop standard calculations and other documentation, which will be expanded later in this section.

Once the work had been completed, there was some discontent from individuals within the business in relation to the machine bed. This discontent was due to the machine bed costing more than the original, and some of the management team were unhappy about this. The increase in the new design compared to the old one was a 33% increase in cost to manufacture. This was frustrating for the researcher as the original quotation that they were comparing the costs from was dated 2019, compared to the 2021 costs for the new bed. Cost inflation over time would also need to be considered when comparing the two beds directly. Additionally, as was mentioned previously, this comparison is complicated further due to COVID-19 and the running down of supplier's stock during this period. As discussed previously the global economy began to recover, the case study company's procurement department found that the cost of goods has increased due to the reduced stock that companies were holding, leading to an increase in demand.

Another factor affecting the cost of the new base was an increase in length. The case study company found that there were seal failures in the field due to the mounting of the forge cylinder. To overcome this seal failure issue, the length of the base had to be increased to accommodate a new style of cylinder mount. Adding material to the base obviously increases the cost, and this was not considered when comparing the cost of the two base designs. This increase in length was not optional due to the failures seen; therefore, the old base design they were comparing it to was no longer a viable base that could be used. Therefore, the cost comparison being undertaken held no merit.

In the previous section, issues in relation to communication were highlighted. This poor communication is also reflected in the discontent with the base design, which was a source of frustration for the researcher. Additionally, as was briefly mentioned earlier, the product development team were having issues getting prices for new designs from procurement. The product development team had requested quotes for numerous parts, including the base of the machine, several times. Procurement told them that live orders were a priority, and the quotations were not forthcoming. Had the quotations been sourced and shared with the team, they would have known that the base was more expensive. They then would have had the option of investigating modifying it to reduce cost or communicate the fact on the price. This was the main factor for instigating an agreement with the head of procurement that the product development would get the same priority level for the next cycle in getting costs back as live orders.

As the machine was designed on a customer order, the team had little time to do actual development due to tight deadlines. This resulted in the machine being issued on large size 100 carriages, as these had been used before on a previous machine of the same capacity and were therefore proven to be appropriate for the application. These carriages are extremely expensive due to them being considered special by the supplier and not standard. After the machine was issued and in service, the team had time to investigate further and found that smaller carriages could have been used. Had these smaller carriages been used, there would have been a potential 2.8% reduction in the production cost of the machine. Due to the considerable savings that could be seen from undertaking this work, it resulted in a significant amount of additional design work at a later date to enable this saving to be achieved. If the case study company had waited for the design to be finished instead of accelerating the work through on a customer order, this rework would have been avoided. Consideration has to be taken here that this was during the COVID-19 period, machine orders were extremely low, and product development had been stopped due to the costs involved in sustaining this department. It is the belief of the researcher that a different decision would have been made had the business not been under the pressure inflicted by this specific period in time.

Add Design Reviews to Framework

A further cause of delays for cycle two was a lack of design reviews and them not being held as frequently as required by the design's complexity. The main driving factors for these delays were the COVID-19 global pandemic and homeworking, which will be expanded on in section 5.2. Although the DFA and DFM manufacture reviews were being held for new designs, there was still a requirement for the Mechanical Design Engineers to have a review and get input from their peers. Although the impact of the COVID-19 global pandemic cannot be changed, reflecting on the period highlighted potential improvements in the framework that could be utilised going forward. Ruminating on the reviews highlighted that there was no official procedure for undertaking them. It was decided that this could be overcome by embedding the reviews in the processes that the Design Engineering team must work to and having them as tollgates. This would ensure that they must be undertaken in future projects and would prevent the delays from happening again.

These tollgates would become a business requirement and form part of the ISO 9001:2015 standard. Working to this standard is a requirement of the business as they require certification to be recognised as a quality company within industry. Additionally, undertaking annual audits to check that the documentation, reviews, and other documents that the design engineering team should be generating are being adhered to is now part of the company’s policy. This will highlight if the process is being followed and if further training is required or if the process is too cumbersome and requires modification. Utilising reflection as a tool resulted in real-time organisational learning (Balzert et al., 2011). Without using this tool in relation to business processes, the innovative ideas generated by the product development team would not have been considered. Encapsulating these ideas in the design team's process will ensure they are facilitated in future Machine orders. Therefore, the improvements will continue and develop as they are refined.

Develop standard Documentation

During cycle two, the product development team used the requirement to undertake calculations to develop template calculations and other documentation. Developing template documents enabled the calculations to be edited and used for cycle three, thus preventing the work from being repeated. Having a template library of calculations is also beneficial for the business as others can utilise the knowledge captured within them, leading to organisational learning. Wherever it was found to be viable, during cycle two, any documentation generated was turned into standard documentation with templates, thus improving departmental efficiency.

Another benefit of generating standard documentation was the opportunity to improve the quality of the documentation that accompanies the machine. Much of this documentation has an impact on other facets of the business, and therefore, their buy-in was required before the documentation could be put into general circulation.

One example of this is the Treatment Specification document developed by the mechanical engineering team. This document comprised a list of codes and associated treatment specifications adjoined to that code. This allowed the engineering team to add the relevant code to a drawing so the manufacturer of the part knew the appropriate treatment to be applied to that part. In the past, the treatment of the individual parts has been defined in the drawing in descriptive text, and this caused issues. If the same part was required for a different machine order with a different finish, the part would have to be redrawn with the new finish.

The concept developed by the mechanical engineering team to prevent this was adding the code to the drawing, for example, using X1 instead of defining the finish on the drawing in descriptive text. The Treatment Specification document would then accompany the drawing, illustrating the appropriate finish in relation to the code on the drawings. The benefit of undertaking this work was that a single Treatment Specification document was generated for the new machine order, rather than the engineering team having to regenerate all the drawings with the new treatment specification.

However, the team acknowledged that this change in procedure impacted the procurement department. Therefore, before implementing this change, they needed to be consulted. The impact on the procurement department was that they would be required to send the Treatment

Specification document to the supplier in addition to the drawing that they sent as a single document in the past.

Emails were sent to the relevant personnel within the procurement department to get their input on the new document generated. Feedback was not forthcoming, although multiple attempts were made to engage and get feedback. A discussion held with the mechanical engineering team highlighted that they had the perception that there was resistance to change within the procurement department and that personnel didn’t want to change the way they worked.

The mechanical engineering team received no feedback on the document generated, and the lack of feedback resulted in hours of additional work. The team decided to implement the new, more efficient process as they generated a considerable number of new drawings. Their justification for doing this was that as this was a more efficient process, it was logical for the business to move forward with this approach. The machine for cycle two was a live order, meaning it was intended for a customer, and therefore, there were deadlines for the team to issue the drawings for procurement. As the deadline approached, the notes on each of the drawings had to be changed to ensure they didn’t reference the unapproved documentation generated by the mechanical engineering team.

The researcher found this lack of engagement from other departments to be demoralising, and the mechanical engineering team voiced similar feelings. When generating this document, the team aimed to improve efficiencies throughout the business, but it appeared that there was resistance to change. The consensus amongst the team was that they should focus their efforts on the things where they could have an impact that didn’t rely on other departments for approval. However, in the short term, this appeared to be a sensible approach as a considerable amount of work was needed to generate the standard modules and incorporate the DFA and DFM improvements. In the long term, though, this approach was not sustainable as this work aimed to improve production efficiency in the design phase of HVLVHV machinery. Therefore, collaboration was required, which must be addressed in the next research cycle.

Develop Appropriate Forms of communication

Although attempts were made to engage with other departments in relation to the standard documentation, much of this communication was via email. This was predominantly a result of COVID-19 and homeworking, but it should be acknowledged that there are better forms of communication for implementing this type of change. Referring to Kotter's (1996) 8-step change model, step 3 states creating a vision for change, and step 4 states communicating the vision. The product development team had not followed either of these steps. Therefore, this needed to be addressed to improve the chances of successfully implementing efficiency improvements in future cycles. If the product development team had utilised appropriate forms of communication for different purposes, they would have had a better chance of getting buy-in from other departments. Considering the situational aspect of the global pandemic, an example of how this could be done would be utilising a Microsoft Teams meeting. Utilising the software to show a presentation highlighting the benefits of the change. As a result of this, it was decided that appropriate forms of communication would be used to show the impact and benefits to different departments for future documentation or process changes. This should ensure engagement and increase the likelihood of buy-in, therefore preventing delays.

During cycles one and two, communication was found to be an issue. For cycle three, a significant effort would be made to ensure that appropriate forms of communication are used to prevent issues concerning communication from continuing. Additional problems seen during cycle two concerning getting quotation prices from suppliers would be overcome due to the agreement with the head of procurement that for the next cycle, the product development would get the same priority level as live orders. Previously, live orders were considered a priority, and the product development team undertaking the machine development for cycle two could not get quotations for new designs. This agreement was intertwined with the formation of the standardisation team and will be expanded on in the next section.

Standardise the Machine before implementing Changes

Finally, it was decided that for cycle three, the order of development would be to standardise the machine and then implement any changes or suggested improvements. Standardising the product first creates a baseline prior to implementing the changes. This was important due to the number of changes and potential variations between modules. Additionally, it was fundamental to the FEA analysis as the previous design, which is the basis for the new design, is proven by its use in service. Therefore, starting with the standard design gives you a proven design and a basis for deflection and stress comparison, among other requirements.

4.1.3 Analysis, Findings and Discussion Cycle 3

The previous section discussed the findings for cycle two of the research; this section will discuss the data analysis findings for cycle three. This work aimed to develop a framework to assist companies in improving production efficiencies in the mechanical design of HVLVHV machinery products. As in the previous cycle, a holistic review of the results was required for this section of analysis. This means that the production efficiencies of various departments needed to be considered for cycle three, not just the mechanical design department.

For cycle three, the following efficiency improvement tools were implemented for verification:

- Machine modules cost – Cost.
- Data Capture Sheets – Time.
- Product improvement forum.
- Undertake a design for assembly review.
- Undertake a design for manufacture review.
- Standardise the machine modules before implementing changes.
- Develop a design specification.

Machine section costs & Data Capture Sheets

Calculating the costs of the new modules for cycle three was extremely difficult. The impact of COVID-19 and the war in Ukraine on steel prices meant that the data on the ERP system was no longer valid for comparison. The company's costs for the manufactured steel parts stored on the ERP system prior to these events were significantly lower than the new quotes. Therefore, comparing prices had no validity. This was further complicated by steel prices fluctuating weekly, so quotations had a very limited validity period. To overcome these issues in relation to costs, the procurement department initially liaised with suppliers and shared drawings of parts both before and after the improvements had taken place. They asked the suppliers to quote on both parts to see if the improvements were successful. Some suppliers were initially happy to do this, but this was soon followed by resistance due to the increased workload without a cash reward. This highlighted the fact that gauging the improvement savings this way was not viable as a long-term strategy. An alternative solution was required, so it was decided that all modifications to each section would be documented, and the Purchasing Manager would put forward an estimated saving based on the original drawings and what would be the impact if implementing the suggested change in terms of cost. As he has many years of experience, the estimate could be considered a reasonable gauge as to whether the improvements have reduced the cost of manufacturing the part. This estimation could then be confirmed once the item was purchased. Appendix 7.8 shows an example of this work. Due to the situation outlined, this was deemed as the most appropriate method to continue the work and gauge success.

Utilising the quantitative data from the company's ERP software for the original part, the new prices from the Purchasing Manager and the data capture sheet enabled a direct comparison of the three modules before and after the changes. This data was compiled in two forms: cost from the ERP system and time from the data capture sheet. As in the previous sections, the machine modules are compared using cost and time metrics for consistency and transparency. Additionally, utilising quantitative data for analysis gives a metric for verification of whether production efficiency improvements have been achieved.

Table 14, Head, Base and Clamp module analysis results

Results			
Cycle Three - Original Machine			
1	Cost of all parts	£76,903.44	
2	Time to assemble	345 hrs	
3	Cost to assemble @ £36.25	£12,506.25	
4	P1 total cost	£89,409.69	
Cycle Three - Post modification Machine			
1	Cost of all parts	£69,894.02	(Saving £7009.42)
2	Time to assemble	320 hrs	(Saving 25 hrs)
3	Cost to assemble @ £36.25	£11,600.00	(Saving £906.25)
4	P2 total cost	£81,494.02	
Time savings Per Machine = 25 hrs			
Cost savings Per Machine = £7915.67			
Percentage Time saving = 7.25%			
Percentage cost saving =8.85%			

<u>Shop floor product improvement forum & Mechanical Design Engineering team product improvement forum & Undertake a DFM & DFA review</u>

Table 13 shows the results of the work undertaken to improve the efficiency of producing the three modules. In total, one hundred and ninety suggestions were submitted for the three modules. Once the selected modifications were undertaken, cost savings were calculated by the purchasing manager as described earlier.

A new data capture sheet was also generated with the updated estimated times to assemble each of the three modules. Undertaking this work resulted in an 8.85% reduction in the cost of producing the three modules when compared to the original design.

The objective of this specific improvements approach was to implement a cost and time reduction strategy in the three selected sub-units of the RFW Machine. This proved to be successful and was achieved using data capture sheets, improvement forums and the analysis of the company's ERP system and existing costs. The improvements resulted in a 10% reduction in the material cost of the machine's modules and a 7.25% reduction in the time to assemble the machine's modules in comparison to the original modules.

Table 15, Head, Base and Clamp analysis results in multi-buy

Results Bulk buy -24.59%			
Cycle Three - Original Machine			
1	Cost of all parts	£76,903.44	
2	Time to assemble	345 hrs	
3	Cost to assemble @ £36.25	£12,506.25	
4	P1 total cost	£89,409.69	
Cycle Three - Post modification Machine			
1	Cost of all parts	£57,108.56	(Saving £19794.88)
2	Time to assemble	320 hrs	(Saving 25 hrs)
3	Cost to assemble @ £36.25	£11,600.00	(Saving £906.25)
4	P2 total cost	£68,708.56	
Time savings Per Machine = 25 hrs			
Cost savings Per Machine = £20701.13			
Percentage Time saving = 7.25%			
Percentage Cost saving =23.15%			

Table 13 shows the production efficiency improvements if procurement were to purchase only one of each of the manufactured components. Table 14 above shows the results if procurement were to purchase two of each of the manufactured components and capitalise on the reduced costs that can be seen from procuring parts in larger quantities. Appendix 7.9 shows the results of this enquiry and how the 24.59% reduction was calculated. Incorporating this cost-saving into the results significantly impacted the cost savings. This change did not impact the time to assemble the three modules, but the cost to procure the three modules was reduced by 25.7% when compared to the original modules. To avoid potential bias by the researcher, the data was independently verified to confirm the accuracy of the findings. The engineering manager undertook this verification within the case study company, who had no specific allegiance to the research and should therefore remain objective. This real-life example shows the potential savings of utilising modularisation in the design of HVLVHV machinery products.

These savings were viable because procurement had confidence that the same module would be used multiple times. Therefore, it allowed them the opportunity to buy larger quantities of the parts that make up the module. Modularisation of the machine involved breaking the product down into smaller, interchangeable components. Additionally, these modules were designed to enable them to be assembled off the machine, which also improved the efficiency of the assembly during the build phase. Designing the modules to enable them to be assembled off the machine also opened the opportunity to pre-assemble modules to keep them in stock.

A procedure was developed that captured the process for developing the modules, and the procedure was then incorporated into the framework. Incorporating the procedure into the framework ensures the production efficiency tool is captured for implementation on future machines. This work was undertaken during cycle three, and the framework developed see Appendix 7.4 is the output framework from this cycle and, ultimately, this research.

Efficiency improvement proposition 3: Utilising a modular design approach will improve production efficiencies in the design of HVLVHV machinery products.

The biggest change for cycle three in comparison to the other cycles was the development of the standardisation team. Collaborating with cross-functional teams proved to be extremely successful and played a significant part in the success of this cycle. The researcher had not foreseen significant additional benefits to this collaboration. Firstly, it expanded the discussions as there was a broader knowledge base and skill set than that of a single department. Culturally, it was beneficial as it gave the team greater exposure to the business contributions of other departments. Before this collaboration, some team members had very little exposure to other departments and how they function, so this collaboration was very rewarding. Additionally, this transparency aided in breaking down some of the silos that had existed historically.

The team comprised personnel who appeared to have a genuine desire for the efficiency improvement initiative to be successful. Working with personnel who have a genuine desire for the success of the initiative was extremely rewarding. A contributing factor to this was that each team member had a specific role, which was clearly defined. This gave the project coordinator the appropriate focus for each team member (Allen., et al., 2014). Therefore, each team member could contribute to the team's long-term vision and deliver the project outcomes. Additionally, as each member of the team had clear roles and responsibilities, the team felt a sense of unity, and this avoided confusion and conflict.

Collaboration is one of the fundamental learning points from undertaking this work. Although it sounds simplistic, it is, in fact, complicated and even more complex to implement and sustain. The work of Ackoff (1994) explains the fundamentals in that a system's performance depends on the performance of its parts. Although, important, if not the most important, aspect of a part's performance though is how it interacts with other parts to affect the system's overall performance. If we consider an organisation as a system and the departments as parts, the interaction of the departments impacts the performance, not the individual parts. For discussion purposes if we consider the Mechanical Design team at the case study company. If this team were to design a world-leading state-of-the-art FWM in isolation without input from other departments. From a sales perspective, is this what the market wants? Are sales now in a position where they are trying to push a product to market? From a procurement perspective, is the machine now extremely expensive to manufacture and are the materials expensive? Also, can it be manufactured? From a production perspective, is it possible to assemble the machine? Does it take considerably more time to assemble now than it did previously? It is key to get input from all departments that touch the machine during its lifecycle. This communication is critical to the success of production efficiency improvement programs in HVLVHV machinery products.

Feedback is another factor that is often overlooked, and this is also key to enabling the implementation of the framework for production efficiency improvements. When developing the framework, an efficient feedback loop needs to be incorporated to capture any improvements in both product and process. This feedback is captured in the framework in a procedure (SOP072) that forms part of the design office and shop floor's internal procedure. This procedure facilitates feedback to the design office concerning drawing errors (red line drawings) or opportunities for improvements to a design. In the previous paragraph, collaboration was discussed in terms of the organisation. Due to the modularisation of the product, interdepartmental collaboration is also critical. As the Mechanical Design Engineers will be working on modules, it is easy for them to overlook a facet of its interaction with other modules in the product. Therefore, interdepartmental collaboration needs to be facilitated in the process.

Efficiency improvement proposition 4: Fostering collaboration will improve production efficiencies in the mechanical design of HVLVHV machinery products.

Standardise the machine modules before implementing changes

Standardising the product first created a baseline prior to implementing the changes. This was important due to the number of changes and potential variations between modules. Therefore, once the modules used for each machine had been listed from the ten-year period selected, the General Arrangement (GA) drawings were listed for each module. Prior to the rationalisation of the legacy data, there were 175 GA drawings for the Piston Rod machines and 213 GA drawings for the Drill Pipe machines. This highlighted how little consideration had been given to standardisation in the past, as there should be one GA per module, equating to 30 GAs per variant of the machine. Having a significant number of drawings that are not required is inefficient and exposes the case study company to quality issues as they risk errors being made and also duplicated. If a single drawing per module exists and an error is rectified, then the error is resolved. Should the error exist on several drawings then each of the individual drawings needs to be rectified before the issue is resolved.

The primary driving factor for the standardisation of commonly used modules was reducing the cost of producing the RFW machine. Therefore, when generating the modules, consideration was required as all modules that are incorporated into the base machine add cost to this machine. This is because additional features are required on modules to enable other modules to be added to them or for interchangeability. A base module, for example, may require additional holes to bolt a bracket module to the side. If this bracket module isn't included in the standard modules but the end product still achieves the customer's desired objectives, then the holes in the base module can be removed. This, therefore, reduces the cost of producing the base module as fewer machined features are required. This example explains why the number of modules had to be reduced to the minimum whilst still achieving the customer’s desired specifications. However, there were several additional benefits to the standardisation of commonly used modules besides cost reduction.

Standardisation of the modules reduced the lead time of machine orders in the case study company. As the modules of the TFW3 machine had now been standardised, during a quiet period, the TFW management team decided to build and stock several of the larger modules that make up the machine. The machine selected for the build-to-stock modules was based on a machine order that the Head of the Business Unit for AWS was confident that they would receive. Having this machine in stock when the order was finally received reduced the procurement phase significantly, as the majority of the long lead machine modules had been manufactured and assembled. Additionally, as the procurement team knew that the same module would be used multiple times, it gave them the option to buy larger quantities of the parts that they put into stock, thus reducing the cost of the modules further. The real-life quantitative example shown earlier in this section evidenced the savings that were seen by utilising modularisation in the design of HVLVHV machinery products.

Additionally, for cycle three, the new standard modules utilised three-dimensional (3D) models in their design, whereas the previous drawings the case study company issued to suppliers didn’t incorporate design automation tools. Utilising the 3D CAD and other design automation tools was found to increase production efficiency. An example that became apparent during this cycle was having the ability to use the original part design three-dimensional (3D) computer-aided design (CAD) for the Finite Element Analysis (FEA). This CAD data was proven to be fit for purpose as it is proven by being used in service; therefore, it sets an ideal standard before any modifications are implemented. Therefore, starting with this standard design gave the Design Engineer a proven design and a basis for deflection and stress comparison, among other requirements. Utilising 3D CAD models allowed for FEA methods to be used. Finite element models reduced the number of expensive and time-consuming physical experiments required, which is a significant advantage of using design automation tools (Mahendran, 2007).

The purchasing manager also explained how these models benefited the suppliers and reduced the cost of manufacturing the parts for the chosen modules. Utilising these 3D models gave the suppliers additional options in how they can manufacture the parts. Utilising models gave the supplier the option of loading the CAD model directly into their CNC machines, or they had the option to use offline programming software to interrogate the CAD data and generate an offline CNC program for manufacturing the part. This reduced the manufacturing time, making the CNC machine much quicker to program than manually inputting the data from the two-dimensional CAD drawing. Driving innovation up the supply chain and involving suppliers benefits both parties. The suppliers can assist with design innovations but additionally improving suppliers' manufacturing efficiencies should reduce the cost for TFW for procuring the part the supplier is manufacturing. Utilising innovation and design automation tools also leads to a more resilient and sustainable supply chain.

Incorporating 3D models into the process also made the inspection of parts quicker as the parts could be inspected in comparison to the model rather than a drawing, which is a faster process. Manufacturing the models from CAD data is also better in terms of quality. There is significantly less chance of making a mistake due to the operator not having to interpret a drawing and manually input the data. Proving this theory will be captured in further work as there was insufficient data to prove this during the duration of the research, but it’s a logical consequence of removing the potential for human error.

In conclusion, modularisation of the machine involved breaking the product down into smaller, interchangeable components. These modules were assembled off the machine, which further improved the build efficiency. A modular design approach was verified to improve production efficiencies in the design of HVLVHV machinery products, and therefore, it was incorporated into the framework.

Efficiency improvement proposition 5: Using design automation tools will improve efficiencies in the mechanical design of HVLVHV machinery products.

Develop a design specification

For cycle three, a design specification was generated as this was fundamental to preventing the delays that were seen during cycle two from happening. It is complex to quantify the efficiency gains achieved from generating this document, but the Engineering team would not have been able to progress without it. The specification didn’t change in the latter stages of the project as was seen during cycle two due to having this clearly defined specification at the outset. The process followed for defining this specification is captured in Appendix 7.15 and the work instruction WI266.

Reflections

The following sections utilise reflection to question what steps were undertaken and whether there is a better, more efficient way of doing them. It also aids the researchers' learning as it challenges the researcher's assumptions of professional knowledge and their own response to the situations that arose during this cycle. It utilises the PDCA cycle to give a consistent approach to the research problem and aid reflection, as shown in the section below.

Cycle 3 – Framework

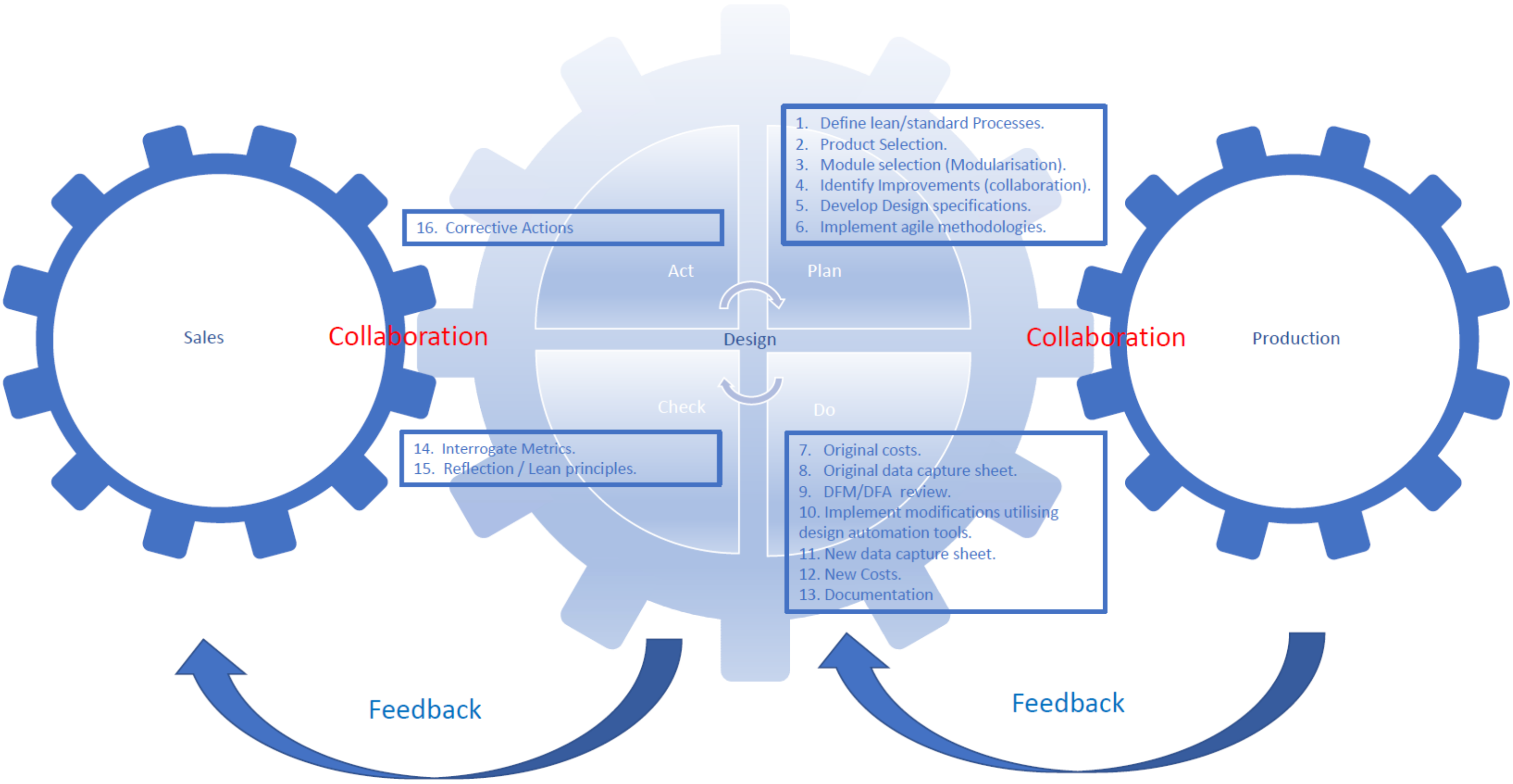

Figure 15, HVLVHV design process efficiency model

Figure 15 shows the HVLVHV design process efficiency model of the work undertaken for cycle three of the research, this being the TFW3 range of machines. This cycle proved to be a success, and several primary learning points were taken from this cycle into the final conceptual model.

The primary factor that differentiates this cycle from the others is the adoption of a more refined framework with standard processes that the mechanical engineering team worked to. However, the framework still evolved through this final cycle as knowledge was attained from undertaking the cycle. Adopting a clear process at the start where wasteful steps had been removed saved significant rework that previous cycles had come up against. Having a clearly defined framework that incorporated iterative design reviews proved significantly more efficient, and at no point did designs have to be totally redesigned from scratch as in previous cycles. This was due to the iterative process of capturing changes as the designs developed.

Lean design principles, which focused on minimising waste in the design process, were utilised in developing the framework. Several techniques were used, including DFA & DFM reviews, mapping the design process, reducing unnecessary steps in the design process, and undertaking a value stream map of the production process. A further way to remove waste in the design process was to optimise the use of resources. This was evidenced by the formation of the standardisation team and the acceleration in progress of cycle three in comparison to other cycles. Finally, reflection and identifying areas of improvement in the organisation's culture were fundamental to the successful implementation of the production efficiency improvement tools.

Another factor that caused several issues in cycle two and made designing the product difficult due to the lack of information was the need for a clearly defined specification. For cycle three, a clear specification was generated before any design work took place, making the design process far more efficient. This was made far easier due to the modularisation of the design, as a mini specification could be developed for each of the modules. This was all intertwined with the implementation of agile methods for this cycle. Agile methods became clear later in the research and therefore were not included in the literature review.

Agile methodologies break down the design into smaller manageable tasks and incorporate a sequence of iterations in the design process (Feldhusen, Lower and Bungert, 2009). Due to the design's modularisation and the standardisation team's formation, this tool aligned itself with this cycle to a high level. Microsoft Project was utilised to manage the tasks, timing of the project and resource allocation. Figure 16 below shows an example of the task breakdown in Microsoft Project for a single module of the machine. However, this same methodology was utilised for all modules on the machine.

Task Name	
FIXED POSITION ROLLER STEADY FOR AUTOMATIC BACKSTOP - TFW3-A08M-200	**Personnel**
TFW3-A08M-200 - Modelling	Lead Design Engineer
TFW3-A08M-200 - Design Review Engineering	Lead Design Engineer / Apprentice Design Engineer / Design Engineers
TFW3-A08M-200 - Detail Design	Apprentice Design Engineer
TFW3-A08M-200 - Design Review Production	Lead Design Engineer / Apprentice Design Engineer / Purchasing Manager / Shop Floor Supervisor
TFW3-A08M-200 - Design Review Manufacturing	Lead Design Engineer / Apprentice Design Engineer / Manufacturing Engineer
TFW3-A08M-200 - Backmods 1	Apprentice Design Engineer
TFW3-A08M-200 - Check	Manufacturing Engineer
TFW3-A08M-200 - Backmods 2	Apprentice Design Engineer

Figure 16, Example agile methodologies incorporation

Using agile methodologies improved the design process efficiency and reduced the risk of errors. The Lead Design Engineer utilised design automation tools to generate a design. A review was then held with members of the design engineering team to check the design was suitable. The Apprentice Design Engineer was present for this review so that they gained insight into the module and the design process, as well as sourcing knowledge from other, more experienced engineers. Once the model had been updated to incorporate any changes by the Lead Design Engineer, the Apprentice Design Engineer was tasked with generating the drawings. They generated drawings from the three-dimensional computer-aided design that the Lead Engineer had generated. Generating the drawings once the model had been reviewed was far more efficient as it meant that changes only had to be incorporated into the model rather than the model and the drawings. Utilising the Apprentice Design Engineer for this task gave them significant exposure to the design process and the drawing standards that they should adhere to, and this was a significant learning opportunity. This also freed up the Lead Design Engineer to start generating the next module, further improving efficiency in the design process.

Incorporating agile methodologies into the project plan helped to prioritise and structure the modules. Utilising this methodology allowed for incremental development of the module as it transitioned through the various reviews. This was found to simplify the project's structuring and allowed for more efficient work distribution and maintenance. It was apparent that incorporating this methodology reduced errors, as rather than just addressing a module, it was split into numerous subtasks, so there was a reduced probability of missing design errors. This also increased the efficiency of cycle three as it allowed for the work to be scheduled so the team had a constant flow of work.

As mentioned previously, once the drawings had been generated, two reviews were held to check the module and see if it could be improved in terms of DFA and DFM. The drawings were shared in advance of the meeting so that any comments could be added to the drawings. This meant that when the meeting took place, it was undertaken as efficiently as possible. The catalyst for this was the high cost of having significant numbers of staff in a meeting at once and utilising this structure for the meetings worked effectively. The proposed changes to the module were discussed and agreed upon during the review. The researcher was also present during the reviews so that they could make a final decision on any points that were being debated. This was important as it meant that when everyone left the meeting, there was a clear and final decision on what changes would be incorporated into the module. Having a clear and open discussion on any proposed changes during these meetings with cross-functional departments meant that it was very easy for the researcher to make these decisions and at no point was there conflict. This was also helped as all members of the team appeared to have a genuine desire for the initiative to succeed, and they, therefore, understood that decisions had to be made to move the project forward.

Any changes were then incorporated into the design before the drawings were updated, and they then went for checking. This check was undertaken by the manufacturing engineer, as he has many years of experience assembling machines. As seen from the above, three reviews are undertaken in total, and there is a detailed checking stage. Breaking the process down into manageable tasks with a dedicated resource improved efficiency in the process and reduced the risk of errors. This could potentially be evidenced by the reduction in the number of errors reaching the shop floor. Proving this theory will be captured in further work.

Although this is the final cycle of the research, the production efficiency improvements should be sustained in the case study company as the framework generated now forms the process for how the mechanical design engineering team works. Additionally, due to the feedback loops within the framework, the researcher believes that the case study company will continually improve. Proving this theory will be captured in further work.

Implementing continuous improvement programs relies on a cultural change in the organization. For organizational change to be a success, it cannot be rushed and takes time. Kotter (1996) recommends an eight-step model for organizational change that aims to establish employee commitment and reduce scepticism. For the production efficiency improvement program to continue, it relies on management's total commitment to the cause. Continuously improving is a fundamental principle of both lean and agile methodologies. By continuously reviewing the design process and capturing potential improvements with the feedback loops, the case study company can achieve further production efficiency gains. This should be a team activity, and again, communication is key. Although the key personnel are the individuals who work in the design process, engagement should be with all personnel within the business, and they should be encouraged to communicate any potential ideas that can improve production efficiency. This openness to improvement should be embedded in both the departmental and organisational culture, and it's the role of senior management to enforce this.

Efficiency improvement proposition 6: Embedding continuous improvement in organisational culture will improve production efficiencies in the mechanical design of HVLVHV machinery products.

This section discussed the production efficiency improvements that have been incorporated into the framework during cycle three. The framework that is the output from cycle three is the concluding framework of the research. Although the framework is concluded, by continuously reviewing the design process and capturing potential improvements with the feedback loops, further production efficiency gains can be achieved in the case study company. The following section discusses the ethical considerations that were contemplated whilst undertaking the research.

4.2 Ethical Considerations

The following section discusses the ethical challenges considered whilst undertaking action research. The key ethical challenges of undertaking action research are discussed, and consideration is given to how they were addressed. The ethical side of undertaking this research was essential and highly complex. The complexity was enforced by the researcher undertaking action research whilst being employed as a practitioner within the case study company. The benefit to this research of being employed as a practitioner within the case study company is greater access than would be given to an individual who was an outside researcher. This greater access allows the researcher, as an actual member of the organisation, to make a more impactful contribution due to insider knowledge about the organisation and its culture and the challenges of implementing change. The disadvantage to undertaking action research as a practitioner within the case study company is the challenge of maintaining an objective stance and remaining detached.

Analysis of undertaking action research whilst being employed as a practitioner within the case study company highlighted several areas that required careful deliberation. Firstly, how does the researcher guarantee a research participant's anonymity? Secondly, how does the researcher get valid consent from a research participant? Finally, how does the researcher avoid political consequences for the researcher or any participants of the research (Coghlan & Brannick, 2005)?

The case study company is a medium-sized company, and confirmation from key stakeholders has explained that what could be considered private or sensitive information appears to rapidly pass among personnel throughout the company. This is relevant as any participants in the research would potentially be known to have participated, and therefore, their anonymity could not be guaranteed. This led to the researcher having to ensure that any views or opinions remained anonymous. This was a requirement for both the researcher and participants, as voicing opinions in the public domain could have potential consequences. This issue was addressed by anonymising any views or opinions expressed. Additionally, utilising an academic writing style aided in overcoming this issue, as having a logical progression of ideas and a strong argument should lead the reader to draw the same conclusion as the researcher presented in the writing.

The researcher was responsible for gaining consent from the employer and the individual employees before undertaking research involving participants. Details of the research are provided verbally and on a participation information sheet. Emphasis is given to the employees that participation is voluntary. Participants are then given a minimum of seven days to decide if they wish to participate. It is clearly emphasised verbally and in writing that if they choose not to participate or withdraw, it will have no bearing on the researcher and the participant professionally and will have absolutely no impact on their employment. A consent form is provided to sign, enabling the participant to make an informed decision on whether they wish to engage in the research. All participants can read English and have no communication issues; therefore, there are no issues concerning communication problems. There is a potential issue that due to the progressive cycles being used, there is potential for the research to develop to the point that the consent forms are no longer valid. This could potentially result in any consent form that a participant filled in requiring additional validation. This issue is overcome by writing additional data on the consent form that covers such eventualities as the research changing focus and the participant's rights and requisites.

Brydon-Miller (2008) states that before a researcher starts the research process, they should have a clear idea of their core values and how they may impact participants. Considering this before starting the research will help the researcher respond to ethical challenges in a conduct aligned with the researcher's core values, as well as allow them to re-examine these values.

Additionally, it is acknowledged that the research philosophy deemed most appropriate for undertaking this work is a Pragmatic approach. Undertaking the research philosophy section highlighted to the researcher the importance of maintaining an objective stance in this research and remaining detached. This could have been challenging as the researcher works in the company where the study took place. Due to the anticipated challenges, the strategy for sustaining an objective approach was to mainly utilise quantitative data and pre-defined metrics.

To avoid potential bias by the researcher, the data was independently verified to confirm the accuracy of the findings. The engineering manager undertook this verification within the case study company, which had no specific allegiance to the research and, therefore, should remain objective. Additionally, support was sought from the supervisory team to ensure that the researcher remained objective and wasn't influenced by any personal bias. In conclusion, it was the intention to publish the findings regardless of the outcome as it would add value to the knowledge currently existing on improving production efficiencies in the mechanical design of HVLVHV machinery products, and therefore, it was the intention to maintain transparency throughout the research process.

In conclusion, before undertaking this research, the Birmingham City University Academic Ethics Committee granted the necessary ethical clearance. Prior to engaging with any participants, they were given details of the research verbally and on a participation information sheet, see Appendix 7.10. Additionally, a signed copy of the participation consent form was required prior to any research being undertaken involving the participant (see Appendix 7.11). The researcher utilised reflection to assist in remaining professional throughout, maintaining an objective stance and remaining detached whilst recognising the challenges of this as a practitioner within the case study company.

4.3 Conclusions and Recommendations

The purpose of this research is to develop a framework to assist companies in improving production efficiencies in the mechanical design of HVLVHV machinery products. The following section details the conclusions and recommendations for the three cycles investigated whilst developing the framework.

4.3.1 Conclusions and Recommendations Cycle One

The purpose of cycle one was to test several tools for improving production efficiencies in the mechanical design phase of the product lifecycle that were found whilst undertaking the literature review. This cycle verified which tools were appropriate for implementation into the framework. It also served to select appropriate data collection methods and determine the criteria for success. For cycle one, the tools were implemented on a single module of the machine.

Although it isn't implemented into the framework, as it isn't specifically a tool for improving efficiency, the VSM was invaluable for collecting data. Therefore, prior to implementing the framework, it is a worthwhile exercise to undertake this process. Once generated, the VSM shows the sequence of all operations in the order in which they are performed and includes inspections, time allowances and materials used in the business process – from the arrival of raw material to the final product (Yerasi, 2011). Undertaking this process baselines the current process and highlights processes with waste that are causing delays. Having this knowledge in advance of implementing the framework gives focus to specific areas of the business where accelerated results can be achieved. Having the potential accelerated results identified in terms of efficiency improvements helps foster engagement as it gives the management team tangible benefits to undertaking the work. An additional benefit of the graphical representation of the process is that it is an excellent tool for stimulating conversation and getting the management team engaged in the project in this early phase.

During this research, the importance of communication and its significance in terms of aiding engagement has been mentioned many times. During cycle one, the researcher missed the opportunity for the MD to discuss the project in detail at the town hall meeting. Had the MD discussed the project in detail, it would have had a significant impact as the MD was presenting, and this would have potentially gained additional support for the project. A further benefit that would have been observed is the avoidance of confusion with the shop floor personnel not truly understanding the plan and when the improvements would be implemented. Having a clear communication plan in advance of implementing the framework would be extremely beneficial and avoid the issues that arose during cycle one.

During cycle three, a standardisation team was developed, and this played a significant part in the success of that cycle. This is the preferred approach to implementing the framework, which is to have a dedicated team who clearly understands the intricacies of the project. This will be expanded on in cycle threes, conclusions, and recommendations; see section 4.3.3. Regardless of the standardisation team, when implementing the framework, its success is intertwined with successful communication and sustaining engagement with stakeholders in the project. As highlighted by Kumar et al., (2014), unless communication is considered, it can lead to anxiety in workers, and a lack of awareness of the purpose of the change can even result in resistance to change (Lodgaard et al. 2016). Therefore, successful communication and sustaining communication with key stakeholders when implementing the framework is extremely important, and this should sustain engagement.

Cycle one proved that adopting the Lean design principles of DRA and DFM reviews and the process and methodology for capturing the results are sound. The process for capturing the data involved utilising the quantitative data from the company's ERP software and the data capture sheets. Therefore, this production efficiency tool was implemented in the framework and is captured in the Tollgates 3.3 & 3.4. This tool formed the first of the efficiency improvement propositions that are incorporated into the framework.

Efficiency improvement proposition 1: Adopting Lean design principles will improve production efficiencies in the mechanical design of HVLVHV machinery products.

When developing the framework for cycle one, it was found that by standardising the processes and work instructions that underpin the framework, unnecessary steps were eliminated, and the process was optimised for efficiency. Although this work has been done for the framework, it can be foreseen that should a company want to implement this framework for their products, they would have additional processes or work instructions specific to their organisation that would require generating. Creating new procedures and work instructions for subroutines in their design process should be streamlined, and waste should be removed before integrating them into the framework. Due to this production efficiency tool being proven during cycle one, it was implemented into the framework. This tool formed the second of the efficiency improvement propositions that are incorporated into the framework.

Efficiency improvement proposition 2: Standardising the mechanical design process will improve production efficiencies in the mechanical design of HVLVHV machinery products.

4.3.2 Conclusions and Recommendations Cycle 2

The purpose of cycle two was to test the framework developed in cycle one on a complete machine. Due to limitations in time and resources, the head module (402-A), the base module (403-A) and the clamp module (408-A) were utilised for the investigation. This verified that the framework developed in the cycle was appropriate for implementation on a complete machine and was effective in improving efficiency in the mechanical design of HVLVHV machinery products.

The first primary learning point discovered during cycle two was a clearly defined specification requirement. The lack of a clear specification for cycle two caused several issues and made designing the product difficult due to the lack of information. Therefore, this document is incorporated into the framework as F224. Should a company want to implement this framework for their products, they should generate this document before undertaking any work defined in the framework. As seen in the framework, the specification document F224 is generated before the team responsible for delivery is involved in the project. Generally, this document is generated by the sales team with input from the customer and various personnel within the case study company. Therefore, although this document is necessary, there can still be ambiguity, and an additional document is required to resolve this.

Due to the reasons outlined, a “Design Brief” document F413 is incorporated into the framework. This document contains additional, more detailed information than a traditional specification. Generating this document gives the engineering team responsible for delivering the product a chance to familiarise themselves with the project and check that they have sufficient information to undertake the project. Should a company choose to implement the framework in their organisation, then the researcher should highlight the importance of this document. Capturing any issues at this early stage in the project can prevent significant costs or delays in the latter stages of the project.

During cycle two, the product specification was defined by the customers' requirements rather than the general market requirements. It is recognised that the product must meet the customers' requirements, but focusing on a single customer can limit the spectrum of customer's products that a potential module can be appropriate for. For example, if a customer wants to weld a range of components between ten and fifty millimetres in diameter, a module should be designed specifically for these diameters. If the general market requirements demand a range of components between ten and sixty millimetres, then the module isn't appropriate for the general market. Therefore, when generating specifications for standard modules, the general market requirements need to be considered rather than specific customers, as this maximises the potential for each module. Consideration does need to be given to rare or extreme customer requirements, though it may be more beneficial to make a special module for these customer requirements rather than incorporating these requirements into the standard module and, therefore, adding additional cost to it.

During cycle two, attempts were made to engage with other departments in relation to the standard documentation; much of this communication was via email. This was predominantly a result of COVID-19 and homeworking, but it should be acknowledged that there are better forms of communication for implementing this type of change. Should a company choose to implement the framework in their organisation, they should consider communication and the best format for the message they are conveying. Ensuring the correct form and frequency of communication are utilised should ensure engagement and increase the likelihood of buy-in, therefore preventing the delays seen in the case study company.

During section 4.1.2, it was discussed how the original intention for the cycle two machine was for it to comprise a new standard modular design and this be a new machine. Due to COVID-19, product development was stopped, and this machine's specification was driven by a specific customer's order, as described earlier in this section. The impact of this is that rather than the product development team working in isolation on development machines, they worked on live orders. Additionally, the format of product development was changed, and rather than having a dedicated team for product development, the work would be used to fill quiet periods in the design office for all Mechanical Design Engineers. Therefore, if an engineer was running low on work, they would pick up some of the product development work.

The intention of the case study company when making this decision was explained as wanting to accelerate product development. The idea of having a greater number of resources available to work on product development sounds positive in principle. The reality was somewhat different, and product development stalled between cycle two and the standardisation team being developed. The potential additional engineers were busy with live orders, so there was no capacity to undertake product development. Additionally, when engineers did pick up tasks, they weren't familiar with the process and generally worked on that section in isolation. This went against the modular concept the business aspired to, where the modules could be fitted to differing machines and were interchangeable. This made the case study company vulnerable to potential errors that could have been costly. This is an inefficient way of working, and should a company choose to implement the framework in their organisation, then the researcher would recommend utilising a dedicated team, as was seen in cycle three. It is acknowledged that there is a cost to having a dedicated resource, but from the work undertaken in the case study company, the savings achieved by the work are far greater than the cost of the resource, and therefore, the team pays for itself.

Finally, it was decided that for cycle three, the order of development would be to standardise the machine and then implement any changes or suggested improvements. Standardising the product first creates a baseline prior to implementing the changes. This was important due to the number of changes and potential variations between modules. This process is incorporated into the framework and captured in WI266.

4.3.3 Conclusions and Recommendations Cycle 3

The purpose of cycle three was to verify the transferability of the framework onto a different machine type. Undertaking this cycle verified the transferability of the framework and its appropriateness for implementation on a completely different machine type. Additionally, it further verified its effectiveness in improving efficiency in the mechanical design of HVLVHV machinery products.

During cycle three, the true benefits of modularisation in terms of cost savings were highlighted. These savings were viable because procurement had confidence that the same module would be used multiple times. This confidence allowed them the opportunity to buy larger quantities of the parts that make up the module. Modularisation of the machine involved breaking the product down into smaller, interchangeable components. Additionally, these modules were designed to enable them to be assembled off the machine, further improving the efficiency of the build phase. Designing the modules to enable them to be assembled off the machine also opened the opportunity to pre-assemble modules to keep them in stock. This reduces the lead time further as assemblies can be pulled from stock rather than built to order.

Should a company wish to implement the framework and achieve the efficiency improvements seen in the case study company, incorporating a modular design into their product is a requirement. The procedure for generating the modules is captured in the framework; see WI266.

Efficiency improvement proposition 3: Utilising a modular design approach will improve production efficiencies in the design of HVLVHV machinery products.

The biggest change for cycle three in comparison to the other cycles was the development of the standardisation team. Having this dedicated cross-functional team was transformative to the project in terms of accelerating the progress. Additionally, as discussed previously, collaborating with cross-functional teams led to a wealth of additional benefits unforeseen by the researcher, including but not limited to organisation culture and having access to a broader knowledge base and skill set than that of a single department. A feedback loop was also incorporated into the framework for production efficiency improvements for cycle three. Should a company wish to implement the framework, having a dedicated cross-functional team has been proven to be the most effective way of achieving efficiency improvements.

Efficiency improvement proposition 4: Fostering collaboration will improve production efficiencies in the mechanical design of HVLVHV machinery products.

During cycle three, the case study company maximised the use of design automation tools to improve efficiencies. Firstly, the new standard modules utilise three-dimensional (3D) models in their design. This opened the opportunity for further tools to be utilised, including FEA software, the ability for suppliers to load the CAD model directly into their CNC machines and then inspect the manufactured part to the CAD model. Using these design automation tools improved the efficiency of the production process, and therefore, should a company wish to implement the framework in their organisation, then they should also maximise the use of design automation tools where possible.

Efficiency improvement proposition 5: Using design automation tools will improve efficiencies in the mechanical design of HVLVHV machinery products.

One of the biggest challenges faced by any organisation looking to achieve production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products is sustaining the change. From the work undertaken, implementing this framework has been proven to improve efficiencies, but sustaining the change relies on a cultural change in the organization. Cultural change needs to be driven by senior management, which needs to embody the desired culture through its actions and communications. Should a company wish to implement the framework, then senior management needs to engage and drive sustained change. Once the framework has been implemented, continuously reviewing the design process, and capturing potential improvements with the feedback loops will assist in achieving further production efficiencies. However, the openness to improvement needs to be embedded in both the departmental and organisational culture, and senior management’s role is to enforce this and drive sustained change.

Efficiency improvement proposition 6: Embedding continuous improvement in organisational culture will improve production efficiencies in the mechanical design of HVLVHV machinery products.

5. Conclusion

This research aimed to qualify if production efficiencies can be achieved during the mechanical design phase when dealing with HVLVHV machinery products. This aim was aligned with several key objectives to assist in the investigation.

- Objective 1 - Undertake research to verify existing tools appropriate for improving production efficiencies in the mechanical design phase of HVLVHV machinery products.
- Objective 2 - Develop a standard process for the mechanical design of HVLVHV machinery products.
- Objective 3 - Develop action research cycles to verify appropriate tools for improving production efficiencies in the mechanical design phase of HVLVHV machinery products.
- Objective 4 - Develop a framework for improving production efficiency in the mechanical design phase of HVLVHV machinery products.
- Objective 5 - Confirm the transferability of the framework for improving production efficiency in the mechanical design phase of HVLVHV machinery products.

The research was conducted with three distinct work packages that form part of the research plan, and these are defined in Figure 7. The research question and the objectives defined drove these work packages.

<u>Objective 1 - Undertake research to verify existing tools appropriate for improving production efficiencies in the mechanical design phase of HVLVHV machinery products</u>

Research objective one was achieved during cycle one of the research projects. A systematic literature review was undertaken, and several tools were identified and thus implemented into the framework for verification. The tools revealed by the literature review included DFM & DFA reviews, product, and process development, PDCA, standard modules, the UWES questionnaire, and finally utilising lean design principles. Of all the tools captured in the systematic literature review, all were incorporated into the final framework besides the UWES questionnaire. Although the questionnaire and process of measuring employee engagement were found to be valuable tools, the impact on this specific research compared to the work required to undertake the questionnaire and survey analysis made it impracticable for implementation into the framework.

Objective 2 - Develop a standard process for the mechanical design of HVLVHV machinery products

The original process for the mechanical design of the products within the case study company was known as the P10 document, see Appendix 7.1. This document described a process but was not underpinned by any detailed documentation describing the internal process within the mechanical design engineering department. The framework output from this research evolved through each cycle, as seen in Appendix 7.2 – 7.4. This framework is a standard process with standard documentation aligned to each element of its composition; see Appendix 7.15. Here, the documentation pertaining to the mechanical design phase between tollgate 3.1 and tollgate 5 is shown. This research objective has, therefore, been achieved, and any efficiency improvements seen are reflected in work undertaken. Additionally, the validity of the documentation and process has been proven by its application in the mechanical design engineering department within the case study company throughout the duration of this research.

Objective 3 - Develop action research cycles to verify appropriate tools for improving production efficiencies in the mechanical design phase of HVLVHV machinery products

Research objective three was applied during each cycle of the research. Additionally, this is reflected in the HVLVHV design process efficiency model section at the end of each cycle. Utilising action research cycles aligned to the PDCA model proved to be successful. Dehe, Bamford, and Kotcharin (2022) discussed that using technical tools such as Plan-Do-Check-Act (PDCA) as a consistent approach to innovation problems aid in capturing knowledge. Using this structure aided the researcher in structuring each cycle, and the primary learning points from each cycle became the actions for implementation in the next cycle.

Objective 4 - Develop a framework for improving production efficiency in the mechanical design phase of HVLVHV machinery products.

The framework developed from undertaking this research is shown in Appendix 7.4. Due to its implementation, significant improvements were seen in the production efficiency of the case study company, as discussed in section 4.1.3. Therefore, it can be concluded that the framework developed from this research is effective in improving production efficiency in the mechanical design phase of HVLVHV machinery products. Research objective four was therefore achieved, and the effectiveness of the framework was verified.

Objective 5 - Confirm the transferability of the framework for improving production efficiency in the mechanical design phase of HVLVHV machinery products

The transferability of the framework was tested during cycle three of the research. When implemented on a different product in the case study company's portfolio, significant improvements were seen in the production efficiency of that product. Therefore, it can be concluded that the framework developed from this research is transferrable and remains effective in improving production efficiency in the mechanical design phase of HVLVHV machinery products. Research objective five was therefore achieved, and the framework's transferability was verified.

Key Findings

The key findings from this research are that the framework developed from this research has proven effective in improving production efficiency in the mechanical design phase of HVLVHV machinery products. Additionally, this must be attributed to the following efficiency improvement propositions being incorporated into the framework: These included adopting lean design principles, standardising the mechanical design process, utilising a modular design approach, fostering collaboration, and using design automation tools. It was not viable to incorporate embedding continuous improvement in the organisational culture into the framework as this needs to be driven by senior management. This highlighted to the researcher that these efficiency improvement propositions need consideration in addition to the framework. Considering these efficiency improvement propositions as learning points when implementing the framework will aid organisational learning and, therefore, increase the chance of the successful production efficiency improvement program described in this research. Management should drive these efficiency improvement propositions and make them engrained in the organisational culture. These efficiency improvement propositions are additional learning points from the research undertaken and are derived from the work undertaken to develop the framework that forms the main output of this research.

Efficiency improvement proposition 1: Adopting lean design principles will improve production efficiencies in the mechanical design of HVLVHV machinery products:

Efficiency improvement proposition 2: Standardising the mechanical design process *will improve production efficiencies in the mechanical design of HVLVHV machinery products*:

Efficiency improvement proposition 3: Utilising a modular design approach will improve production efficiencies in the design of HVLVHV machinery products:

Efficiency improvement proposition 4: Fostering collaboration will improve production efficiencies in the mechanical design of HVLVHV machinery products:

Efficiency improvement proposition 5: Using design automation tools will improve efficiencies in the mechanical design of HVLVHV machinery products:

Efficiency improvement theory 6: Embedding continuous improvement in organisational culture will improve production efficiencies in the mechanical design of HVLVHV machinery products

Summary

Prior to the research commencing, the case study company was in a challenging position where it needed to make positive changes to remain competitive in an increasingly pressured market. The researcher identified that a key component to improving the company's competitive position was to focus on how profitability could be improved. This led to conducting research to test the viability of achieving production efficiency improvements during the mechanical design phase when dealing with HVLVHV machinery products.

The research commenced in 2018 through to 2024. There was turbulence within the case study company during this period and the importance of this research was apparent in terms of the appropriateness of the timing of the research. During this time the company entered a state of flux due to both internal and external factors, see pages 20 – 21 and specifically paragraph two on page 21. This included internal factors such as compulsory redundancies and a high turnover of senior leadership and also the external factors such as the Ukrainian war and the Covid-19 pandemic.

Despite these significant challenges, over the course of this research, the researcher was able to develop a framework that incorporates the efficiency improvement tools described previously. When the procurement department utilised the opportunity to procure two of the products rather than one-off as they had done previously, the cost to procure the three modules was reduced by 25.7% when compared to the original modules and the build time was reduced by 7.25%. Although further savings could be achieved by buying larger quantities, due to the low volumes of product produced per annum in HVLVHV machinery products, this is not a viable option and is therefore not included in the comparison. This real-life example shows the potential production efficiency improvements that can be seen by utilising the framework developed during the mechanical design phase for HVLVHV machinery products. Feedback from key stakeholders in the project from within the case study company has been extremely positive and is captured in Appendix 7.13 and 7.14, and this includes both the Commercial and Supply Chain Manager and the Head of Operations.

Based on these significant findings, substantial changes have been implemented in the company by the researcher. The company is now focused on its core product of friction welding machines and is seeing significant benefits from utilising standard modules. There has been a noticeable efficiency improvement in the Mechanical Design Engineering team, and they are now able to issue a machine in a week rather than the several months that it took previously. The utilisation of standard modules has therefore driven productivity improvement within this department. The utilisation of standard modules has also driven productivity improvement within the build process as the fitters who assemble the modules are assembling the same modules and therefore learning the most efficient assembly method. The case study company is also seeing significant cost savings due to the procurement team having the confidence to purchase bulk quantities of parts. This has led to the case study company now being in a position where the machine price and lead time are reduced to being close to that of its direct competitors. The overall effect of this is that the outcome of the implantation of the researcher's work has enabled TFW to remain competitive as a company.

5.1 Contributions to theory & practice

The following sections discuss the contributions of this research and are split into two areas: contribution to theory and contribution to practice.

Contribution to theory:

The key contribution of this research for theory is the development of a framework for improving production efficiencies in the mechanical design phase of HVLVHV machinery products. It builds upon existing research and gives a new concept for application in terms of the framework. The framework's effectiveness is proven by being applied in an industrial application and therefore verifies the tool's effectiveness, which was incorporated from existing academic literature found during the literature review. Additionally, there is a contribution to knowledge as the tools have been applied, and this reinforces the established effects in a new environment. The framework is proven in the case study company and, therefore, offers the opportunity for other researchers to undertake further work and test the validity of the framework in other companies that manufacture HVLVHV machinery products.

Additionally, when undertaking the systematic literature review, although it revealed some very interesting literature, the results indicated what appears to be a gap in the literature. The literature review focused on the specific keywords “Manufacturing”, “Design”, “Efficiency”, and “Jobbing shop” or “HVLVHV” or “Bespoke” as the filter to limit it to documents containing these words. None of the papers reviewed discussed improving production efficiency during the mechanical design phase of HVLVHV machinery products. Additionally, none of the papers covered mechanical design, as they were more focused towards clothing manufacturing and construction. As the results from the literature review indicated a lack of data on the research subject it identifies that this research is relevant both in terms of time but also importance. This is an opportunity to contribute to what appears to be a gap in the literature on increasing production efficiency during the mechanical design phase of HVLVHV machinery products.

This research has also extended the application of Modularisation by applying Modularisation theory to improve production efficiencies in the mechanical design phase of the product lifecycle of HVLVHV machinery products. Historically, most of the research undertaken on Modularisation has focused on areas with high production volumes with much of the research being focused on the construction sector. This research has highlighted the value of Modularisation when implemented into lower volume production during the design phase and, therefore, has extended the theory on this efficiency improvement tool. Utilising modularisation gives a manufacturer the ability to fulfil the customer's needs with interchangeable modules but at a lower cost than bespoke machines.

A further contribution to theory is the identification of the efficiency improvement propositions. Five of the propositions were verified through application in the framework, which is a contribution to theory. Verifying the proposition of embedding continuous improvement in the organisational culture was not viable as this needed to be driven by senior management. As well as the verification of the propositions the identification of them is a contribution theory as they are additional learning points that can be tested outside of the framework.

Contribution to practice:

The environment that this research focuses on, this being the manufacture of HVLVHV machinery products, is a very niche area. The results from the literature review indicate that there appears to be a gap in the academic literature. This leaves very little supporting data for a company wishing to improve production efficiency during the mechanical design phase of HVLVHV machinery products. The results from this research indicate that the case study company achieved time, cost, and quality improvements by implementing the framework developed.

These improvements can be attributed to the identification and implementation of the efficiency improvement propositions. Although five of the propositions were verified through application in the framework, it was not viable to incorporate embedding continuous improvement in the organisational culture into the framework as this needs to be driven by senior management. The researcher believes that these efficiency improvement propositions need consideration in addition to the framework. The identification of these propositions is a contribution as they are additional learning points when implementing the framework. Additionally, considering them, they aid organisational learning and increase the chance of the production efficiency improvement program described in this research being successful.

As the case study company is ISO 9001 certified, the processes that underpin the framework are aligned to achieving certification. Therefore, should a company choose to implement the framework and follow the underlying processes, it would assist in achieving ISO 9001 certification and passing an audit. However, it must be understood that the standards are not business improvement tools to drive change and improve organisational performance. The processes developed by this research are different in that they assist a company in achieving adherence to the ISO 9001 standard for the Mechanical Engineering Design function of their business. The byproduct is that they improve production efficiencies in the Design of HVLVHV machinery products.

Therefore, the main contribution to practice is the sharing of a fit-for-purpose Strategic Design Management framework integrated into the business management system. The framework operates at a level equivalent to achieving ISO 9001 certification and the results indicate the framework is effective in improving production efficiencies in terms of time, cost, and quality during the mechanical design phase of HVLVHV machinery products. The underlying model to the framework is a further contribution to practices as it is a structured way to understand a complex process. It also offers a consistent and standard approach to the problem and helps in communicating the process for achieving efficiency improvement in HVLVHV machinery, see the HVLVHV design process efficiency model on page 136.

5.2 Impact

The proposed research methodology in this thesis was in the form of action research within a single case study company. The contribution to practice was in the sharing of a fit-for-purpose Strategic Design Management framework integrated for improving production efficiencies in the mechanical design phase of HVLVHV machinery products. As the implementation of the framework proved to be a success, the company saw both cost savings in manufacturing their machines and a reduction in the assembly time.

Due to the framework incorporating Lean design principles, standardising the mechanical design process, utilising a modular design approach, fostering collaboration and using design automation tools, the organisation should see several additional benefits, including quality improvements, faster employee development, and increased morale. These impacts are complex to evidence and, therefore, are not included in this investigation. However, they will be considered in future research and implications. Customers of the case study company saw a reduction in lead time, which made the case study company more appealing as a supplier than its direct competitors, as they have a greater lead time.

The proposed research will add to the academic literature currently existing on increasing production efficiency during the mechanical design phase of HVLVHV machinery products where there is limited data. The framework output from this research could be utilised in other industries, and again, this will be discussed in future research and its implications. Should a company choose to implement the framework and follow the underlying processes, it would assist in achieving ISO 9001 certification and passing an audit. The process developed by this research assists a company in achieving adherence to the ISO 9001 standard for the Mechanical Engineering Design function of their business, with the byproduct being that they improve production efficiencies in the Design of HVLVHV machinery products. Therefore, a further impact of this work is the potential to assist a company in achieving ISO 9001 certification. This is work that future researchers could undertake, further adding to the knowledge within academia.

Throughout the development of this research, one focus was on publications, and undertaking this work will contribute further to practice and theory. As the intention of publishing this work was considered from the outset, the researcher had intended to publish regardless of the outcome. Even if the implementation of the framework had failed and production efficiencies hadn't been achieved, it would have still added value to the current knowledge on this subject.

During section 1.8, timeline events several challenges were highlighted that occurred during the timeline of this research including a global pandemic and a war in Ukraine These events added additional challenges to the manufacturing sector to those discussed earlier in the problem statement section. The purpose of discussing this chain of events is to highlight the challenges faced by the case study company during this period of work. At the start of the research, the intention was for this work was to reduce the costs of manufacturing the products to enable the case study company to remain competitive. Although it is acknowledged that the issues discussed are global as they are faced by everyone in the manufacturing sector.

Although the company's competitors are also facing these challenges, the situation regarding reducing the costs of manufacturing its products to remain competitive was still pertinent. Additionally, this chain of events appeared to have a significant impact on the mindset of the management team. Prior to the period discussed, there was a desire to improve but very little momentum, and the strategy, or lack thereof, was directionless. After the events described, the management team's mindset changed, and the focus was on improving efficiencies within the business. The formation of the standardisation team evidenced this.

Therefore, although it is difficult to authenticate it is the belief of the researcher that undertaking this research and achieving the results that have been evidenced whilst being exposed to the global challenges during this period had a significant impact on the management team’s mindset. This resulted in a significant shift in their perspective on strategy and the importance of driving efficiency improvements throughout the business. Had the research not been undertaken and the results not been evidenced, the researcher believes that even considering the global challenges, the mindset of the management team wouldn’t have been altered to the level it has, and therefore, this mindset shift has an impact.

5.3 Future research and implications

At the outset of this research, the manufacturing style within the case study company was aligned with bespoke manufacturing. This is a highly skilled and labour-intensive production, with the machine orders being designed or customised specifically for each customer. Due to the standardisation of the modules and the confidence within the business that the modules would be used, they decided to build and stock several of the larger modules that make up the machine during a quiet period in assembly. This machine with modules built to stock was based on a machine order that the Head of the Business Unit for AWS was confident the case study company would receive.

This change in strategy led to several benefits for the case study company. When a customer order was received, the procurement phase was reduced significantly, as the majority of the long lead machine modules were manufactured and assembled. Additionally, it allowed procurement to buy larger quantities of the parts they put into stock, thus reducing the cost of the modules. There are negatives to this strategy, though holding inventory reduces cash flow as payment for the product can’t be received until it is sold.

Another potential strategy that could be incorporated into that of the case study company’s existing one is by linking procurement of the product to a build schedule and incorporating just-in-time (JIT) manufacturing techniques. Work undertaken by Matsui (2007) on Japanese manufacturing companies proved that JIT production systems contribute to improving competitive performance. This could be at odds with bulk procurement, though and the benefits this allows the case study company to exploit. Therefore, this is an ideal opportunity for further investigation to see if both strategies can be aligned to reap both benefits. The outcome of this work could be a coordinated, evidence-based, holistic production strategy for HVLVHV machinery products.

Due to the case study company utilising design automation tools, the chance of mistakes being made by the operator manufacturing the part should be significantly reduced. This is because the operator is no longer required to manually input the data. There was insufficient data to prove this during the duration of the research, but it's a logical consequence of removing the potential for human error. Therefore, this is a further body of work that requires further investigation to build on the body of work completed to date. Additionally, standardising the modules and using design automation tools should improve quality and reduce the number of errors reaching the shop floor in the case study company. This is additional work that also requires further investigation.

As the framework implemented in the case study company now forms the process for how the mechanical design engineering team works, production efficiency improvements should be sustained. Additionally, due to the feedback loops within the framework, the researcher believes that the case study company will continually improve. Furthermore, due to the framework incorporating Lean design principles, standardising the mechanical design process, utilising a modular design approach, fostering collaboration, and using design automation tools, the organisation should see several additional benefits, including quality improvements, faster employee development, and increased morale. These impacts are complex to evidence and, therefore, require further investigation.

Additional work would be needed to implement the framework output from this research in other industries. This is work that future researchers could undertake, further adding to the knowledge within academia. Additionally, should a company choose to implement the framework and follow the underlying processes, it would assist in achieving ISO 9001 certification and passing an audit. This is additional work that future researchers could undertake, and it could be linked to transferring the framework to other industries.

5.4 Limitations of the study

The primary limitation of this research was enforced by the researcher undertaking action research whilst being employed as a practitioner within the case study company. Although this was a necessity as the case study company manufactured the HVLVHV machinery products that the research hinged on, there was a potential for bias. This bias was minimised by utilising mainly quantitative data, and the PDCA give a consistent approach to the research problem and aids reflection. Additionally, support was sought from the supervisory team to ensure that the researcher remained objective and wasn't influenced by any personal bias.

The purpose of cycle three was to evidence the transferability of the framework to a different product in the case study company's portfolio. This was achieved, and it could be concluded that the framework developed from this research is transferrable and effective in improving production efficiency in the mechanical design phase of HVLVHV machinery products. This is the only measure of effectiveness, though it is being applied in a single case study company and to a single type of Machinery. Therefore, at this stage, it cannot truly be considered generalisable. To validate the generalisability, further work is required to apply the framework to a different industry and machine type.

During cycle three, there were issues with getting cost data for parts. The procurement department liaised with suppliers and shared part drawings before and after the improvements took place. Initially, the suppliers were happy to quote on both parts, but then there was understandable resistance as they quoted on parts and gave away their valuable time without getting an order. This justification for the lack of order was the purpose at this point: to measure if the improvements had reduced the cost to manufacture the parts, not to procure them. This resulted in the researcher utilising the purchasing Manager to put forward an estimated saving as he has many years of experience in procurement and manufacturing. Due to this individual's experience and knowledge, this was considered an acceptable measure for this research. It would have given the data more validity if quotations had been sourced for the parts before and after the changes from three separate suppliers, and the average cost could then be used as the basis of the measure to verify whether the changes had been successful. Unfortunately, this was not viable due to the reasons already explained, and it is acknowledged that the costs could be considered subjective; therefore, this is identified as a limitation of the research.

For cycles two and three of the research, it was decided that although all of the machine modules would have the data capture sheets generated, only three would be the research's focus. These three modules comprised the head module (402-A), the base module (403-A) and the clamp module (408-A). The main factors instigating this decision were issues in gaining access to shop floor Mechanical Fitters and the time it took to generate the data capture sheets. However, these modules form the majority of the mechanical elements of the machine and, therefore, are reflective of the efficiency improvements that would be seen in all modules. Capturing data for three modules rather than all the mechanical modules that form the machine is recognised as a limitation of the research.

This research took place over a six-year period in a dynamic industrial setting. An example of this is that the Managing Director was changed four times in the case study company during this period. Additionally, as mentioned in the impact section, numerous global influences impacted the organisation. Therefore, it would be disingenuous to claim that all the efficiency improvements seen within the company were a result of the research. The researcher was there to facilitate change within the case study company. As this was action research, there were numerous participants that had an impact on the research with their contribution, as highlighted by the acceleration of progress due to the formation of the standardisation team. The discussion on the case study company sustaining the change highlights an ideal opportunity for future research to measure the impact when the researcher is not facilitating the efficiency improvements whilst being absorbed in the research and transformation program.

Finally, this research focused on a Medium-sized company that manufactures RFW machines in the UK. The improvements were during a transition period of standardising their existing product range modules. As the company evolves and looks to develop new products, it should still be able to maximise the production efficiency of said products due to the framework and underlying working practices that they adhere to. However, sustaining the discipline to work to the framework needs to be driven by management and measured by audits. Additionally, to sustain the production efficiencies seen in the mechanical design phase of HVLVHV machinery products, the company needs to embed continuous improvement in the organisational culture driven by senior management.

6. References

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7. Appendices

7.1. Original P10 Procedure

1.0 PURPOSE

The purpose of this procedure is to control design and development activities to insure conformance to customer requirements.

2.0 SCOPE

This procedure shall apply to all design and development activities carried out by TFW and KUKA.

3.0 PROCEDURE

3.1 Responsibility

3.1.1 The Engineering Manager(s) and Design Engineers shall be responsible for the following activities unless specified otherwise.

3.2 Design And Development

Design and Development Inputs
Project Launch Document (PLD), Sales Risk Register (SRR) and Sales Cost Sheet (SCS)(MIKA) issued by SALES department shall include all customer's specified and implied contractual and statutory requirements. The above documents must be approved by all parties involved in the project during T1 toll gate review.

↓

Design and Development Planning
Project Execution Plan (PXP), Baseline Timing Pan (TP) and Project Cost Sheet (PCS) shall be raised by the PROJECTS department and shall include all of the key design stages together with responsibilities and timing requirements. The above documents must be approved by all parties involved in the project during T2 toll gate review.

↓

Design and Development Outputs
Functional Design Specification (FDS) outlining the project specifications and full scope followed by Design Risk Assessment (DRA) shall be produced by ENGINEERING department and must be approved by all parties involved in the project during T3 toll gate review.

Design and Development Outputs
Files, electronic or hard copy shall be raised which shall identify/include drawings and calculations as appropriate which will enable verification against the contractual needs.
Drawings and calculations shall be reviewed and approved by the originator and checked by Mechanical Design Manager or Technical Competence Centre Co-ordinator. Relevant Design Review documents must be stored on Vault system and minutes of reviews shall be maintained.
Specify, as applicable, any critical items, including any key characteristics, and specific actions to be taken for these items
(Drawing Control see below)
Bills of Materials and Detail/GA drawings shall be produced by ENGINEERING department and must be approved by all parties involved in the project during T4 toll gate review.

3.3 Design Document Control

3.3.1 All Company raised drawings shall be prepared in accordance with the Company standard drawing sheet. (Ref. Templates set up in Autodesk/CATIA Software & KSUK Drawing Issuing Procedure Issue 7 for creating new drawings in Inventor & AutoCAD).

3.3.2 The BOMS's, (Bills of Materials) mechanical, hydraulics and electrical as appropriate) shall constitute the master list for drawing issue control purposes. The MRP on Visibility shall and the Vault systems shall supplant the above for new projects.

3.3.3 All drawings and drawing revisions shall be reviewed and approved by the originator and checked by a qualified drawing office person (Mechanical Design Manager or Technical Competence Centre Co-ordinator in the first instance).

3.3.4 (Pre MRP systems) Where a drawing is revised, the BOM shall be amended and up-issued accompanied by a Change request document. A brief description of the change shall be identified on the drawing and within the Change request.

3.3.5 All drawings issued shall contain a modification table clearly displaying the date of issue, initials of the originator and of the checker, brief description and change request number if applicable (Ref. KSUK Drawing Issuing Procedure Issue 7).

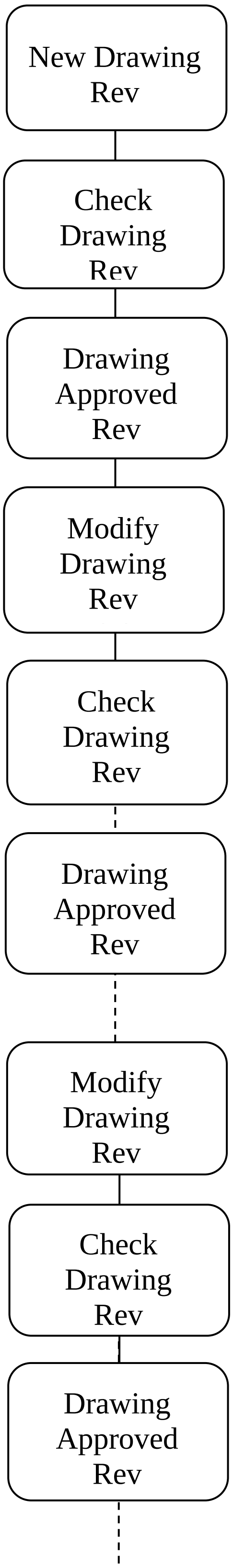
3.3.6 Parts designed for the contract shall be identified with the project number suffixed with a sequential Part/Drawing number derived from the BOM. (ref. F 41)

3.3.7 When drawings are issued to the machine builders by the drawing office the Parts List shall be date stamped with the date issued. (ref. F 42)

3.3.8 When a document has been superseded the obsolete document shall be marked as being obsolete and retained for reference purposes in Archive folder (to be created as and when required).
Superseded drawings are managed and retained by the Vault system automatically (see Vault procedure below).

3.3.9 Configuration management shall be controlled via the DMS/MRP software whereby any change to an approved drawing shall warrant the completion of a change request document within the system. The change request document shall identify each aspect of the change (Ref. KSUK Drawing Issuing Procedure Issue 7).

3.3.10 DMS (Vault) Procedure



Note: Vault DMS system stores not only issued drawing revisions but also every version of a given document every time it has been checked in by a user (date of access, user name and comments are also recorded).

Programme/Software Control

3.4.1 The name and versions of the software used for programming the machine shall be recorded on the Software Issue & Revision Record (ref. F 43) by the commissioning engineer at the point of machine acceptance.

3.4.2 The programme issue numbers shall be the contract number suffixed with an alpha notation for the PLC software and a numeric suffix for the Welder software.

3.4.3 All revisions to the Programmes after machine acceptance shall be recorded on the Software Issue & Revision Record (ref. F 43)

3.4.4 Copies of the above data shall be either kept on disk, on the server or on the Software Engineers PC under the contract/issue number.

3.4.5 Programmes shall be validated as a consequence of function testing. (ref. P 08)

3.5 Design and Development Change Control

3.5.1 Design and development changes shall be identified and records maintained as part of the drawing Change Request software.

3.5.2 Changes shall be reviewed, verified and validated, as above, and approved before implementation.

3.5.3 The review of design and development changes shall include evaluation of the effect of the changes on constituent parts and product already delivered. Records of the results of the review of changes and any necessary actions shall be maintained within the Change Request software.

3.5.4 Aerospace and Nuclear customers/product shall be required to confirm the acceptance of a proposed change and issuing by the client an amended ‘User Required Specification’.

4.0 RECORDS

- Design files, both hard copy and electronic shall be maintained for the lifetime of the machine/installation.
- The Engineering Manager shall be responsible for maintaining the hard copy files and the computer system administrator responsible for the electronic documents.

7.2. Cycle 1 – Output Framework

Pre-Order to Tollgate T1 Phase 1.

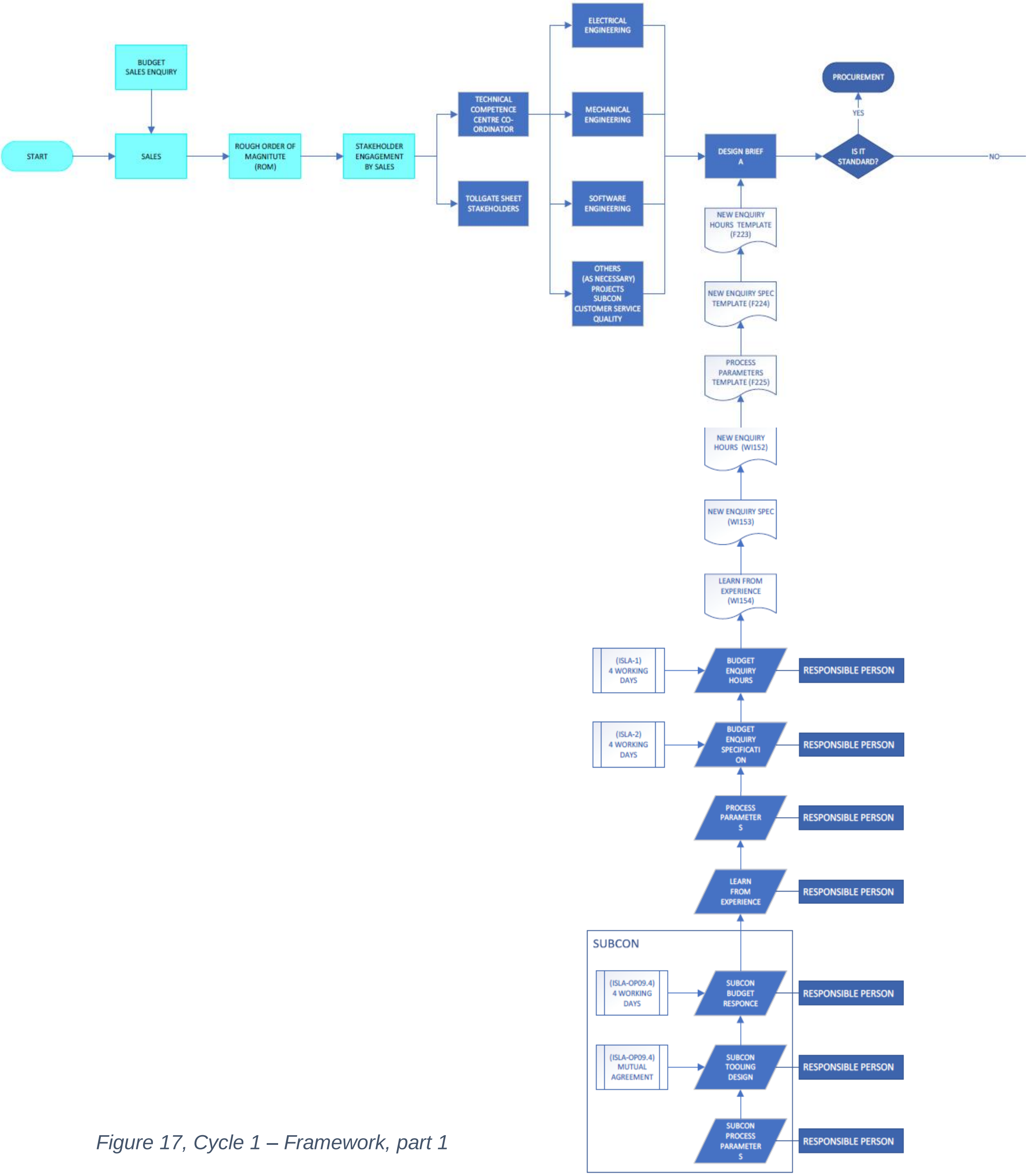


Figure 17, Cycle 1 – Framework, part 1

Pre order to Tollgate T1 Phase 2.

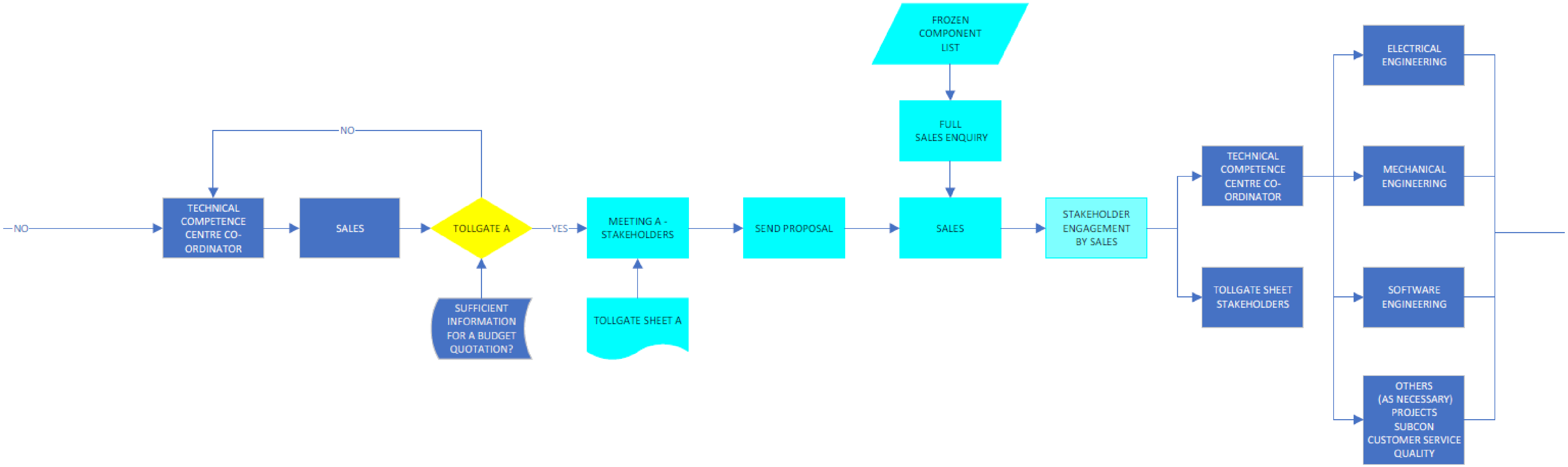


Figure 18, Cycle 1 – Framework, part 2

Pre order to Tollgate T1 Phase 3.

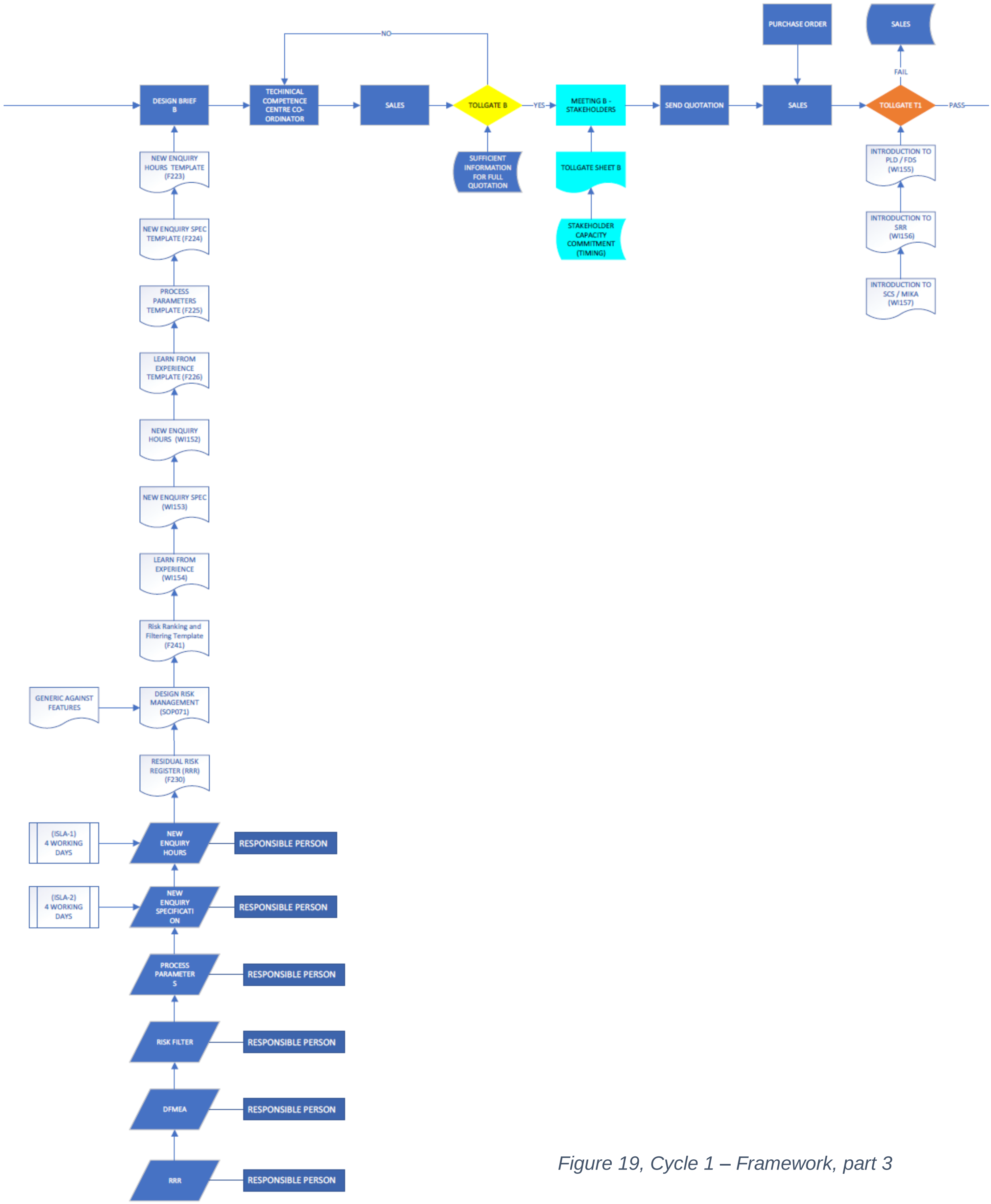


Figure 19, Cycle 1 – Framework, part 3

Tollgate T1 to Tollgate T3.2 Design.

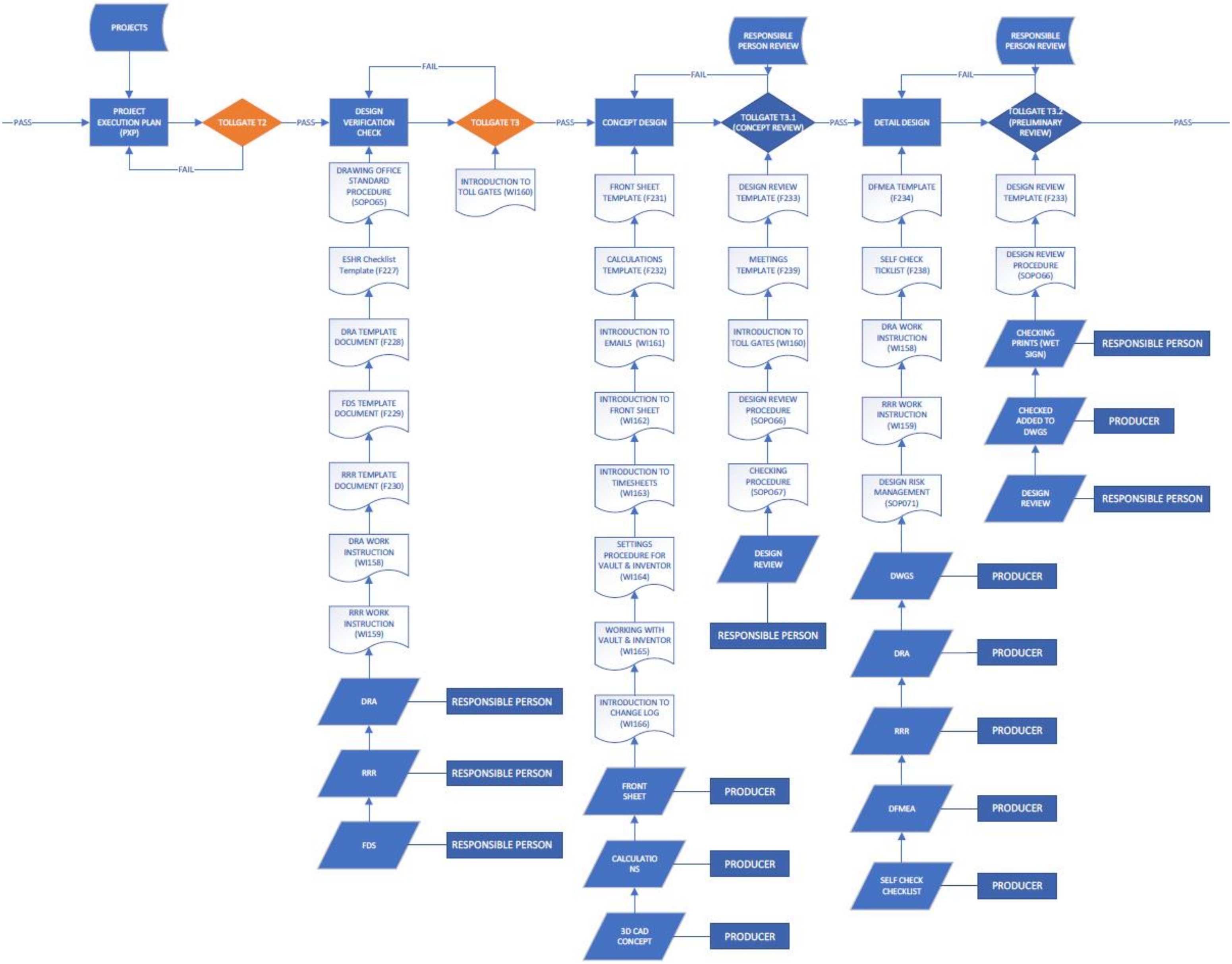


Figure 20, Cycle 1 – Framework, part 4

Tollgate T3.2 to Delivery to customer.

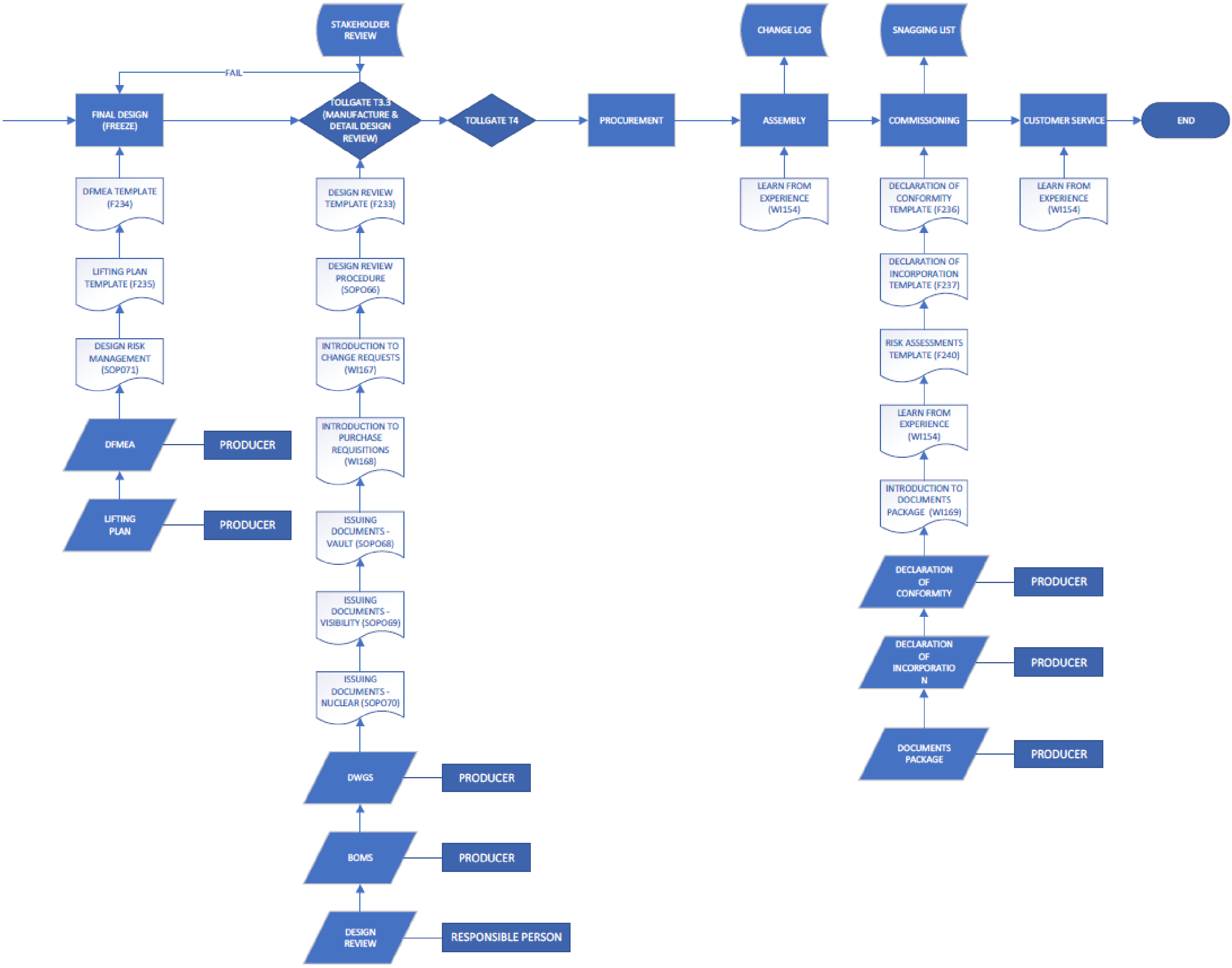


Figure 21, Cycle 1 – Framework, part 5

7.3. Cycle 2 – Output Framework

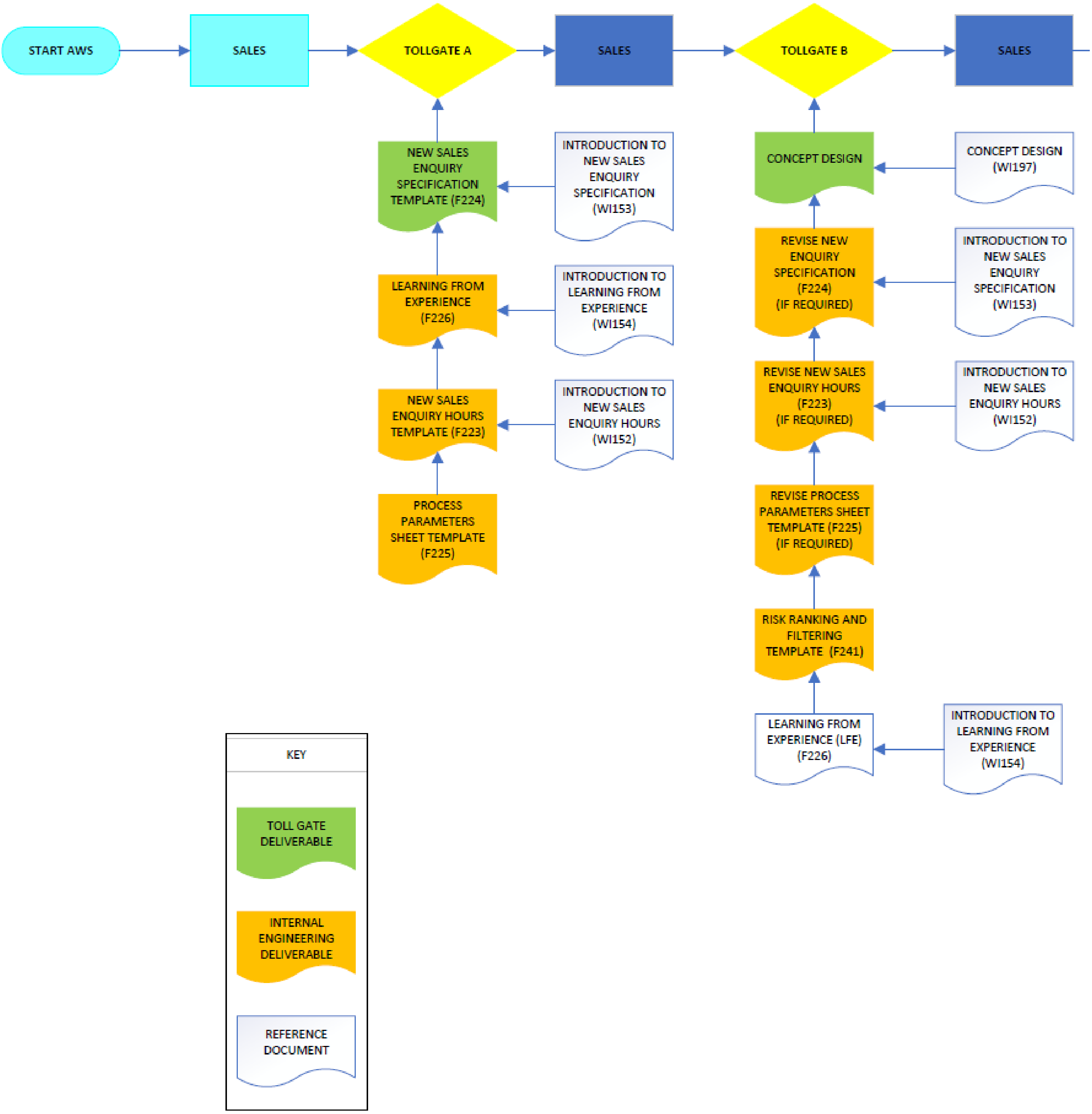


Figure 22, Cycle 2 - Framework, part 1

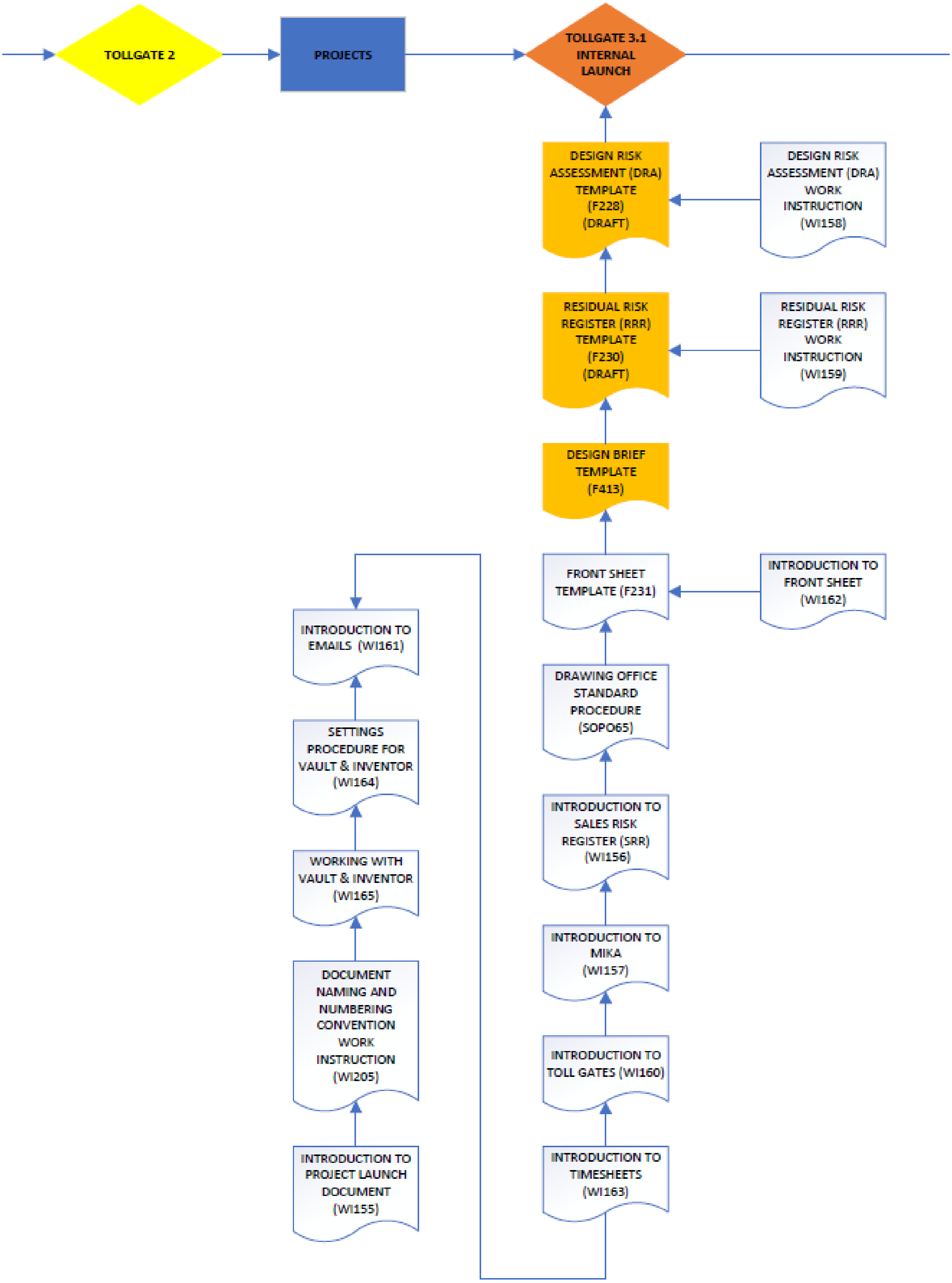


Figure 23, Cycle 2 - Framework, part 2

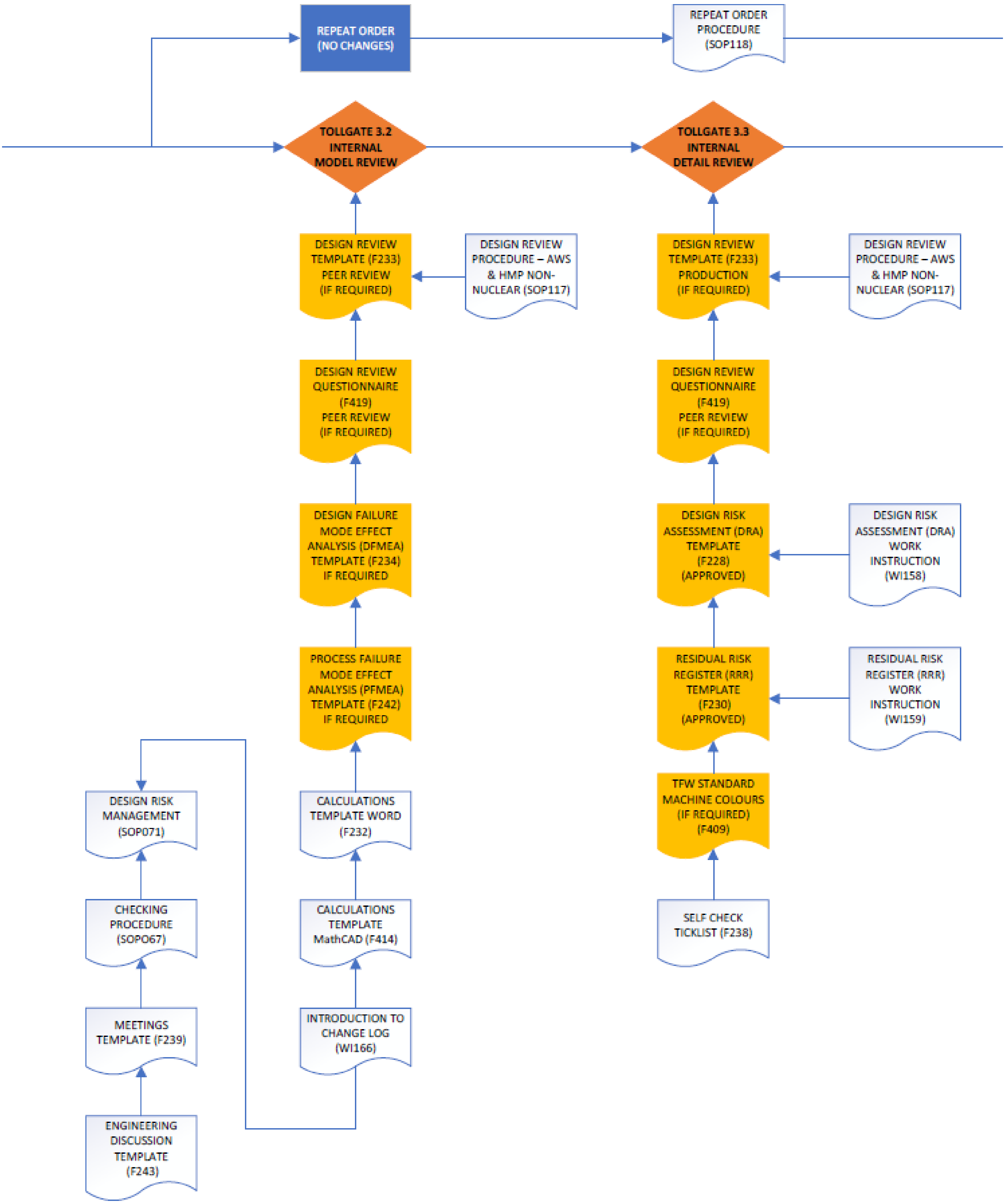


Figure 24, Cycle 2 - Framework, part 3

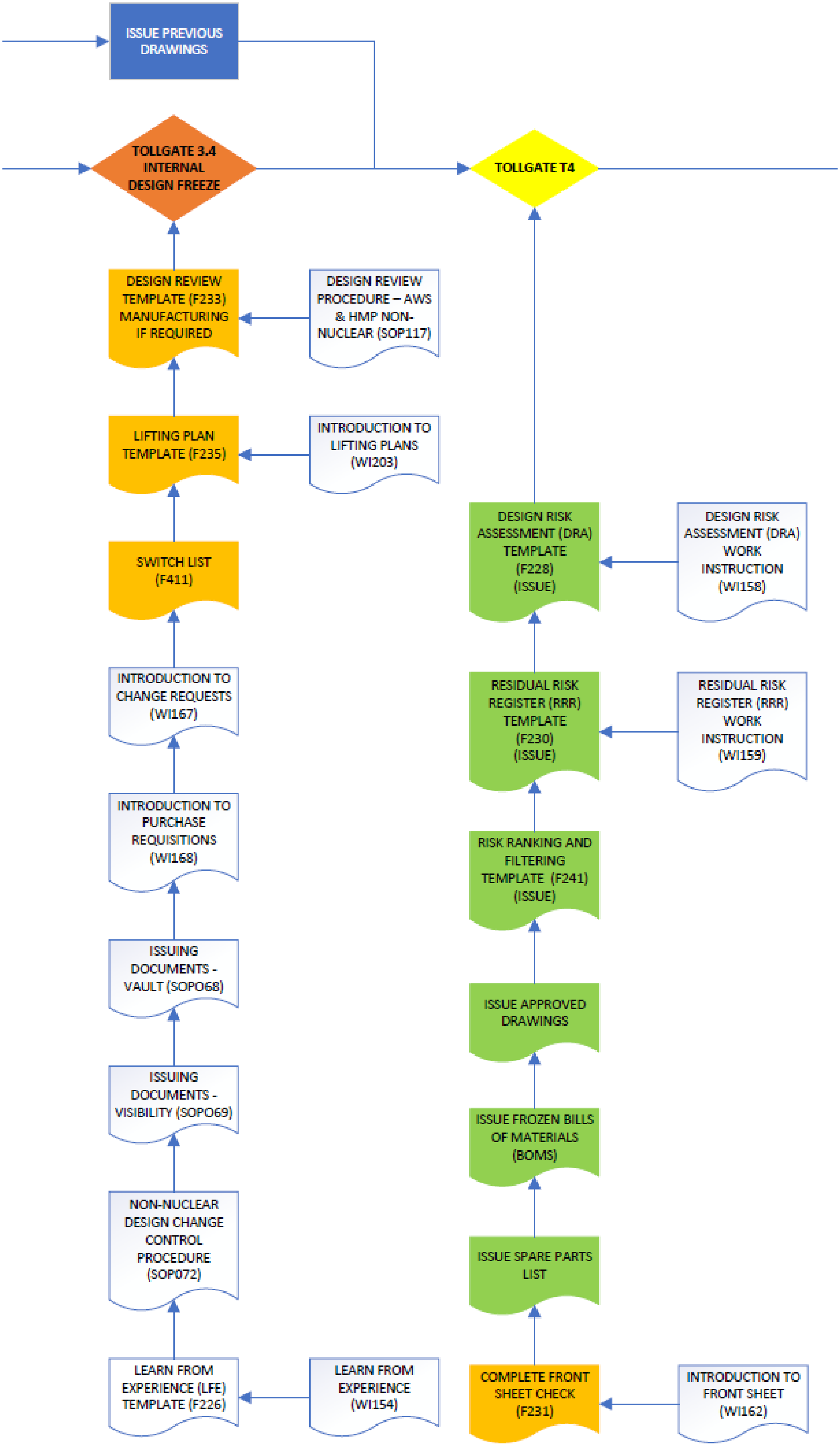
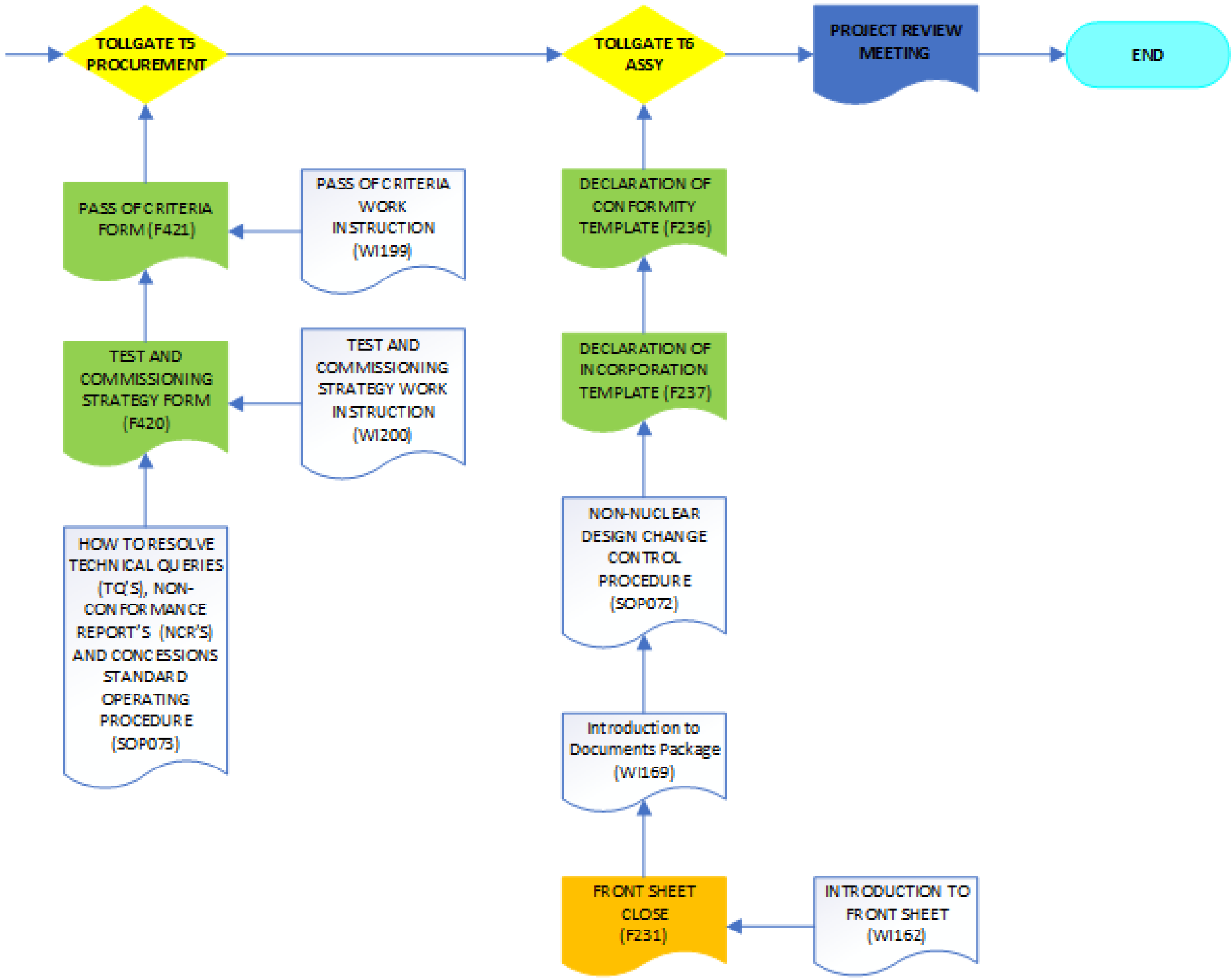


Figure 25, Cycle 2 - Framework, part 4



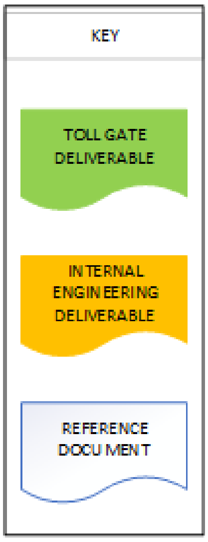


Figure 26, Cycle 2 - Framework, part 5

7.4. Cycle 3 – Output Framework

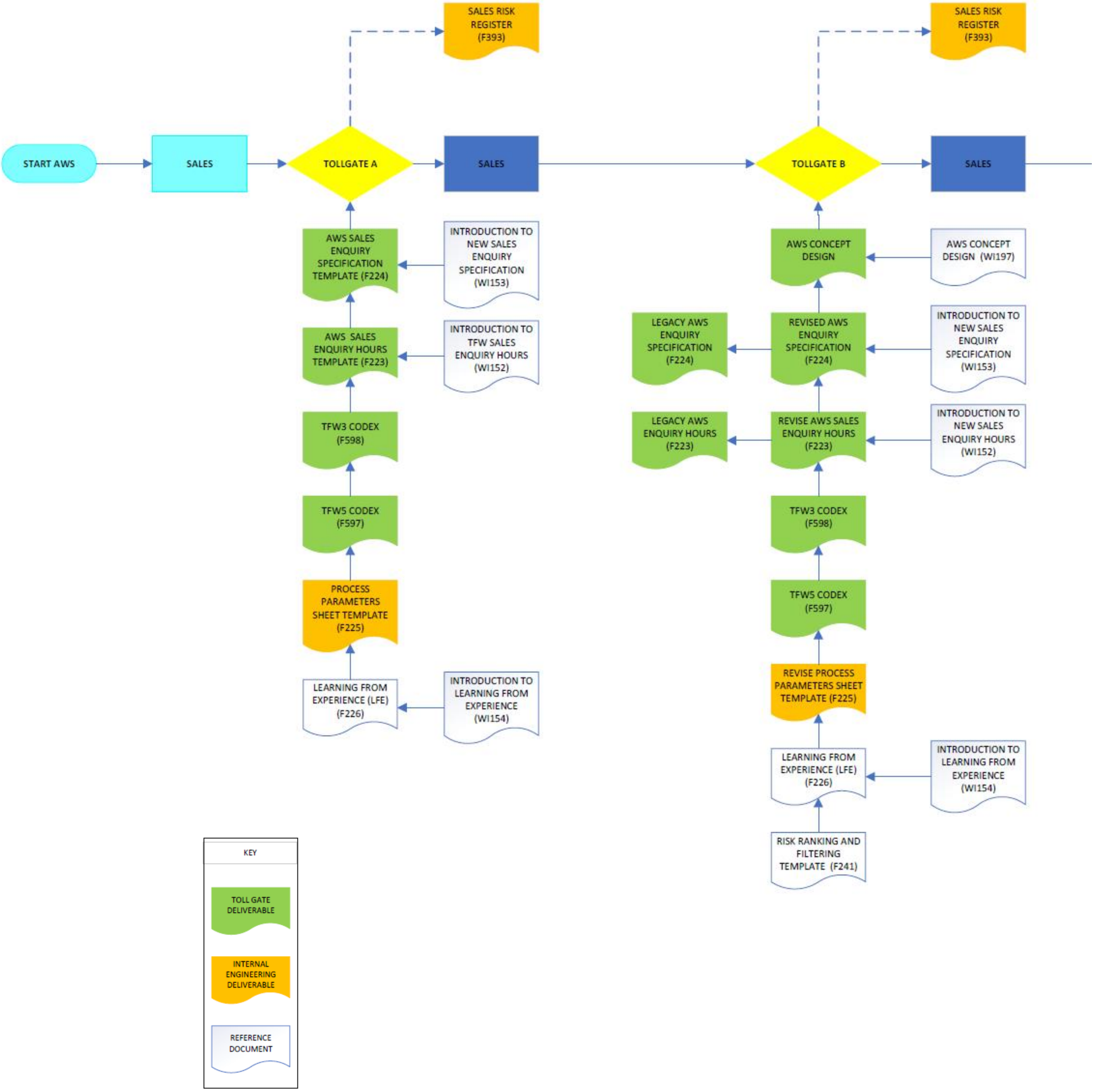


Figure 27, Cycle 3 - Framework, part 1

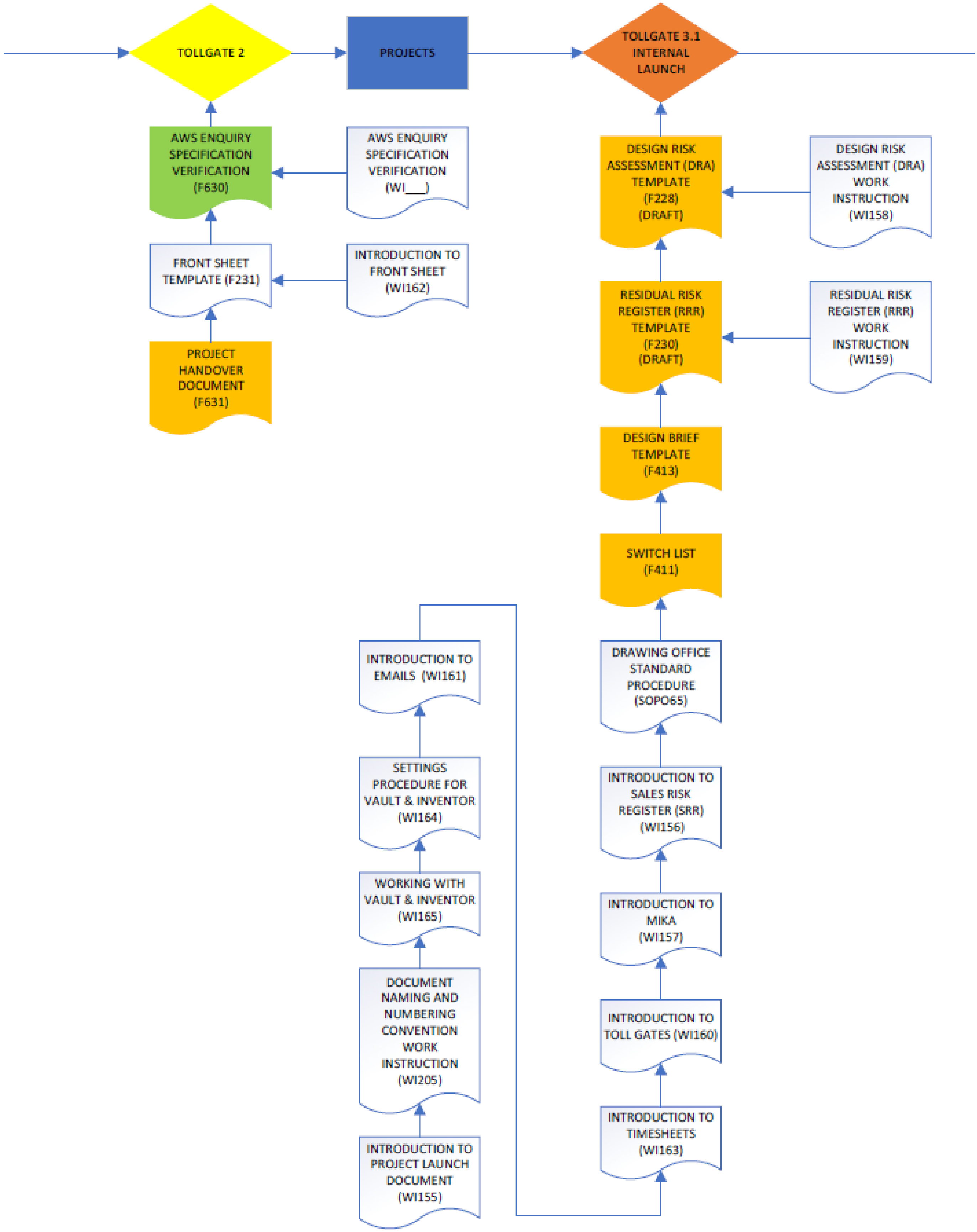


Figure 28, Cycle 3 - Framework, part 2

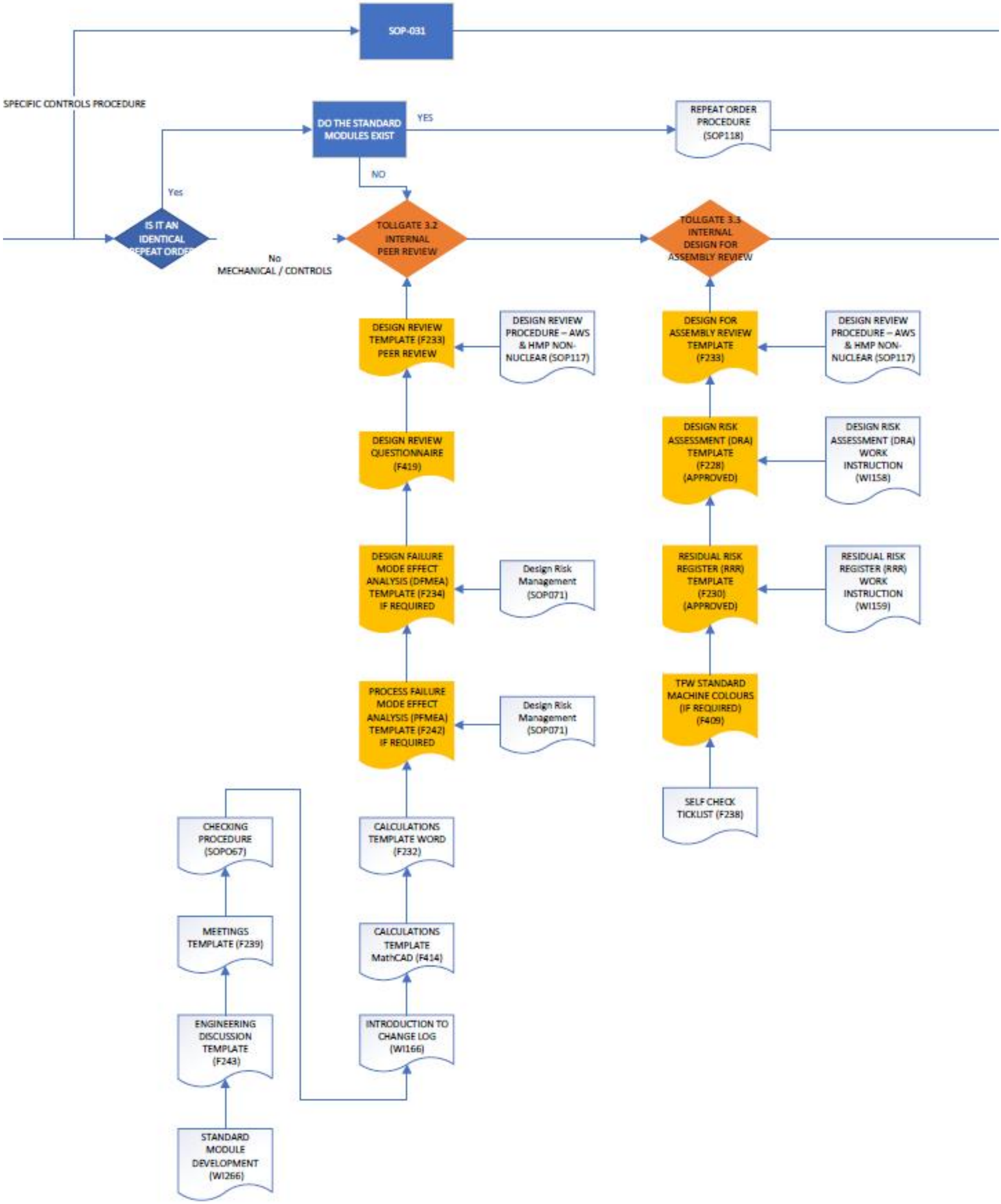


Figure 29, Cycle 3 - Framework, part 3

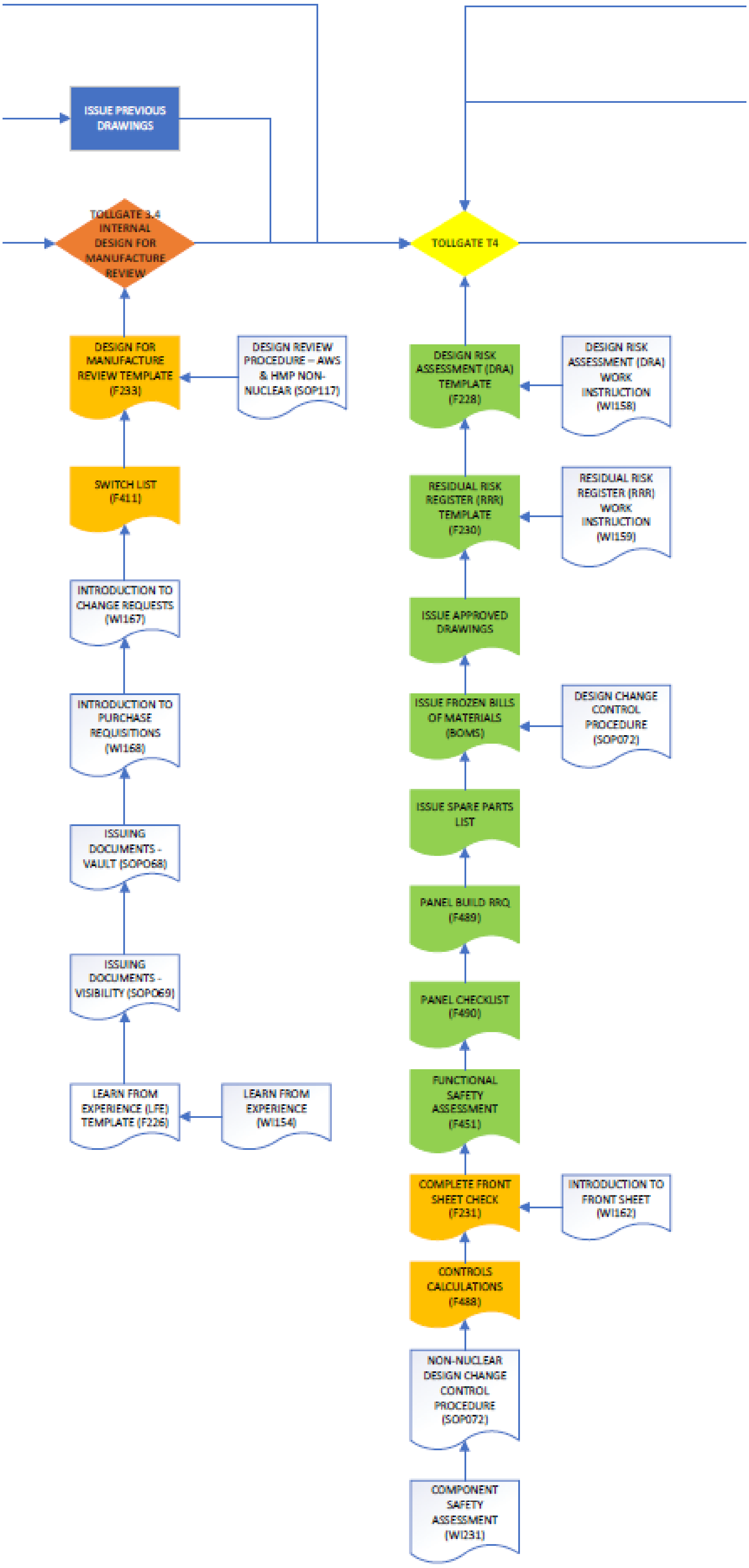


Figure 30, Cycle 3 - Framework, part 4

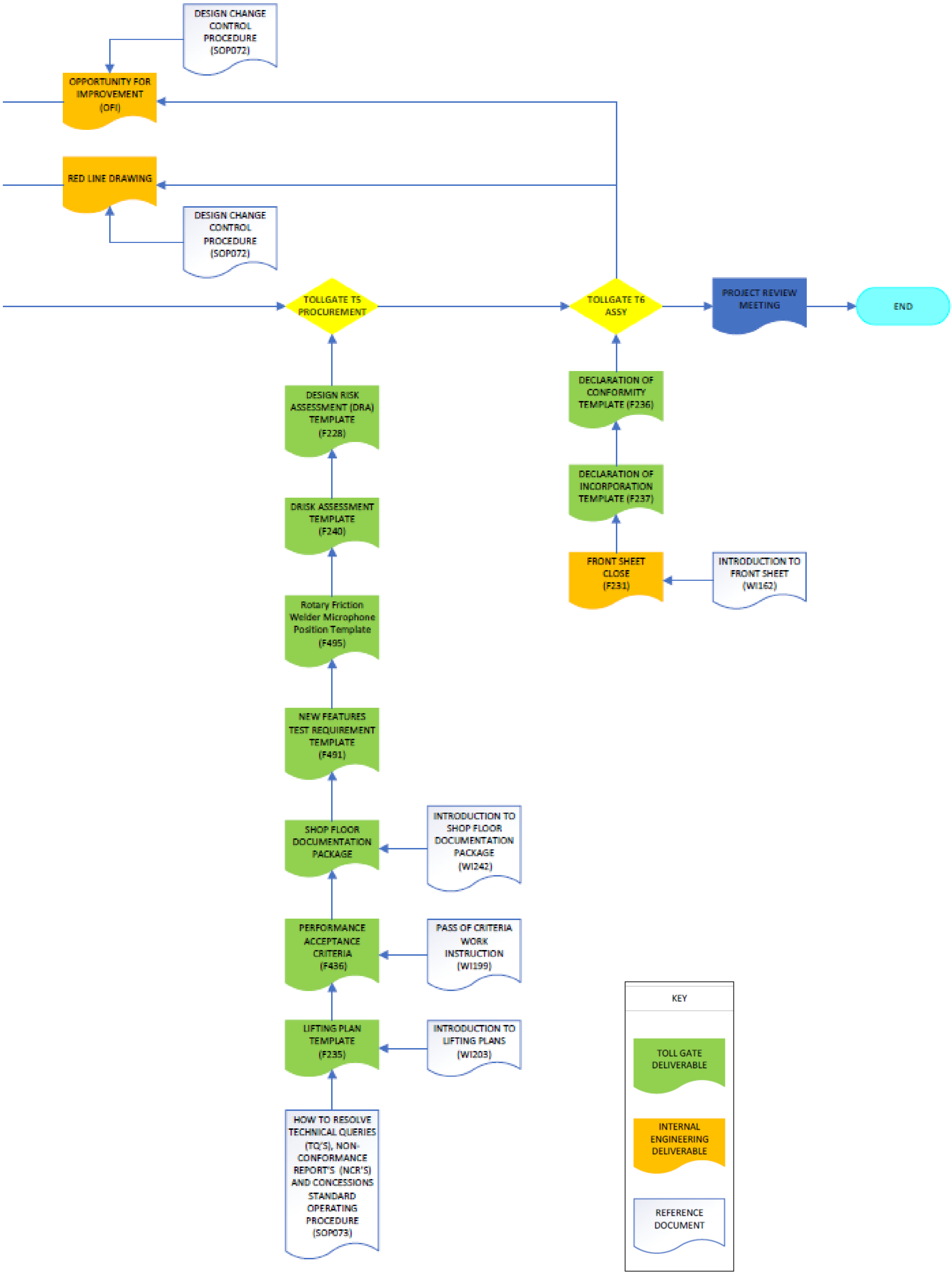


Figure 31, Cycle 3 - Framework, part 5

7.5. UWES Questionnaire

UWES Manual; page 48

English version

Work & Well-being Survey (UWES) ©

The following 17 statements are about how you feel at work. Please read each statement carefully and decide if you ever feel this way about your job. If you have never had this feeling, cross the '0' (zero) in the space after the statement. If you have had this feeling, indicate how often you feel it by crossing the number (from 1 to 6) that best describes how frequently you feel that way.

	Almost never	Rarely	Sometimes	Often	Very often	Always
0	1	2	3	4	5	6
Never	A few times a year or less	Once a month or less	A few times a month	Once a week	A few times a week	Every day

1. ________ At my work, I feel bursting with energy* *(VI1)*
2. ________ I find the work that I do full of meaning and purpose *(DE1)*
3. ________ Time flies when I'm working *(AB1)*
4. ________ At my job, I feel strong and vigorous *(VI2)**
5. ________ I am enthusiastic about my job *(DE2)**
6. ________ When I am working, I forget everything else around me *(AB2)*
7. ________ My job inspires me *(DE3)**
8. ________ When I get up in the morning, I feel like going to work *(VI3)**
9. ________ I feel happy when I am working intensely *(AB3)**
10. ________ I am proud on the work that I do *(DE4)**
11. ________ I am immersed in my work *(AB4)**
12. ________ I can continue working for very long periods at a time *(VI4)*
13. ________ To me, my job is challenging *(DE5)*
14. ________ I get carried away when I'm working *(AB5)**
15. ________ At my job, I am very resilient, mentally *(VI5)*
16. ________ It is difficult to detach myself from my job *(AB6)*
17. ________ At my work I always persevere, even when things do not go well *(VI6)*

* Shortened version (UWES-9); VI= vigor; DE = dedication; AB = absorption

7.6 Example Data Capture Sheet

TFW5-02LH-A	Head Assembly

Task ID	Ref No	Part No & Description	Method Description	HSE / PPE	Quality Points Checks / Inspection Equipment		Jigs, Tools & Facilities Equipment	Consumables	Comments, Including Problems Photo, Video & Knacks
1	TFW5-02-A-ID1	TFW5-02LH-A087 - Head Casting LH	• Visual Check on all holes and Check that a few in each group are tapped to the correct depth and that the fit is ok.	Safety Glasses, Safety Boots	60	min			
2	TFW5-02-A-ID2	TFW5-02LH-A087 - Head Casting LH	• Remove any sharp edges and do a visual check for any marks or lumps/Bumps that may have be done during transit or manufacture. Polish Chamfer on back of head for Bearing Sleeve (TFW5-02-A055)	Safety Glasses, Safety Boots	60	min		Oil Stone	
3	TFW5-02-A-ID3	TFW5-02-A055 - Bearing Sleeve	• Remove sharp edges and clean out oil holes.	Safety Glasses, Safety Boots	30	min		Oil Stone, White Spirits	
4	TFW5-02-A-ID4	TFW5-02-A055 - Bearing Sleeve	• Turn head with crane so facing down and try bearing sleeve in rear of head.	Safety Glasses, Safety Boots Inspect that lifting equipment: crane and slings are in good condition	30	min	Crane, Sling		
5	TFW5-02-A-ID5	TFW5-02LH-A087 - Head Casting LH	• Head casting should be cleaned internally to remove any slag and debris.	Safety Glasses, Safety Boots	1440	min	Airline Blow gun	White Spirits	
6	TFW5-02-A-ID6	TFW5-02LH-A087 - Head Casting LH	• Painting of the head cast	Safety Glasses, Safety Boots	1920	min		Paint + Body Filler + Masking Tape	
7	TFW5-02-A-ID7	TFW5-02LH-A087 - Head Casting LH	• Move Head casting to floor for Cryogenics to load bearing using Cryogenic Bearing Cradle	Safety Glasses, Safety Boots Inspect that lifting equipment: crane and slings are in good condition	30	min	TFW5-402-T001-Cryogenic Bearing Cradle,Crane, Sling		
8	TFW5-02-A-ID8	TFW5-02LH-A087 - Head Casting LH M1060-00010 - M125 Front Bearing	• Cryogenics come in and freeze in the front Bearing.	Safety Glasses, Safety Boots Inspect that lifting equipment: crane and slings are in good condition, Cryogenic gloves	30	min	TFW5-402-T001-Cryogenic Bearing Cradle,Crane, Sling		
9	TFW5-02-A-ID9	TFW5-02LH-A087 - Head Casting LH M1060-00013 - M125 Rear Bearing	• Cryogenics come in and freeze in the Rear Bearing.	Safety Glasses, Safety Boots Inspect that lifting equipment: crane and slings are in good condition, Cryogenic gloves	30	min	TFW5-402-T001-Cryogenic Bearing Cradle,Crane, Sling		
10	TFW5-02-A-ID10	TFW5-02LH-A087 - Head Casting LH	• Re-try the Bearing Sleeve in the back of the Head Casting. If doesn't fit needs to go on the lathe to clean up. Need to check the Bearing sleeve tolerance using a micrometer and check to drawing.	Safety Glasses, Safety Boots	30	min	Micrometer, Lathe		
11	TFW5-02-A-ID11	TFW5-02LH-A087 - Head Casting LH	• Turn the head casting onto its back on timbers on the floor	Safety Glasses, Safety Boots Inspect that lifting equipment: crane and slings are in good condition	15	min	Crane, Sling, Timber		
12	TFW5-02-A-ID12	TFW5-02-A108 - Slide Pad F1205-12031 - Soc C/Sunk Head Screw ø5x12 (Brass)	•Mark out and Countersink DX Strip to suit 5mm Countersunk Brass Screws and remove frayed edge on oil groove	Inspect that lifting equipment: crane and slings are in good condition	240	min	Vernier height gauge, Pillar Drill, Countersink drill bit, Scriber	Abrasive Cloth	
13	TFW5-02-A-ID13	TFW5-02-A108 - Slide Pad	• Stone back of DX Strip to remove any burrs	Safety Glasses, Safety Boots	30	min		Oil stone	
14	TFW5-02-A-ID14	TFW5-02-A108 - Slide Pad TFW5-02LH-A087 – Head Casting F1205-12031 - Soc C/Sunk Head Screw ø5x12 (Brass)	• Fix slide pad to head casting using 32 x M5 C/Sink Screws and Loctite down	Safety Glasses, Safety Boots	30	min	3mm Hex Key	Loctite	
15	TFW5-02-A-ID15	TFW5-02-A214 - Linear Bearing Block	• Grind any out faces to remove errors, eg Run Out	Safety Glasses, Safety Boots	90	min	Angle grinder		
16	TFW5-02-A-ID16	M1059-00001 - Linear Roller BRG TFW5-02-A214 - Linear Bearing Block F1200-05040 - Soc Hd Cap Scw Grade 12.9 M5x40 F1225-00055 - ø5 Type Vs Schnorr Safety Washer No.414600	• Fit the Bearing to the Linear Brg Block using M5 Capscrews and Washers	Safety Glasses, Safety Boots	5	min	4mm Hex Key		

7.7 Global total production of Crude Steel

Total Production of Crude Steel *

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Austria	5 662	7 206	7 474	7 421	7 953	7 876	7 687	7 438	8 135	6 885
Belgium	5 635	7 973	8 026	7 301	7 127	7 331	7 257	7 687	7 842	7 980
Bulgaria	726	737	835	633	523	612	543	527	652	666
Croatia	43	95	96	1	135	167	122	0	0	136
Czech Republic	4 594	5 180	5 583	5 072	5 171	5 360	5 262	5 305	4 550	4 938
Germany	32 670	43 830	44 284	42 661	42 645	42 943	42 676	42 080	43 297	42 435
Finland	3 066	4 029	3 989	3 759	3 517	3 807	3 988	4 101	4 003	4 146
France	12 840	15 414	15 780	15 609	15 685	16 143	14 984	14 413	15 505	15 387
Greece	2 000	1 821	1 934	1 247	1 030	1 022	910	1 158	1 359	1 467
Hungary	1 403	1 678	1 746	1 542	883	1 152	1 675	1 274	1 901	1 989
Italy	19 848	25 750	28 735	27 252	24 093	23 714	22 018	23 373	24 068	24 532
Latvia	692	655	568	805	198					
Luxembourg	2 141	2 548	2 521	2 208	2 090	2 193	2 127	2 175	2 172	2 228
Netherlands	5 194	6 651	6 937	6 879	6 713	6 964	6 995	6 917	6 781	6 813
Poland	7 128	7 993	8 779	8 366	7 950	8 558	9 198	9 001	10 332	10 167
Portugal	1 614	1 543	1 942	1 960	2 050	2 070	2 030	2 010	2 076	2 215
Romania	2 761	3 721	3 828	3 292	2 985	3 158	3 352	3 276	3 361	3 550
Slovak Republic	3 747	4 583	4 236	4 403	4 511	4 705	4 562	4 808	4 974	5 225
Slovenia	430	606	648	632	618	615	604	613	648	654
Spain	14 358	16 343	15 504	13 639	14 252	14 249	14 845	13 616	14 441	14 320
Sweden	2 804	4 846	4 867	4 326	4 404	4 539	4 557	4 817	4 926	4 654
United Kingdom	10 074	9 708	9 478	9 579	11 858	12 033	10 907	7 635	7 491	7 268
European Union (28)	**139 432**	**172 909**	**177 791**	**168 589**	**166 390**	**169 215**	**166 298**	**162 224**	**168 515**	**167 655**
Albania (e)	221	390	464	500	550	560	150	50		
Bosnia-Herzegovina	519	592	649	700	722	793	819	806	756	695
Macedonia	270	292	386	217	100	188	121	169	273	266
Montenegro (e)	130	130	140	120	70	140	150	120	120	120 e
Norway	595	530	610	700	605	600	590	620	603	575
Serbia	1 061	1 254	1 324	346	396	583	955	1 173	1 477	1 973
Switzerland	934	1 320	1 400	1 450	1 530	1 475	1 475	1 500	1 450	1 500 e
Turkey	25 304	29 143	34 107	35 885	34 654	34 035	31 517	33 163	37 524	37 312
Other Europe	**29 034**	**33 650**	**39 079**	**39 917**	**38 627**	**38 374**	**35 778**	**37 601**	**42 203**	**42 441**
Azerbaijan (e)	120	120	120	120	173	180	180	180	180	200 e
Belarus	2 417	2 530	2 614	2 687	2 245	2 513	2 510	2 188	2 343	2 470 e
Kazakhstan	4 146	4 220	4 699	3 676	3 275	3 681	3 910	4 289	4 641	3 964 e
Moldova	426	240	313	335	190	351	443	126	469	497 e
Russia	60 011	66 942	68 852	70 209	69 008	71 461	70 898	70 453	71 491	72 042 e
Ukraine	29 855	33 432	35 332	32 975	32 771	27 170	22 968	24 218	21 417	21 100
Uzbekistan	716	716	733	736	746	723	643	654	654	646 e
C.I.S.	**97 691**	**108 200**	**112 663**	**110 739**	**108 408**	**106 079**	**101 552**	**102 108**	**101 195**	**100 919**
Canada	9 292	13 009	12 891	13 507	12 417	12 730	12 473	12 646	13 208	13 443
Cuba	267	278	282	277	322	256	284	244	221	225
El Salvador	56	64	97	72	118	121	124	100	96	99
Guatemala	224	274	294	334	385	395	403	314	294	300
Mexico	14 132	16 870	18 110	18 073	18 242	18 930	18 218	18 824	19 955	20 204
Trinidad and Tobago	417	572	603	628	616	487	591	36		
United States	59 384	80 495	86 398	88 695	86 878	88 174	78 845	78 475	81 612	86 607
North America	**83 772**	**111 562**	**118 675**	**121 586**	**118 978**	**121 093**	**110 938**	**110 638**	**115 386**	**120 879**

Total Production of Crude Steel *

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Argentina	4 013	5 138	5 611	4 995	5 186	5 488	5 028	4 126	4 624	5 162
Brazil	26 506	32 948	35 220	34 524	34 163	33 897	33 258	31 642	34 778	35 407
Chile	1 308	1 011	1 615	1 671	1 323	1 079	1 112	1 153	1 158	1 145
Colombia	1 052	1 208	1 287	1 302	1 236	1 208	1 211	1 272	1 253	1 219
Ecuador	259	372	463	425	570	667	720	576	561	583
Paraguay	54	59	30	44	45	47	48	35	24	25
Peru	718	880	877	981	1 069	1 078	1 082	1 168	1 207	1 217
Uruguay	57	65	81	78	91	94	97	61	58	60
Venezuela	3 808	2 207	2 980	2 359	2 139	1 485	1 345	553	444	129
South America	**37 776**	**43 888**	**48 165**	**46 379**	**45 822**	**45 043**	**43 900**	**40 587**	**44 106**	**44 947**
Algeria	597	662	551	557	417	415	650	650	415	2 000 e
D.R. Congo (e)	30	30	30	30	30	30	30	30	30	30 e
Egypt	5 541	6 676	6 485	6 627	6 754	6 485	5 506	5 036	6 870	7 807
Ghana (e)	25	25	25	25	25	25	25	25	25	25 e
Kenya (e)	20	20	20	20	20	20	20	20	20	20 e
Libya	914	825	100	315	712	712	352	492	422	396
Mauritania (e)	5	5	5	5	5	5	5	5	5	5 e
Morocco	499	485	654	539	558	501	516	520	550	600
Nigeria (e)	100	100	100	100	100	100	100	100	100	100 e
South Africa	7 484	7 617	7 546	6 938	7 162	6 412	6 417	6 141	6 301	6 327
Tunisia	155	150	150	150	150	150	50	50	50	50 e
Uganda (e)	30	30	30	30	30	30	30	30	30	30 e
Africa	**15 400**	**16 624**	**15 696**	**15 337**	**15 963**	**14 885**	**13 701**	**13 099**	**14 818**	**17 390**
Iran	10 908	11 995	13 197	14 463	15 422	16 331	16 146	17 895	21 236	24 520
Israel (e)	300	300	300	300	300	300	300	300	300	300 e
Jordan (e)	150	150	150	150	150	150	150	150	150	150 e
Oman (e)			200	300	500	1 500	2 000	2 000	2 000	2 000 e
Qatar	1 448	1 970	2 038	2 145	2 236	3 019	2 593	2 521	2 644	2 575
Saudi Arabia (1)	4 690	5 015	5 275	5 203	5 471	6 291	5 229	5 461	4 831	5 240
Syria (e)	70	70	70	10	10	5	5	5	5	5 e
United Arab Emirates	200	500	2 000	2 408	2 878	2 390	3 006	3 149	3 309	3 247
Middle East	**17 766**	**20 000**	**23 230**	**24 979**	**26 967**	**29 986**	**29 429**	**31 480**	**34 475**	**38 037**
Bangladesh (e)	70	78	85	87	84	90	100	100	100	100 e
China	577 070	638 743	701 968	731 040	822 000	822 306	803 825	807 609	870 855	928 264
India	63 527	68 976	73 471	77 264	81 299	87 292	89 026	95 477	101 455	109 272
Indonesia	3 501	3 664	3 621	2 254	2 644	4 351	4 854	4 746	5 195	6 183
Japan	87 534	109 599	107 601	107 232	110 595	110 666	105 134	104 775	104 661	104 319
D.P.R. Korea (e)	1 300	1 300	1 300	1 280	1 250	1 250	1 250	1 250	1 250	1 250 e
South Korea	48 572	58 914	68 519	69 073	66 061	71 543	69 670	68 576	71 030	72 464
Malaysia	5 354	5 694	5 941	5 612	4 693	4 316	3 784	2 764	3 215	4 108
Mongolia (e)	35	35	35	35	40	45	45	50	50	50 e
Myanmar (e)	25	25	25	25	30	35	35	35	35	35 e
Pakistan (e)	1 199	1 401	1 592	1 631	1 845	2 423	2 892	3 553	4 966	4 719
Philippines	824	1 050	1 200	1 260	1 308	1 196	968	1 075	1 378	1 475
Singapore	664	728	752	688	434	540	501	520	596	618
Sri Lanka (e)	30	30	30	30	30	30	30	30	30	30 e
Taiwan, China	15 814	19 755	20 178	20 664	22 282	23 221	21 392	21 751	22 438	23 240
Thailand	3 646	4 145	4 256	3 641	3 613	5 835	5 069	5 400	6 762	6 403
Viet Nam	2 700	4 314	4 900	5 298	5 474	5 847	5 647	7 811	11 473	15 471
Asia	**811 865**	**918 450**	**995 475**	**1 027 114**	**1 123 680**	**1 140 987**	**1 114 224**	**1 125 522**	**1 205 487**	**1 278 002**
Australia	5 249	7 296	6 404	4 893	4 688	4 607	4 925	5 259	5 328	5 689
New Zealand	765	853	844	912	900	859	793	577	657	652
Oceania	**6 014**	**8 149**	**7 248**	**5 805**	**5 588**	**5 466**	**5 717**	**5 837**	**5 985**	**6 341**
World	**1 238 749**	**1 433 432**	**1 538 021**	**1 560 444**	**1 650 423**	**1 671 128**	**1 621 537**	**1 629 096**	**1 732 171**	**1 816 611**

* - Includes all qualities: carbon, stainless, and other alloy.

(1) - HADEED only.

7.8 DFM Cost saving estimate

	DFM TFW3-A08A	Original Cost	Reduction	New Cost
	TFW3-A08A-200			
1	Check wipers.			
	TFW3-A08A-302	£158.75	30	£128.75
2	Remove hole and add a grub screw in side rather than a hole. (Add to parker Cylinder drawing).			
	TFW3-A08A-304	£98.75	15	£83.75
3	Tolerance too tight.			
4	Make as a matched pair.			
5	Can this be 3/8" Gauge plate = 9.525?			
	TFW3-A08A-306	£18.75	5	£13.75
6	Check material, should be gauge plate.			
	TFW3-A08A-307	£58.75	25	£33.75
7	Check material, should be gauge plate.			
8	Remove hardening			
	TFW3-A08A-308	£290.00	0	£290.00
9	Dimensions to be matched pairs			
	TFW3-A08A-309	£348.50	0	£348.50
10	Dimensions to be matched pairs			
11	Add a flatness tolerance.			
	TFW3-A08A-310	£225.00	0	£225.00
12	Dimensioning style to be changed.			
13	Add a flatness tolerance.			
	TFW3-A08A-311	£225.00	0	£225.00
14	Dimensioning style to be changed.			
15	Add a flatness tolerance.			
	TFW3-A08A-312	£1,675.00	120	£1,555.00
16	Quantity of holes (use 2 see 330) and dowels not required.			
17	Add relief mid angle so easier to machine in corner as not tied up.			
	TFW3-A08A-313	£188.75	10	£178.75
18	Why toleranced?			
19	Add a flatness tolerance.			
	TFW3-A08A-314	£188.75	10	£178.75
20	Why toleranced?			
21	Add a flatness tolerance.			
	TFW3-A08A-317	£168.75	50	£118.75
22	Material only comes as diameter make gauge plate and remove hardness.			
	TFW3-A08A-318	£275.00	0	£275.00
	TFW3-A08A-326	£350.00	40	£310.00
23	Only to be issued as a special			
24	Change material			
	TFW3-A08A-327	£350.00	65	£285.00
25	Can the slot be 0.5 bigger rather than a tolerance.			
26	Does the 70H8 need to be so tight?			
27	Make out of 3 pieces, top gauge plate.			
	TFW3-A08A-328	£5,200.00	150	£5,050.00
28	Can the slot in the top middle view go straight through?			
29	Remove the plugs as they are an assembly task.			
30	Show as tapped holes only.			
	TFW3-A08A-330	£58.75	15	£43.75
31	Remove dowels and a hole.			
	TFW3-A08A-331	£55.00	0	£55.00
32	Remove "Machining requirements as they deem necessary note"			
	TFW3-A08A-332	£1,675.00	300	£1,375.00
33	Change corners as hard to achieve.			
34	Remove dowels and a hole.			
	TFW3-A08A-333	£25.00	0	£25.00
35	Change material to EN3.			
36	Add part number to part			
	TFW3-A08A-334	£88.75	0	£88.75
37	Skim mounting face, min cleanup.			
	TFW3-A08A-335	£34.75	5	£29.75
38	Change material to Silver Steel			
39	Review the depth of the hole.			
40	Review the tolerance on the spanner flats.			
	TFW3-A08A-336	£159.00	15	£144.00
41	Tac weld rather than weld.			
	TFW3-A08A-337	£78.50	0	£78.50
42	Add part number to part			
	TFW3-A08A-338	£20.00	0	£20.00
43	Change material to EN3 Bright.			
	TFW3-A08A-344	£47.50	5	£42.50
44	Remove the retaining holes			
45	Review the tolerance, should it be finish sized on "assy"?			
46	Add part no			
		£12,062 Original	£860 Saving	£11,202 New

7.9 Procurement of 1-off vs 2-off

Item No.	Qty	Drawing No.	Issue No.	Description	Price Each	Delivery	Percent Save %
1	2	T706 -A13A-301	001	Pallet	£3,300.00	10 Wks	
1	4	T706 -A13A-301	001	Pallet	£2,940.00	10 Wks	-10.91
2	2	T706 -A13A-302	001	Spring Plate	£443.00	10 Wks	
2	4	T706 -A13A-302	001	Spring Plate	£348.00	10 Wks	-21.44
3	2	T706 -A13A-302	001	Spring Plate	£443.00	10 Wks	
3	4	T706 -A13A-302	001	Spring Plate	£348.00	10 Wks	-21.44
4	2	T706 -A13A-303	001	Location Bung	£1,192.00	10 Wks	
4	4	T706 -A13A-303	001	Location Bung	£947.00	10 Wks	-20.55
5	1	T706 -A13A-304	001	Backstop Support	£1,241.00	10 Wks	
5	2	T706 -A13A-304	001	Backstop Support	£920.00	10 Wks	-25.87
6	1	T706 -A13A-305	001	Backstop Spacer	£254.00	10 Wks	
6	2	T706 -A13A-305	001	Backstop Spacer	£185.00	10 Wks	-27.17
7	1	T706 -A13A-306	001	Backstop	£825.00	10 Wks	
7	2	T706 -A13A-306	001	Backstop	£547.00	10 Wks	-33.70
8	2	T706 -A13A-307	001	Seating Pad	£289.00	10 Wks	
8	4	T706 -A13A-307	001	Seating Pad	£186.00	10 Wks	-35.64
Price Is To Machine Complete Including Material.							
						Average	-24.59

7.10 Participation Information Sheet

BIRMINGHAM CITY
University

Doctor of Business Administration

Dear Colleague,

As you may know, I am currently studying for a Doctor of Business Administration degree. As part of the course I will be carrying out an action research project. I have been reading about implementing Lean Business Process Re-Engineering in High Value, High Variety low volume manufacturing and, as a result, I am going to be trying out some new ideas in our company, Kuka Systems UK Ltd. In order to fully understand the impact of the changes I'm making, I will be carrying out some data collection during the module, these activities including expert interviews and focus groups. The data I will be collecting from you in these activities is in relation to process and procedural improvements and are standard practice in industry and will therefore contain no sensitive data. During the expert interviews we will be asking how you assembly a specific rotary friction welding machine sub-section. During the focus groups we will be asking what improvements can be made to that specific machine sub-section in terms of design for assembly and design for manufacture.

I am carrying out this research in line with the *Ethical Guidelines for Educational Research, fourth edition (2018) which you can read in full HERE.* However, to summarise the key points:

Making changes and improvements to production approaches is a normal and expected function of all managers within an organisation. The changes I will be making will be based on carefully selected contemporary research and scholarship articles available so I have every expectation that, as a result, the business should be improved. Additionally, all participants in this group will have played a part in implementing these improvements. However, whether you wish to take part in the data collection aspects is entirely up to you. If you agree to take part but later change your mind that is fine, and I will remove any non-anonymized data immediately.

Wherever possible I will collect data anonymously. When that is not possible, for example, during interviews, I will anonymise the data for presentation. No individual employees will be identifiable in the final write-up. If you would like to see the final product of the research, please ask and I will send you a copy at no charge. In the interests of security, I will keep all data stored on my password protected laptop or secured USB stick. I will not share the non-anonymized results with anyone else (except in the very unlikely event that the data includes evidence of criminal activity or a breach of statutory regulations). When the project is completed, I will destroy the data.

I will attempt to make sure all data collection methods are quick and easy to complete and will not be too onerous. However, in the interests of transparency and fairness I am not able to offer any further incentive. You do have my personal assurance that any decision to take part, not take part or withdraw will have no bearing on our professional relationship and will have absolutely no impact on your employment.

I hope the above information is clear and provides you with everything you need to decide about whether you are happy to take part in the interviews and focus group. However, if you would like to talk about this further, please come and discuss with me at your convenience or email me at lee.jesic@kuka-systems.co.uk

If you wish to complain about any aspect of how you have been approached or treated in respect of this research study, please contact the blsssethics@bcu.ac.uk or my research supervisor Dr Susan Sisay @ susan.sisay@bcu.ac.uk:

If you are happy to take part, please complete the attached consent form.

Regards

Lee Jesic

Date: 19/08/2020 Version No.: 03

7.11 Participation Consent Form

BIRMINGHAM CITY
University

Doctor of Business Administration

Participant Consent Form

Research carried out by:
Lee Jesic

Study Title:
Doctor of Business Administration – "Lean Business Process Re-Engineering, High product value, low volume and significant variety".

Invitation to Participate:
Steve Leadbeater

Please respond appropriately to the following statements: (delete as appropriate)

a) I have read and understand the information sheet provided. YES/NO

b) I have had the opportunity to ask questions YES/NO

c) I understand that participation is entirely voluntary. YES/NO

d) I agree to take part in an expert interview. YES/NO

e) I understand that I have the right to withdraw at any stage of the study without prejudice.
YES/NO

f) I understand my right to anonymity/confidentiality. YES/NO

Signed:___________________________ Date: _08/07/2021______________

7.12 Transcribe video Kuka Now August 2023

Hello all, So, just a very quick few words from me today. We have obviously been through a difficult time, a difficult time for various people within the business and the management team has had to make some tough decisions concerning the future direction of the business and as difficult as that can be I do feel that we are now able to move forward with clarity and a clear focus on developing the business in the coming years.

The global economic situation is making the closing out of orders for large capital goods which we manufacture a longer process than we would hope, but the levels of enquiries we are seeing for our machines and the automation of them are still at a high level which is encouraging. The strategy of standardisation and therefore the ability to kick off procurement and production of sub-assemblies against sales forecast is starting to give us advantages. Standard products mean that we're now able to speak to the supply chain to talk about opportunities that we've never had before to reduce the manufacturing costs of our product. The build of standard assemblies against future sales also allows us to smooth out production peaks and troughs and also offer a reduced lead time on standard machines which is very attractive to our customers.

By the time you watch this video, I am hopeful that we will have received an order that will utilise a number of the standard sub-assemblies that we currently have in progress. This will then automatically kick off the process of internal reordering again which will allow us to offer a better value shorter lead time product to our customers on an ongoing basis. We do have hard work ahead of us but success will come with innovation, effort and teamwork. Thank you for taking the time to watch.

Steve Leadbeater, Kuka Now August 2023

Commercial and Supply Chain Manager

7.14 Letter from Head of Operations

KUKA

Mr Lee Jesic
Mechanical Engineering and Product Development Manager
KUKA Systems UK Ltd
Hereward Rise
Halesowen
B62 8AN

Friday 23rd February 2024

Dear Lee,

I am writing to extend my thanks to you and the Product Development Team and request that you share this letter with them. The work undertaken by the Product Development Team has resulted in improved efficiencies across the business and the way we procure and build our machines.

As a result of utilising standard modules in the make-up of our machines we now have the ability to build to stock. The net result gives us the opportunity to buy larger quantities thus reducing both lead times and procurement costs. The added advantage of using this approach means our stock is based on sales forecast and pipeline which will make our products more competitive and desirable within the market.

Thank you for the hard work and commitment by yourself and your extended team in driving this strategy forward. I very much look forward to working with you as we continue to sustain the efficiency improvements.

Yours sincerely,

Neal Owen
Head of Operations

7.15 Framework – Underpinning documentation

Manual

Achieving production efficiencies HVLVHL Machinery

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1 Description

The following manual aims to support personnel in achieving production efficiencies during the mechanical design phase when dealing with HVLVHV machinery products. This document contains the framework for attaining said production efficiencies and the template document that aligns with the framework.

2 The HVLVHV production efficiency framework

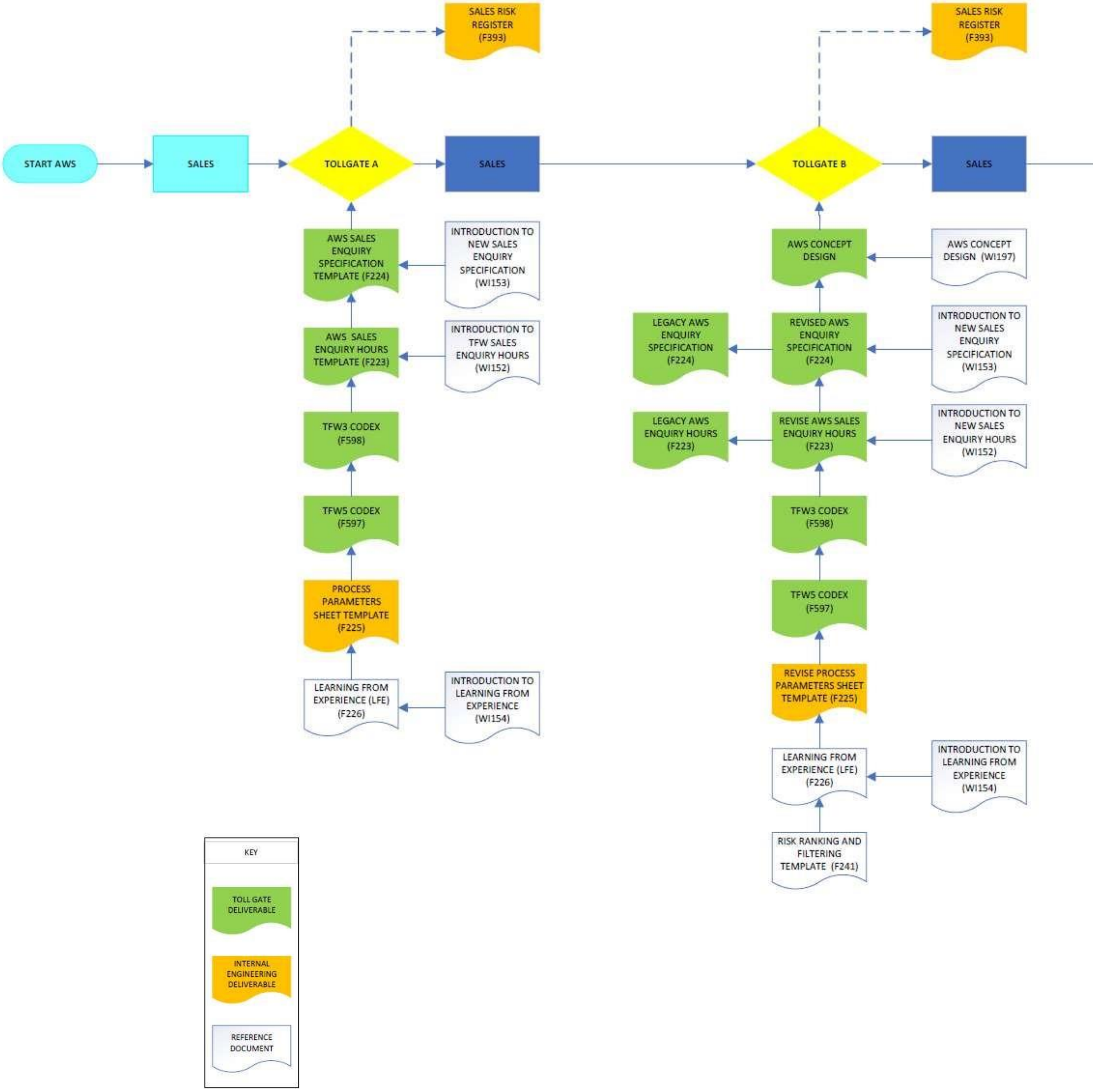


Figure 1, Cycle 3 - Framework, part 1

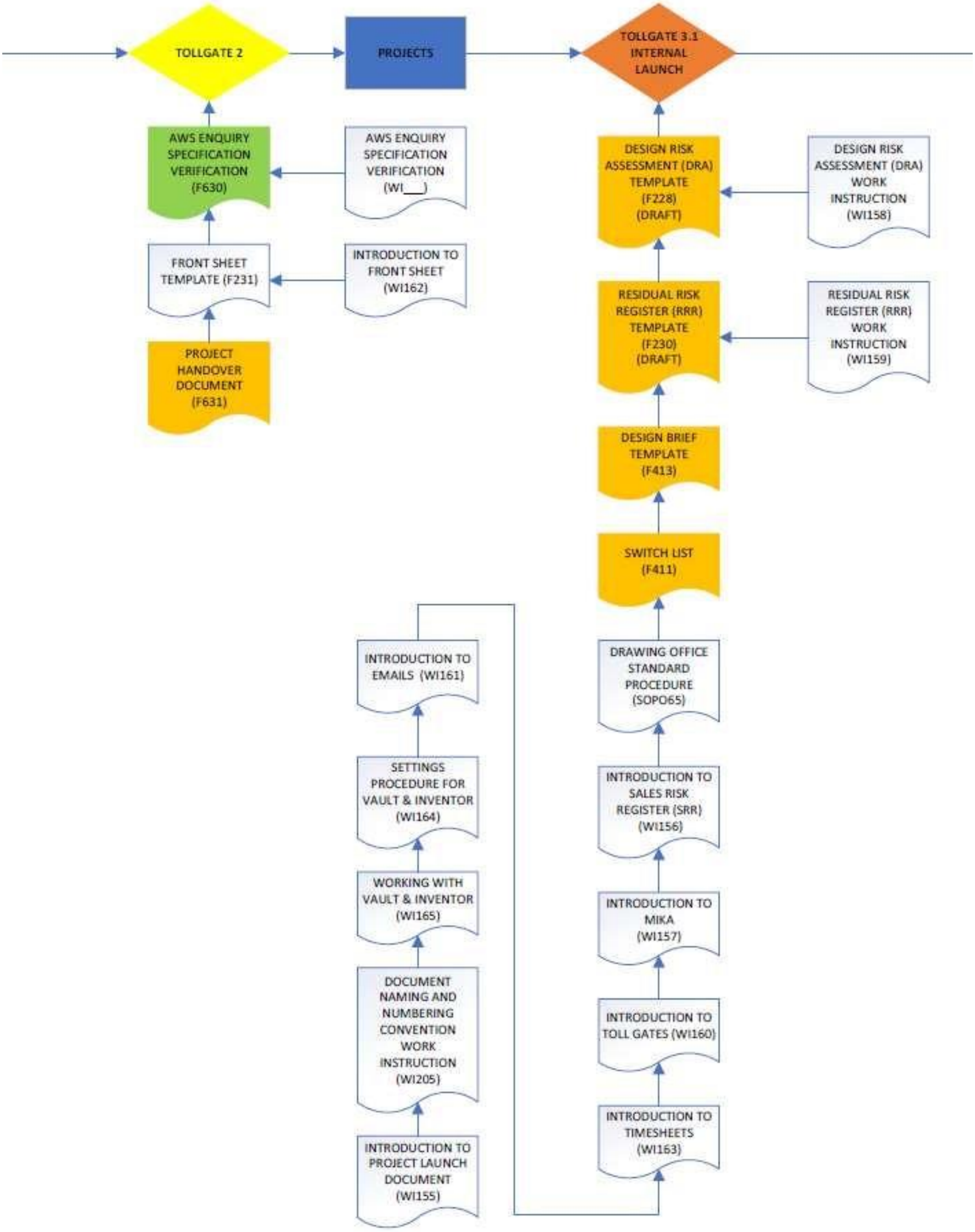


Figure 2, Cycle 3 - Framework, part 2

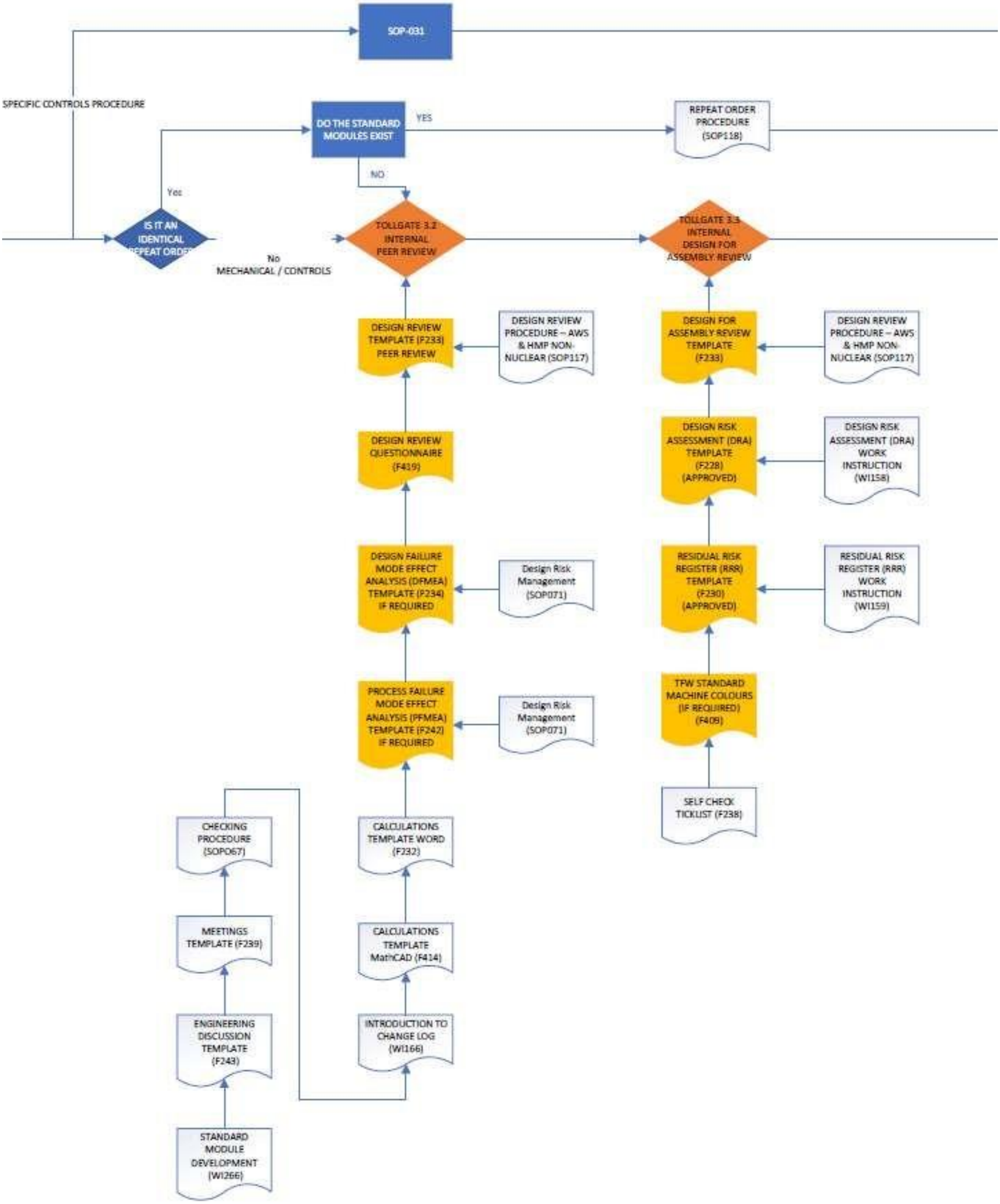


Figure 3, Cycle 3 - Framework, part 3

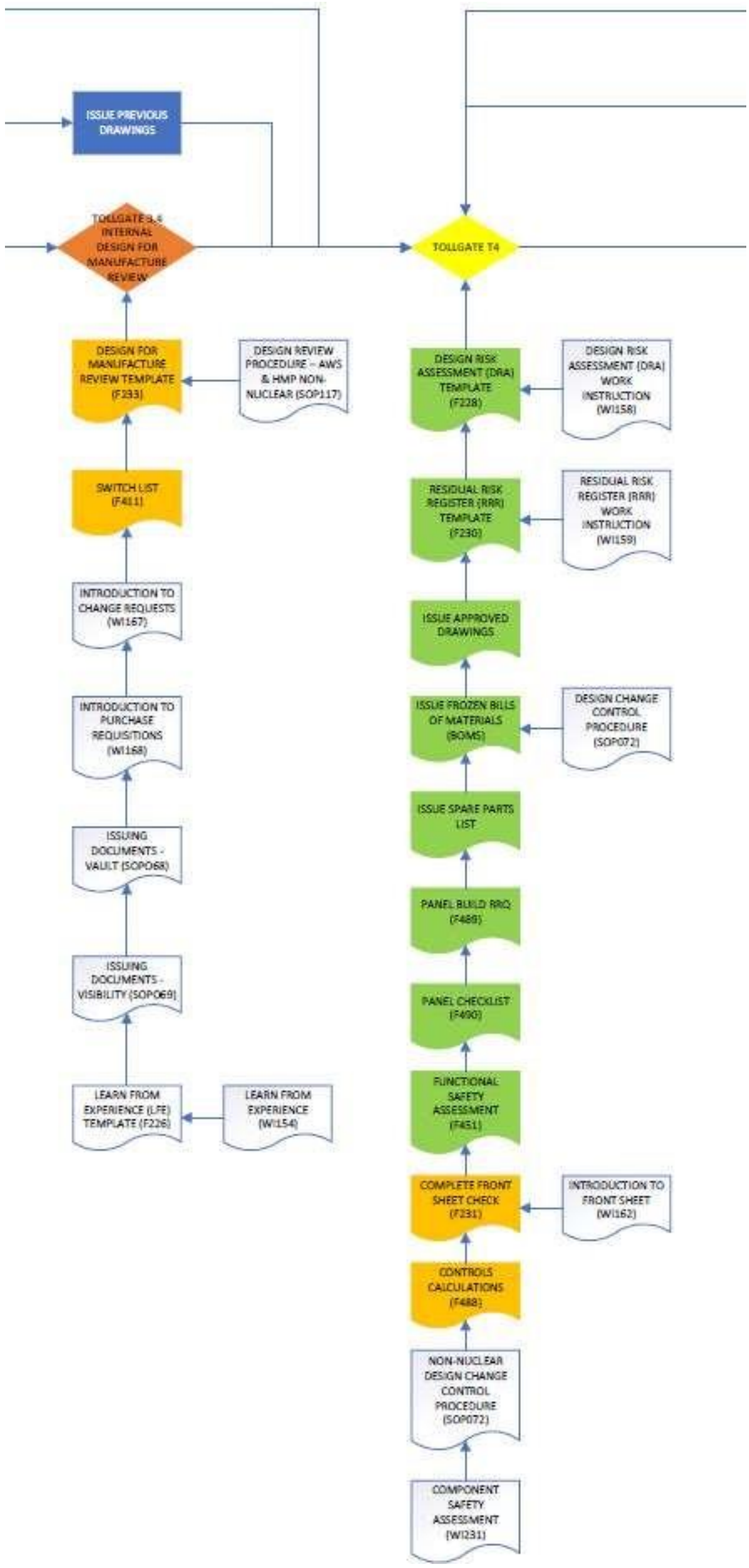


Figure 4, Cycle 3 - Framework, part 4

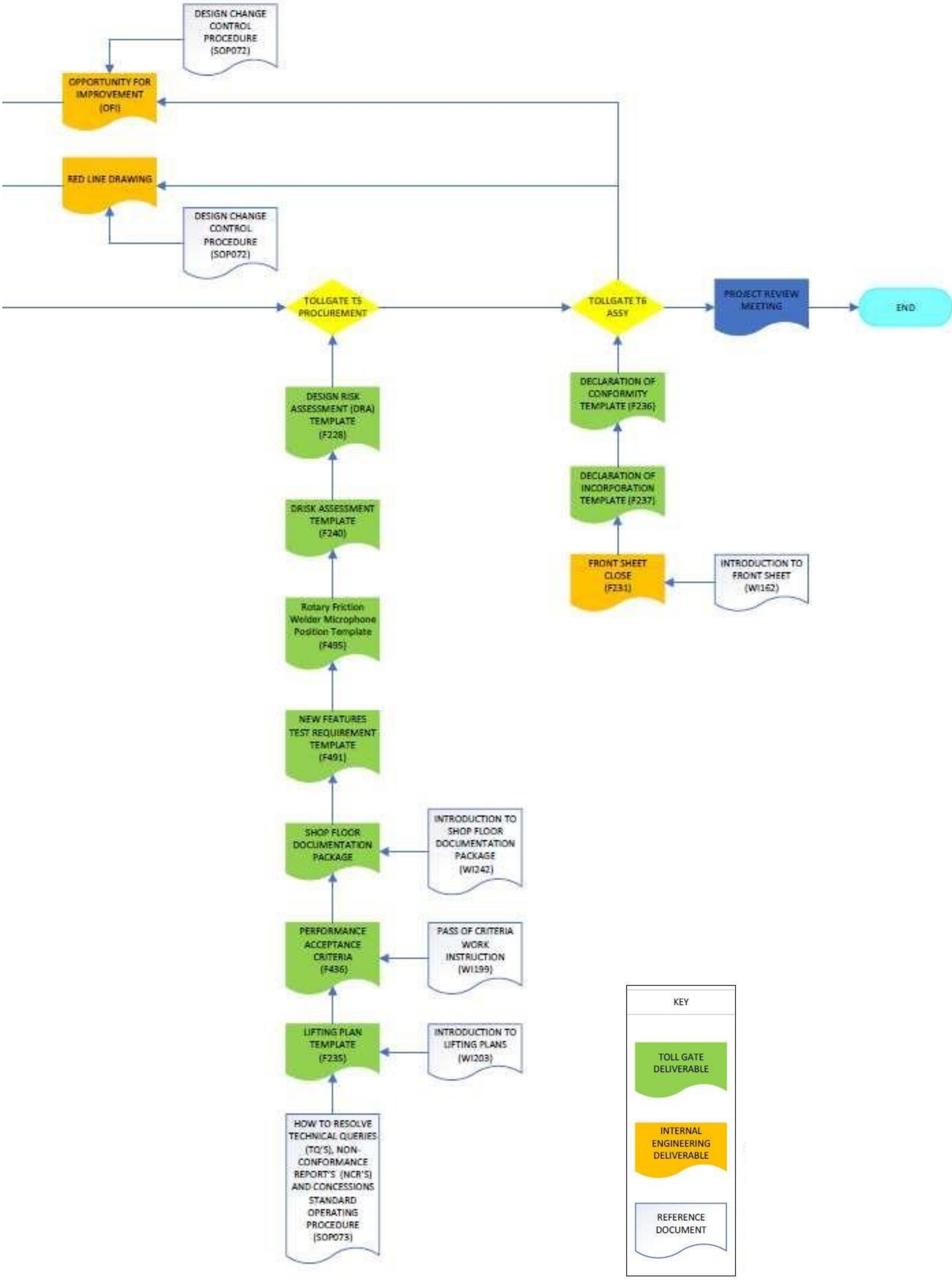


Figure 5, Cycle 3 - Framework, part 5

3 SOP065 – Drawing Office Standard

SOP065 - Drawing Office Standard

Document Number:	SOP065
Process Owner	
Description:	Drawing Office Standard

	Print Name	Sign	Date

Amendment History

Issue	Amendment	Author	Date
Draft	Initial Issue		

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
LFE	Learning From Experience
Responsible Person	Is the person given the responsibility for ensuring that the technical or engineering document is produced (or modified) in order to meet a specific business need.

1, Purpose

The purpose of this procedure is to provide an overview of the arrangements for the management of any design projects, to promote understanding and therefore successful delivery of design solutions to support projects. The procedure outlines the engineering standards to which the company should aspire.

The procedure provides a summary of:

- Legislation and regulatory requirements to be met by the organisation and how they impact on the design arrangements.
- Design principles and expectations of the design solutions including the application of risk informed solutions.
- The company practices and procedures which form our design process.
- The engineering standards that are used to deliver the detailed design.
- The design guidance that is available to support development of designs and maintenance of existing designs.

2, Quality Management System Requirements

The design arrangements are certified to Quality Management Standard ISO 9001:2015 and address the arrangements from design concept through to design implementation.

3, Regulations

The design arrangements and design solutions are required to meet Legislation and Directives such as the Health and Safety at Work Act 1974 (HASAWA). A significant number of Acts may apply to any individual design and are supported by the relevant Code of Practice. The Responsible Person is required to identify the relevant legislation and ensure that it is delivered by the design solution.

The procedure arrangements include provision to ensure the control and delivery of a design solution that will meet relevant Legislation. Reference is made for the ‘designer’ to produce and control a Register of Regulations to which the design solution shall be delivered.

4, Engineering Standards

Detailed design is developed by the suitable selection and application of engineering standards. The specific design functions also possess a series of design guides to inform the designer of good practice and experience on aspects of the design.

Throughout the complete lifecycle engineering design relies heavily on the use of engineering standards. Their use may be required to meet the law, ensure performance/reliability for safe operation, to enable substantiation or reliability claims for safety analysis, repeatability, or compatibility. Therefore, it is important that adequate and appropriate standards are identified, selected, used and conformance verified.

Nominally the expected hierarchical use or selection of Standards would be as indicated in the list below:

1. International – IAEA, European, worldwide adopted US standards,
Japanese 2. National – BS EN (European harmonised), BS, DIN
3. Company Standards.

The use of design standards provides numerous benefits including predictability of outcome, consistency of quality and interchangeability. They provide a benchmark and yardstick to judge conformance and alternatives. The application of standards also promotes solutions & practices that work (national, industry or the company) and a reference point for later evaluations including cost savings. The company accesses and uses both external and internal standards. The external standards are enabled through a licensed service provider via a periodically renewed contract.

<u>All</u> design work will be carried out to BS 8888: 2017 – Technical Product Documentation and Specification. As a minimum.

5, Procedures

For all Procedures, please see Procedure SOP10 – Design Procedure.

6, Design Process

The use of a structured design process provides confidence in the technical adequacy of a design and ensures that the design satisfies the requirements and includes additional design input considerations such as constructability, operability, and operating experience.

Principles:

Design Start-up and Strategy:

- A clearly defined Specification is agreed before design work is initiated.
- The Specification will identify any relevant historical information, Learning from Experience (LFE).
- The scope of Specification is clear, unambiguous, and agreed prior to commencing work.
- Selection of procedures and standards are appropriate to the scope of work.
- The use of Computer Aided Engineering tools is appropriate to the work and takes due account of configuration management, future record keeping and modification requirements.
- Technical risks are identified, recorded, owned, eliminated, or mitigated, and have fallback plans.
- Residual risks are communicated to those affected.

Specification of Requirements:

- The Specification is produced for all design work appropriate to the size and complexity of the scope.

- Specification contains the functional requirements and relevant constraints for each stage of the complete life cycle. Where requirements / constraints apply to more than one stage they clearly identify the stages to which they apply.
- Data and drawings issued as part of the Specification are verified for accuracy as far as possible prior to issue.
- Where appropriate, Specifications are checked and validated prior to approval.
- Key stakeholders validate each requirement as necessary and that all requirements have been captured. Validation tests each requirement with the questions “how will I know if it has been achieved? Will the intended deliverer understand what is required?

Recording the Design Intent:

- Design intent is captured so that it can be maintained through all following life-cycle stages.
- Recording of design intent includes manufacturing processes where this impacts significantly on the characteristics of the equipment.

Verification of the Design:

- Modelling and analysis should be used appropriately during the design process to verify the design.
- All engineering work is checked and approved in line with SOP067 - How to Produce, Check & Approve Technical and Engineering Documents.
- Assumptions used in computer models and calculations are verified.
- Design reviews are scheduled according to the significance of the design. Reviews check compliance with the requirements and corporate standards. See Procedure SOP066 – Design Review Procedure.
- Testing at works, on rigs, on installation or during commissioning is performed to assure that the systems or equipment performs according to the design requirements.
- The extent and location of testing is commensurate with the consequences of potential nonconformity with the design intent.

4 SOP067 – How to Produce, Check & Approve Technical and Engineering Documents

SOP067 - How to Produce, Check & Approve Technical and Engineering Documents

Document Number:	SOP067
Process Owner	
Description:	How to Produce, Check & Approve Technical and Engineering Documents

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
Approver	Is the person appointed by the Responsible Person to validate that the document is fit for its intended purpose, meets the customer requirements, and can be released for its intended use.
CAD	Computer-Aided Design
Checker	Is the person (or team of people) appointed by the Responsible Person to verify the technical and engineering content of the document.
PDF	Portable Document Format
Producer	Is the person (or team of people) appointed by the Responsible person to produce (i.e. prepare, draft, create, or modify, etc.) the technical or engineering document
Responsible Person	Is the person given the responsibility for ensuring that the technical or engineering document is produced (or modified) in order to meet a specific business need.
Technical and engineering document	May be any document which contains technical, engineering, or other related information intended to be shared with or communicated to others, or to record information as a business record. This could include both physical documents, such as Design Brief's, drawings, calculations, technical reports, etc. as well as electronic documents, such as word-processed document files, PDFs, CAD drawing files, etc.

1, Purpose

The purpose of this procedure is to assist those involved in the production, checking, or approval of technical and engineering documents to ensure that a consistent quality and approach to the delivery of these documents is followed within the company.

2, Scope

This procedure applies to all technical and engineering documents produced by the company. personnel or external organisations working on the company’s behalf. It applies to all technical and engineering documents produced by the company using the company Templates, drawing frames, or forms etc. regardless of whether the documents are produced in-house by the company staff or whether they are produced by external/other organisations for the company.

This procedure need not apply to documents which have been produced by external organisations using their own templates, drawing frames, or forms, etc. where that organisation retains responsibility for and control over the technical contents of the document. However, the company employee responsible for the relevant overall work package must ensure that the external organisation employs appropriate arrangements to ensure the quality of its documents is equivalent to those produced following this procedure, a Design Review may be required where the company employee responsible shall be in attendance.

3, Process

3.1, Identify the Need to Produce a Document

The production of any document (including non-technical or engineering documents) must be based on a clear business need or requirement for the use of that document.

This need could come from the requirement to transfer verified information from one group to another, for example, a scheme drawing, or technical specification used to convey information / requirements to a sub-contractor who are producing automation for integration into an automated cell. It could arise from the need to record a decision or outcome, such as the minutes of a meeting or a note for the record.

Typically, technical and engineering documents will be identified as deliverables within a project, task, or contract.

In identifying a need to produce a document it is essential that thought is given to the intended reader(s) of the document and the purpose for which the document is to be used. Technical or Engineering documents should not be produced unless there is a clear business need, a defined purpose for the document, and an identified intended reader (or group of readers) for the document.

In identifying the need for the document, the Responsible Person must consider:

- The type of document required. (eg. a technical specification versus a drawing); Who retains control of the document?
- What kind of information it should contain?

3.2, Appointing a Responsible Person

Typically, the Responsible Person will be a defined role holder within a project team such as, a Project Manager, Design Manager, Project Engineering Manager, or Responsible Engineer, etc. or a manager within a department or functional group.

The appointment of Responsible Person to produce documents may come from the role itself, such as Project Manager, where the role description identifies this accountability. However, such an appointment could be made for a specific task where their accountability has not been identified previously.

The Responsible Person must satisfy themselves that they fully understand the business requirements for the document(s) to be produced and their intended use or purpose. The Responsible Person must ensure that the appropriate competent people are selected, and that enough time and resources are allocated to produce the document.

Where the requirement covers multiple documents, the Responsible Person should draw up a schedule to identify the number and type of documents required and identify the production and validation & verification arrangements appropriate to each.

Where the company documents will be produced by external organisations or other third parties, the Responsible Person must ensure that, as part of the contractual arrangements, the external organisation is made aware of the company requirements for the documents to be produced and their intended use or purpose.

The Responsible Person must ensure that the external organisation allocates enough time and competent resources to deliver the documents to the required quality.

3.3, Establish Checking Level Required

The Responsible Person must assign a level of checking commensurate with the purpose of the document to be produced, its intended use, and the risks associated with errors, omissions, or ambiguity.

The Responsible Person must identify the appropriate level of checking required for the document(s) before production of the document commences.

In determining the level of checking required for the document(s) the Responsible Person must consider the following issues:

- What is the purpose of the document?
- What type of document is to be produced?
- What is the significance of the document to the project / to the company?
- At what stage will the document be used by the project?
- What are the consequences of inadequate content or inaccuracy?

The Responsible Person must ensure that enough time and resources are allocated within the delivery programme to check the document to the assigned level. The level of checking assigned by the Responsible Person must not be dictated by the remaining time available to the Project. The Responsible Person must plan and secure enough time and resources within the programme of work to check the document to the appropriate level.

The Responsible Person must also plan and secure enough time and resources within the programme of work to carry out any reviews or other governance activities which may be necessary for certain documents.

Guidance on the typical requirements for each level of checking is given in APPENDIX 1.

3.4, Appointing the Producer, Checker and Approver

The Responsible Person must appoint suitably qualified and experienced people to fulfil the roles of Producer, Checker, and Approver of the document.

The Responsible Person must ensure that the people appointed to carry out these roles are competent to do the work, i.e. they possess the appropriate skills, knowledge, experience, and training to undertake the work for which they have been selected.

The Responsible Person can appoint themselves to any of the roles if they possess the appropriate skills, knowledge, experience, and training to carry out the role. Typically, the Responsible Person might wish to take the role of Approver. However, the Responsible person can fulfil the role of Producer or Checker where it is appropriate to do so, and they possess the necessary skills, knowledge, and experience for that type of document.

The Responsible Person should ensure that the appointments are recorded in the Quality Plan (or similar document) for the project or work package.

- The Responsible Person must ensure that the Producer (or Production Team, where the document covers several disciplines or specialities within disciplines) has the appropriate skills, knowledge, experience, and training to produce the complete document assigned, to the appropriate standard and quality. This applies both to the production of new documents and to the modification of existing documents.

- The Responsible Person must ensure that the Checker (or Checking Team, where the document covers several disciplines or specialities within disciplines) has the appropriate skills, knowledge, experience, and training to check the complete document assigned, to the appropriate standard and quality, as required for the level of checking allocated. This applies both to the checking of new documents and to the checking of existing documents after they have been modified. The Responsible Person \must ensure that the Checker is independent and did not play a part in the production of the document for which he has been appointed to check.

The Responsible Person must ensure that the Approver has the appropriate skills, knowledge, experience, training, and authority to approve the document. There should only be a single Approver required for any document. This applies both to the approval of new documents and to the approval of existing documents after they have been modified.

However, for some types of documents, individuals may only be authorised to carry out a specific role by their appointment to an organisational position or through a delegated power.

This may be identified within the company training records and their competency covered by formal role or line management assessment.

3.5, Producing the Document

The production of a document refers to both the generation of a new document or the modification of an existing document.

For many documents there will be an obvious and clearly identifiable Producer. For example, where the document is a conventional CAD drawing, the Producer is typically the engineer or designer who created the drawing. For other documents, such as specifications or reports, there may be more than one Producer for the document, especially where the document is a multi-disciplinary document which covers several technical or engineering disciplines or specialities within disciplines. In the instance of multiple people compiling the document this will then be known as a production team.

The Producer must have the appropriate skills, knowledge, experience, and training to produce the complete document allocated to them to the appropriate standard and quality.

Where the appointed Producer is not considered to be fully competent, for example, where they are still training (such as an apprentice, graduate, or junior engineer) and is working under the supervision of a Mentor or other supervisor, care should be taken to ensure that the true Producer is identified. Where mentors or supervisors are working in this way they must not be appointed as the Checker for the document, see section 3.6)

The Producer should produce the document to meet the specific business needs identified. The document should be suitable and enough to deliver the business need, avoiding unnecessary or redundant detail. The Producer should create a document which addresses the specific need at hand and must avoid creating complex or catch-all documents which might address some future, yet undefined, potential use for the document.

The Producer must produce the document in line with the appropriate standards, guides, and Codes of Practice, etc. for that type of document. The Producer must ensure that the document is produced using the correct forms or templates for that type of document and is written in an appropriate style for its intended reader(s) and its intended use. See company Procedure SOP065 – Drawing Office Standard Procedure.

The Producer must ensure that the finished document:

- Fully complete.
- Suitable and enough for its intended purpose.
- Avoids ambiguity, needless generalities, repetition, and unnecessary background information.
- Ensure the document includes appropriate references to supporting documents and source material.

The Producer must ensure that his full name (or the names of the Production Team, where applicable) is stated clearly within the document, for example, on the front sheet for a specification or in the modification box for drawings, etc.

Where existing documents are being modified or amended the Producer must ensure that the reasons for the amendments are identified appropriately within the document or Change Request Process (See company Work Instruction WI167 – Introduction to Change Requests) so that a clear audit trail for the modification is maintained.

This can be done in several ways:

- In the case of drawings, the Producer should state clearly the revised purpose of the document (which might be different to the original purpose at the time it was first produced), the reasons for the modification and, where appropriate, what has changed in the modified drawing in the 'mod box' on the drawing sheet.
- For other documents, such as technical reports, specification's, etc. the Producer should state clearly the reasons for the modification and, where appropriate, the key aspects which have changed in the modified document —either in a 'history sheet' or in the body of the document. This could be included within the 'purpose', 'scope', or an 'introduction' at the beginning of the document.

Basic checks:

Before issuing the checking print to the Checker, the Producer must carry out their own 'Self-check' of the document to ensure that it is complete and of an acceptable quality to issue for checking. See company Work Instruction F238 –Self Check Tick List Template.

Once the Producer has completed the document, they should issue a copy of the document to the Checker for checking.

3.6, Issuing the Document for Checking

Checking refers to the process of confirming that the document is complete and free from errors and/or omissions, i.e. verifying the technical content of the work to a level corresponding with its purpose and appropriate for the customer's needs. Where multiple Checkers are involved in the checking of a document those involved are termed the Checking Team.

A checking print is a printed hard copy of the document used by the Checker to verify the technical content of the document. The Checker does this by marking the document to confirm the information, to amend incorrect information, to add missing information, or to comment on ambiguous information.

The Checker or Checking Team must have the appropriate skills, knowledge, experience, and training to check the complete document allocated to them to the appropriate standard and quality.

The purpose of checking documents -

The purpose of checking is to confirm that the document is error free before it is approved and released to the intended readers for its intended purpose. The process of checking must not be used to complete part-finished or sub-standard documents.

The checking process is intended to ensure that:

- The document is error-free.
- The document meets the business need.
- The document is fit for its intended purpose.
- The document has been written in a style that is suitable for its intended reader(s).
- The document has been produced using the appropriate methods and standards.
- The document has been produced using the appropriate templates or forms
- The document contains valid technical content, including relevant metadata and references.
- The document is suitable for use, processing, and retention as a record.

The Checker must check the whole document to the appropriate level (see appendix 1) by methodically reading, analysing, and verifying each statement. Where the document being checked is one which has been amended or modified the Checker must check the whole document and any related documents and not just the elements of the current document which have been amended, added, or deleted from the previous version.

Notes for the Checker -

In order to demonstrate that a systematic and methodical approach has been taken by the Checker the following convention for marking the checking print should be adopted by the Checker:

- Verification or confirmation of a statement should be indicated by tick (or similar mark) in BLACK on the checking print.
- Deletions should be indicated by striking through the text (or other content) using a BLUE pen;
- Corrections or additions to the text should be marked clearly using RED a pen, and;
- Comments, queries, or requests for clarification should be marked clearly using a GREEN pen.

Should any deletions, additions, corrections, or other comments be identified by the Checker he should discuss his findings with the Producer and then return the document to the Producer to carry out the corrections or other adjustments he has marked on the checking print (i.e. repeat step 3.5).

3.7, Is the Document ready for Approval?

No errors identified:

Following the checking stage, if the Checker considers that the checking print is error-free and has been produced to the required quality, the Checker must pass the checking print to the Approver to demonstrate that the information within the document has been verified and the checking process is complete.

Errors identified by the Checker:

Following the checking stage, if the checking print is not considered error-free the Checker must return the annotated checking print to the Producer to amend as indicated (i.e. repeat from step 3.5).

However, if the following points have been observed:

- There are several substantial defects.
- The type of defect identified is significant or critical to the functionality or safety of the technical content of the document.
- The document still contains errors following a previous return to the Producer for amendment. new defects have been introduced by the Producer during the amendment process.

The Checker must discuss the status of the document with the Responsible Person to determine a suitable solution.

a) the checking print should be returned to the Producer to amend the document as indicated; (repeat from step 3.5)
b) an alternative Producer should be appointed to amend the document; (repeat from step 3.4)
c) An alternative Checker should be appointed to re-check the document after it has been amended as directed by the original Checker, (repeat from step 3.4).
d) A new document should be produced which allows the technical and engineering content of the document to be presented more appropriately (ie. repeat from step 3.2)

The Responsible Person must decide which course of action is taken. In any case, the Producer of the amended document should generate a new checking print to be used by the Checker at the second iteration.

3.8, Issue the Document for Approval?

Following successful checking of the document the Checker must pass the final verified checking print to the Approver to demonstrate that the information within the document is error-free, to the required quality, and is suitable for approval.

The Approver must have the appropriate experience, training, knowledge of the requirement for the document, and the authority to validate that the document is fit for its intended purpose, meets the customer requirements, and to approve the document for release.

3.9, Is a Document / Design Review Required?

Within this procedure, a review refers to the process of independent scrutiny or peer review. However, before the document is approved, the Approver must ensure that any reviews which have been identified within the Quality Plan or Contract Requirements (or specified by other procedures) have been carried out. See company SOP066 - Design Review Procedure.

3.10, Review the Document / Design Review

Where the review process confirms that the document has been produced to the required quality, the Checker must pass the validated checking print (or the version of the document which was submitted for formal review) to the Approver to demonstrate that the information within the document has been verified and the checking and review process is complete.

Where a formal review of a document has been carried out it is often appropriate to record some details of the review in a review document. See company SOP066 - Design Review Procedure.

If, however, following a formal review amendment are suggested it must be returned to the Responsible Person determine what the most appropriate course of action is before the document can be approved and released for use.

Whilst the reviewers are responsible for the accuracy and validity of their advice or opinions it remains the responsibility of the Approver to ensure the document is fit for its intended purpose before it is released. Therefore, the Approver must decide whether any recommendations, deficiencies, or discussion points, etc. identified by the reviewers should be acted upon or not.

3.11, Approve the Document

The ‘Approver’ is the person appointed by the Responsible Person to validate that the document is fit for its intended purpose, meets the customer requirements, and can be released for its intended use. The Approver must have enough awareness of the business needs and requirements to understand the potential consequences of use of the document once it is released.

Where the approver considers that the document is fit for its intended use:

Following the checking stage (and review of the checking print) if the Approver considers that the document is error-free, has been produced to the required quality, and is fit for its intended use the Approver should approve a master copy the document by signing the document in the appropriate place and instructing the producer to release the document through Vault.

The Approver must ensure that the purpose for which the document has been approved is defined and identified clearly on the document. The purpose of approval should be clear, specific, and relate directly to the business need for which the document was produced —and the reason the document is released for use. For example, ‘APPROVAL FOR MANUFACTURE’, ‘APPROVAL FOR DESIGN REVIEW’ etc.

Upon completion the finished approved document must be forwarded to the appropriate Document Controller for formal issue and distribution See company Procedure SOP069 – Issuing Documents – Visibility or company Procedure SOP070 – Issuing Documents - Nuclear.

4, Appendices

4.1, Appendix 1

Checking refers to the process of confirming that the document is complete and free from errors and/or omissions —i.e. verifying the technical content of the work to a level commensurate with its purpose and appropriate for the customer’s needs.

The purpose of checking is to confirm that the document is error free before it is approved for release to the intended readers for its intended purpose.

The amount of effort required to check the document will depend on the type of document, the nature of its content, and the purpose for which the document will be used.

The ‘level of checking’ applied to any document should a measure of the relative importance of the document and the consequences of error, inaccuracy, or completeness. The level of checking is an indicator of the extent of the work or effort anticipated to verify the technical content of the document.

The level of checking is not a measure of the number of allowable mistakes; all documents should be error free after they have been checked —checking to Level 1 should yield an error-free document just as should a check to Level 3.

A document which contains errors after checking at whatever level is not fit for purpose.

For many documents a simple check of the arithmetic or technical statements will suffice. For some documents, such as calculations, a detailed check of the methodology or modelling technique might be required. For others, such as specifications, a comprehensive check of the references and supporting information might be necessary to confirm that the document is fit for its intended purpose.

The following table provides guidance on what is expected for the level of checking assigned:

Typical Checking Requirements for this level	The check should confirm:
Level 1	
Proof-read the complete document	The document content is readable, understandable, and in logical sequence. The author (and company) have been identified. It is correctly/uniquely identified with the appropriate reference number, and the version/modification status is identified.
Order of magnitude checks for any technical content	Any figures & values used are correct to the appropriate accuracy (eg. round figures rather than many decimal places.) Any values, statements, or figures used are appropriate for the document and are credible.

Confirmation of validity of any reference documents identified	Any supporting references identified are available and appropriate to the document. The information contained in the references should not be essential to the use or understanding of the document but should be identified to substantiate or establish the source of information in the document.
Fit for purpose' check, i.e. confirm the document meets the business requirement and is appropriate for its intended use.	Conforms to quality requirements and format
Completed and validated in accordance with company or external rules, processes, procedures, codes and standards	Any protective marking on the document is appropriate for content

<u>Level 1 checking should not be assigned to any documents with any safety significance.</u>

Level 1 checking should only be assigned to documents with a low financial, programme, or commercial consequences if found to be incorrect —or documents where there is an opportunity to correct such defects readily.

Typically, Level 1 checking should only be assigned to documents such as those issued for estimating or assessment purposes, rather than action, where a subsequent check will be carried out (usually to Level 2 or 3) before the document is issued.

For example, a document could be checked at Level 1 for approval for issue for the purpose of estimating or evaluation but will be checked to a higher level before it is approved and released for the purpose of manufacture.

<table>
<tr><td colspan="2">Level 2</td></tr>
<tr><td>Consisting of Level 1 Check with the inclusion of the following:</td><td></td></tr>
<tr><td>Validate the arithmetic or technical basis</td><td>The Checker should re-trace the Producer’s steps in producing the document, e.g. Follow step-by-step the calculation, or re-assess the technical basis and methodology of the report.</td></tr>
<tr><td>Validate accuracy of the content</td><td>Any figures & values used are correct to the appropriate accuracy, this is likely to be a higher degree of precision or accuracy than a level 1 check (e.g. decimal places not round figures.)</td></tr>
<tr><td>Confirm the adequacy of the audit trail</td><td>Any supporting references identified are the valid, at the latest version, and the data selected from the reference source is correct and valid.</td></tr>
<tr><td colspan="2"><u>Level 2 checking should only be assigned to documents with minor safety significance.</u>

Level 2 checking should only be assigned to documents for action (eg. manufacture, purchasing) where the Responsible Person has determined that the safety, operational, financial, programme, or commercial consequences will be low if later found to be incorrect.</td></tr>
<tr><td colspan="2">Level 3</td></tr>
<tr><td>Consisting of Level 2 Check with the inclusion of the following:</td><td></td></tr>
<tr><td>A comprehensive check of the total contents of document</td><td>A level 3 check should look for ambiguity, error traps, etc. in the content or presentation.

Any figures & values used are correct to a higher degree of precision or accuracy (e.g. >2 decimal places or fine tolerances.)</td></tr>
</table>

Verify that learning (internal and external sources) from similar applications has been researched and incorporated	In the case of calculations, where novel methods have been used (for example computer modelling or FE analysis) more conventional methods should be deployed to confirm the validity of the results.
	For some types of documents, a specific type of checking process might be required (e.g. A defined approach or methodology to confirm the validity of the technical content.

<u>Level 3 checking should be assigned to any documents with safety significance —including conventional, nuclear, radiological, chemo toxic, or environmental —or other business liabilities or consequences for the company.</u>

Level 3 checking should be assigned to any documents where the Responsible Person has determined that the safety, operational, financial, programme, or commercial consequences could be substantial if later found to be incorrect.

4.2, Flow Diagram

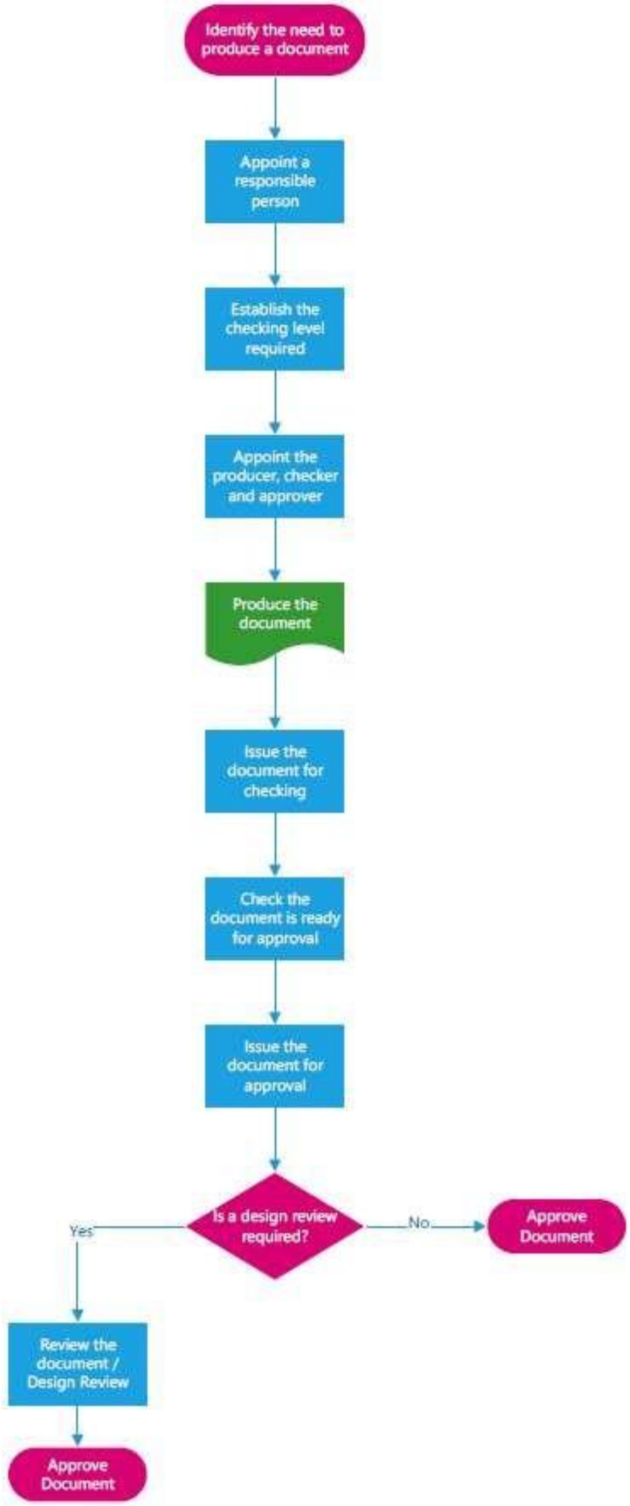


Figure 6, Producing, Checking and Approving documents process flow

5 SOP068 – Issuing Documents - Vault

SOP068 - Issuing Documents - Vault

Document Number:	SOP068
Process Owner	
Description:	Issuing Documents - Vault

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
Draft			
01			
02			

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
DMS	Document Management System
Document	May be any document which contains technical, engineering, or other related information intended to be shared with or communicated to others, or to record information as a business record. This could include both physical documents, such as specification's, drawings, calculations, technical reports, etc. as well as electronic documents, such as word-processed document files, PDFs, CAD drawing files, etc.
DMS	Document Management System
PDF	Portable Document format
Producer	Is the person (or team of people) appointed by the Responsible person to produce (i.e. prepare, draft, create, or modify, etc.) the technical or engineering document.
Responsible Person	Is the person given the responsibility for ensuring that the technical or engineering document is modified in order to meet a specific business need.

1, Purpose

This procedure defines the process which is to be followed by the Mechanical Engineering department when issuing or modifying documents.

2, Process

When the request / requirement for a drawing to be produced or modified has been processed, understood, and accepted by the Responsible Person they will issue the task to a Producer. Ensuring the process & requirements set out in the company Procedure SOP067 - How to Produce, Check & Approve Technical and Engineering Documents are being adhered to.

Upon completion of the task, the document will then be issued to the relevant parties by releasing the document to an 'Issued' state in the Vault. The issuing process is outlined within this procedure.

2.1, Document First Issue

For issuing a document for the first time the producer will follow these steps:

1. Assuming the Document is saved in the relevant folder within the Vault (See company Work Instruction WI14 – Working with Vault and Inventor). The document will be at ''Initial State' 0.1.
2. The relevant document can be issued in Vault from the 'Initial State' to 'Intermediate' using the change state action. The Document will now be at state 0.2.
3. The Document will be issued for checking. See company Procedure SOP067 - How to Produce, Check & Approve Technical and Engineering Documents.
4. Upon completion of step 3. The modification box on the Document will be updated to show who has checked / approved the Document.
5. The relevant document will then be up issued in Vault from the 'Intermediate' state to 'Issued' using the change state action. The Document will now be at state 1.
   Note: For Inventor Drawings the drawing file and associated models will need to be approved simultaneously due to Vault restrictions.
6. Once the document has been set to 'issued' within the Vault a Portable Document format (PDF) file will be automatically generated and stored within the Vault.

2.2, Document Modification

If a document needs to be updated or modified for any reason the producer will follow these steps:

1. The relevant document will be up issued in Vault from the ‘Issued’ state to ‘Initial State’ using the change state action. The Document will now be at state 1.1 for example.
2. The Producer must ensure that the reasons for the amendments are identified appropriately within the document or Change Request Process (See company Work Instruction WI16 – Introduction to Change Requests) so that a clear audit trail for the modification is maintained.
   This can be done in a number of ways:
   - In the case of drawings, the Producer should clearly state the revised purpose of the document (which might be different to the original purpose at the time it was first produced), the reasons for the modification and, where appropriate, what has changed in the modified drawing —either in ‘notes’ on the drawing or in the ‘mod box’ on the drawing sheet.
   - For other documents, such as technical reports, Specification`s, etc. the Producer should clearly state the reasons for the modification and, where appropriate, the key aspects which have changed in the modified document —either in a ‘history sheet’ or in the body of the document. This could be included within the ‘purpose’, ‘scope’, or an ‘introduction’ at the beginning of the document.
3. The Document is then to be updated to make them fit for purpose with the changes required.
4. The relevant document will be up issued in Vault from the ‘Initial’ state to ‘Intermediate’ using the change state action. The Document will now be at state 1.2 for example.
5. The Document will be issued for checking. See company Procedure SOP067 - How to Produce, Check & Approve Technical and Engineering Documents.
6. Upon completion of step 5. The modification box on the Document will be updated to show who has checked / approved the Document.
7. The relevant document will then be up issued in Vault from the ‘Intermediate’ state to ‘Issued’ using the change state action. The Document will now be at state 2 for example. Note: For Inventor Drawings the drawing file and associated models will need to be approved simultaneously due to Vault restrictions.
8. Once the document has been set to ‘issued’ within the Vault a PDF file will be automatically generated and stored within the Vault.

2.3, Document First Issue Flow Diagram

2.4, Document Modification Flow Diagram

6 SOP069 – Issuing Documents – Visibility

SOP069 - Issuing Documents - Visibility

Document Number:	SOP069
Process Owner	
Description:	Issuing Documents - Visibility

	Print Name	Sign	Date
Originator:			
Process Owner			
Process Owner			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
Draft	Initial Issue		

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
BOM	Bill of Materials
DMS	Document Management System
Document	May be any document which contains technical, engineering, or other related information intended to be shared with or communicated to others, or to record information as a business record. This could include both physical documents, such as FDS's, drawings, calculations, technical reports, etc. as well as electronic documents, such as word-processed document files, PDFs, CAD drawing files, etc.
Producer	Is defined as the person (or team of people) appointed by the Responsible person to produce (i.e. prepare, draft, create, or modify, etc.) the technical or engineering document
Responsible Person	Is defined as the person given the responsibility for ensuring that the technical or engineering document is modified in order to meet a specific business need.
RFC	Request for Change

1, Purpose

This procedure defines the process which is to be followed by the Mechanical Engineering department when issuing or modifying documents using Visibility.

2, Process

When the request / requirement for a drawing to be produced or modified has been processed, understood, and accepted by the Responsible Person they will issue the task to a Producer. Ensuring the process & requirements set out in company Procedure P04 - How to Produce, Check & Approve Technical and Engineering Documents are being adhered to.

Before drawings are issued to the purchasing or production department in accordance with the procedure explained below, please ensure all drawings are checked as per the 'Mechanical Engineering Drawing Modification & Checking Procedure' document and "issued" in Vault. If drawings aren't "issued" in Vault, the purchasing department are unable to view drawings and make arrangements for their manufacture.

2.1, Document First Issue

2.1.1, Visibility

For issuing a document for the first time the producer will follow these steps:

1. If required, create a front sheet for the contract you're working on. i.e. T70000. If a front sheet for the contract already exists with issued sub-assemblies, the revision of the front sheet must be raised.
2. Create a Bill of Materials (BOM) for the sub-assembly you're issuing using the General arrangement number i.e. T70000-A02A-200.
3. If "component part numbers" aren't already present within Visibility create them i.e. T70000A02A-301.
4. Populate the BOM with all manufactured parts and bought-out items.
   Note: The "Ref" number allocated to each item should match the associated item balloon called up on the general assembly drawing. As a rule of thumb manufactured parts are

allocated a “ref” number which corresponds with the last 3 digits of their “component part number”. i.e. “ref” 301 would correspond to “component part number” T70000-A02A-301. All bought-out items are allocated numbers from 500 onwards.

5. Add the sub-assembly BOM you’ve generated to the front sheet. If the revision of the front sheet requires raising as described in the first bullet point, ensure this is done so before the subassembly BOM is added. Check that the quantities of this sub-assembly are correct.
6. If the BOM is complete then change it to “Frozen”, see section 3.
7. Generate a PDF of the front sheet for the first issue of a BOM on the contract only.
8. If the revision of the front sheet has been raised to enable the sub-assembly to be added a Request for Change should be created.
9. The PDF of the First issue BOM should be saved with an appropriate file name i.e. T70000-First Issue within Vault.

2.1.2, Change Request (RFC)

1. Create a RFC document in Vault following "WI167 - Introduction to Change Requests", unless first issue of front sheet.
2. Populate accordingly and check against the BOM’s you’ve generated.
3. Change the status of the RFC document to “issued”.

2.1.3, Email

1. Create an email and populate with the relevant personnel from Production, Purchasing and Projects.
2. Write in the subject of the email the project number, project name, RFC number and a subject description i.e. Project Number: <T70000>, Project Name: <Customer Name>, RFC Number: <RFC0001>, Subject Description: <Head Assembly First Issue>.
3. Attach the RFC document or BOM for first issue to the email.
4. Write a brief description of the work undertaken.
5. Send email.
6. Store the email in the relevant contract folder in your inbox. If there isn’t a folder already created, create one.

2.2, Document Modification

If a document needs to be updated or modified for any reason the producer will follow these steps:

NB. If the BOM is frozen the steps in 3.1 should be followed.

2.2.1, Visibility

1. Raise the revision of the front sheet and sub-assembly you're modifying. Ensure the revision of the BOM's are raised in this particular order.
2. Raise the revision of the "component part number" you're modifying. Alternatively, add the new "component part number" or bought out item to the sub-assembly BOM.
3. Generate a change request detailing the change.

2.2.2, Change Request (RFC)

1. Create a RFC document in Vault.
2. List all modified, added or removed parts and check against the BOM's you've generated.
3. Change the status of the RFC document to "issued".

2.2.3, Email

1. Create an email and populate with the relevant personnel from Production, Purchasing and Projects.
2. Write in the subject of the email the project number, project name, RFC number and a subject description i.e. Project Number: T70000, Project Name: <Customer Name>, RFC Number: 0001, Subject Description: Head Assembly Modification.
3. Attach the RFC document to the email.
4. Write a brief description of the work undertaken.
5. Send email.
6. Store the email in the relevant contract folder in your inbox. If there isn't a folder already created, create one.

2.2.4, Reference Only Modifications

In certain instances, a requirement to record modifications undertaken by the shop floor may be requested. If this is the case, the procedures outlined above should be followed. The RFC document and email should clearly state that the modification undertaken is reference only, and no action is required. This prevents unnecessary work for the purchasing department. The exception to this is detailed in the following sections:

2.2.5, User Error Modifications

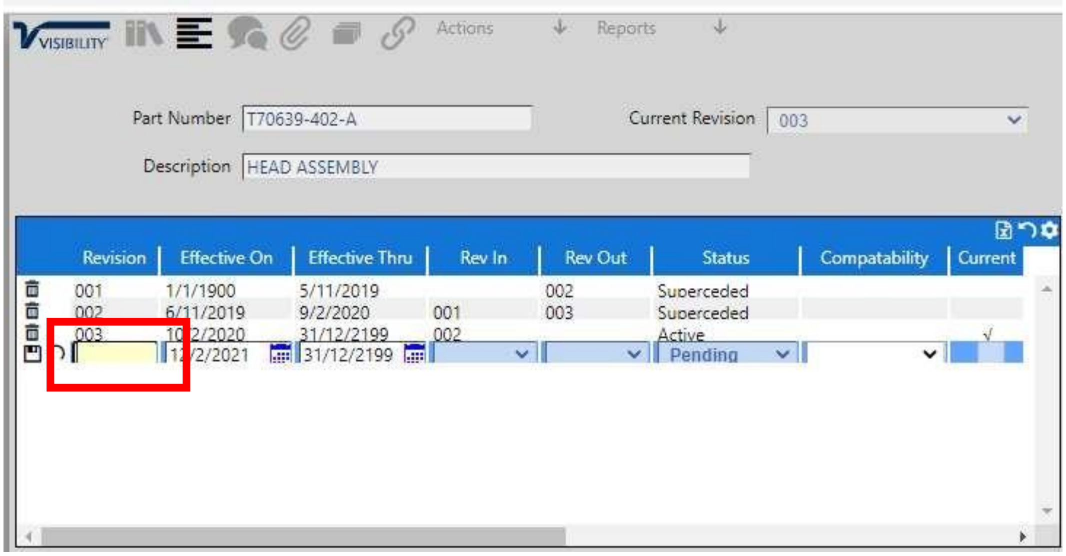
If for whatever reason a drawing requires modifying but the function of the part hasn't been affected i.e. adding a missing dimension, the following procedure should be followed.

1. Raise the revision of the front sheet and sub-assembly you're modifying. Ensure the revision of the BOM's are raised in this particular order.
2. Raise the revision of the "component part number" you're modifying. Ensure the revision of the "component part number" is raised after completion of the first bullet point.
3. No RFC or PDF document needs to be created.
4. No email needs to be sent.

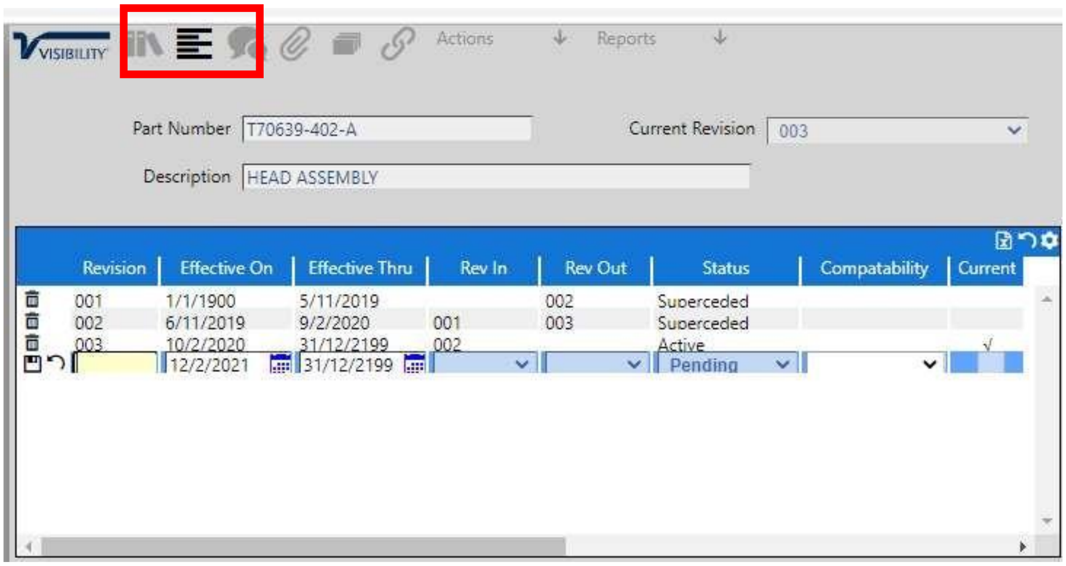
3, Frozen BOMs in Visibility

Upon completion of a Machine/Cell sub-section all drawings and Bills of Material's (BOMs) should be issued to procurement as and when they are checked and approved. The procedure detailed in previous sections should be followed. Once the BOM and all Drawings are issued the BOM should be converted to a frozen state, and this should be communicated to procurement. To communicate to procurement that the BOM is in a Frozen state the procedure above should be followed and upon issuing the final issue the following steps should be followed.

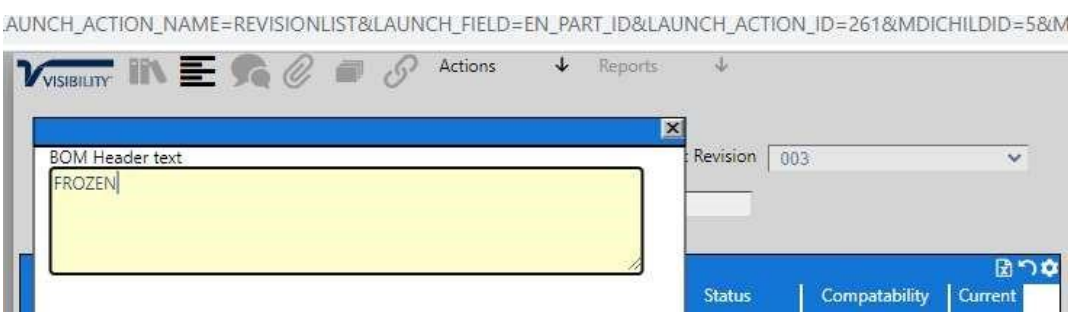
- Up rev the part to the next sequential number, typing it into the Revision column shown below.



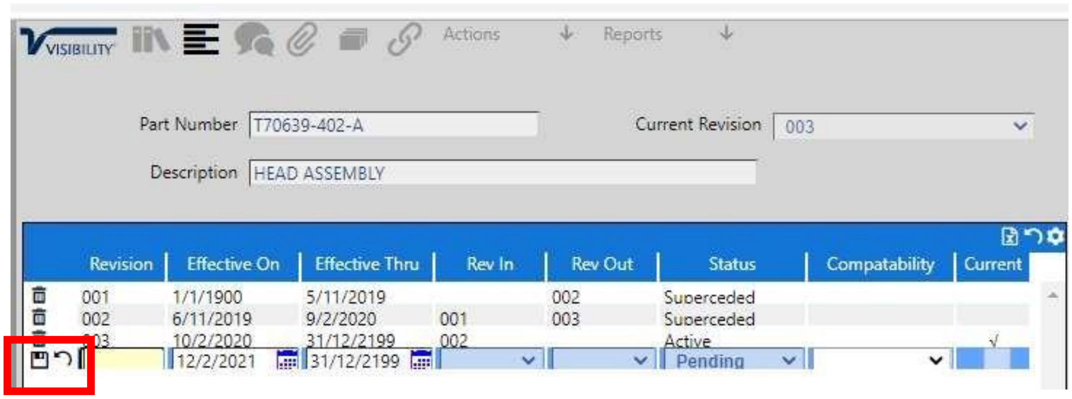
- Click on the text Icon.



- Type Frozen in the text box.



- Save the change.



These drawings are then defined as approved status or freeze point and cannot be changed until the end of the contract. All BOM's that have been issued to procurement should have a PDF created and this should be added to the relevant contract folder within Vault. Any drawings being issued on that BOM should be checked within Vault. The check should include checking that the latest issue of the drawings matches with the revision in vault and that only the latest issue of the drawing is in the contract folder. Therefore, any old revision levels of the drawing should be added to the Archive folder within the relevant contract folder in Vault. In the instance of an approved technical and engineering document needs to be modified then the process "SOP072 – Non-Nuclear Design Change control" must be adhered to.

3.1, Procuring goods on a Frozen BOM

If for any reason an oversight has occurred and parts are missing from a frozen BOM that need procurement, then the following steps should be taken.

1. Ensure the parts are in visibility so that they can be added to the BOM when appropriate but don’t change any BOM’s.

2. Email the purchasing manager requesting the parts are added to the BOM stating the sections, quantity, and description as below:

K05792-4100

1-off - 219504 - CALIBRATION PLATE 10mm

K05792-4500

4-off - F1235-00997 - Ø22 (M20) WASHER DIN 9021 – BZP

K05792-4262

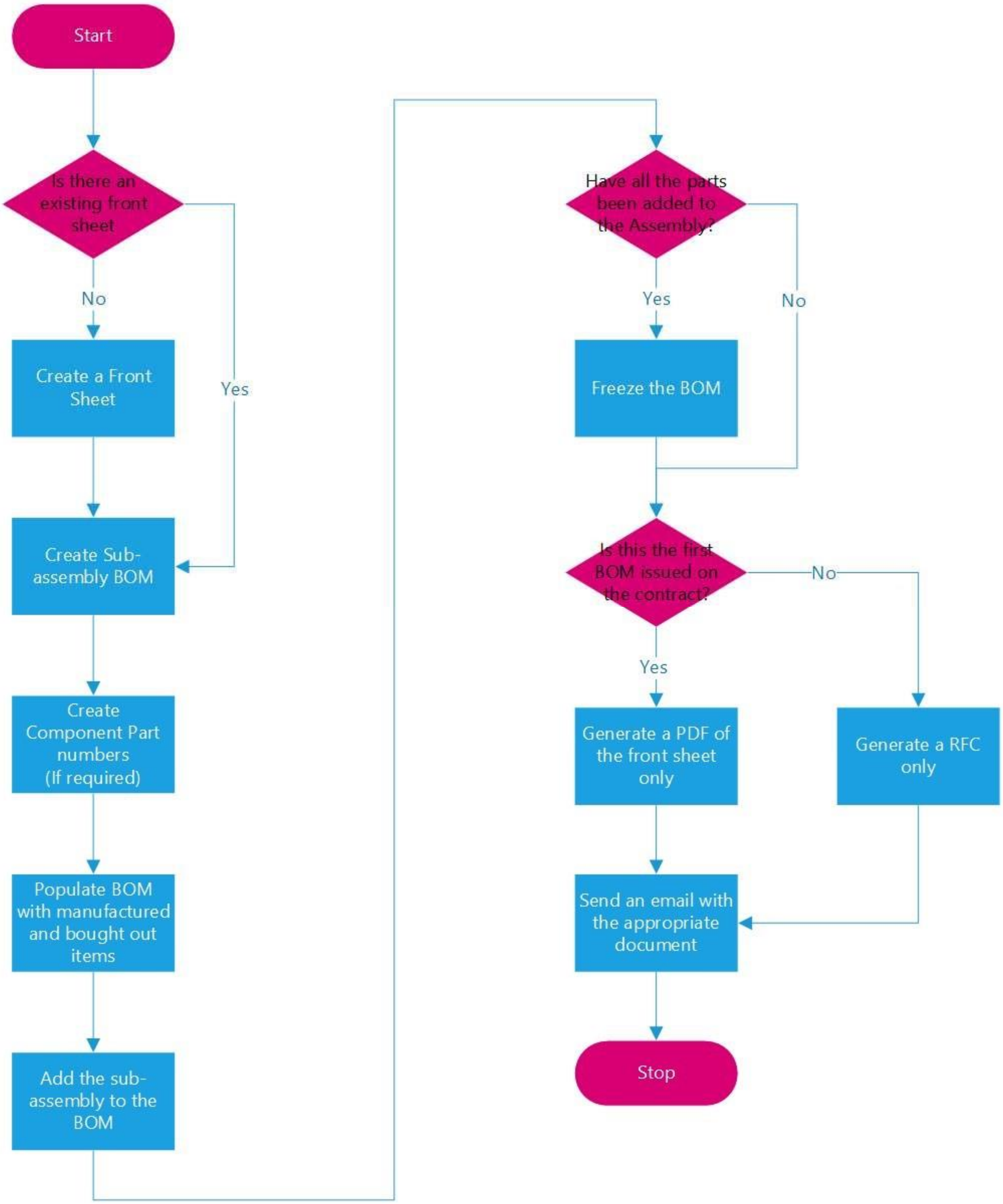
1-off - M1064-00013 - NORBAR TORQUE TRANSDUCER #Q5091 - SEE QUOTE
1-off - M1064-00006 - TTT INSTRUMENT (SEE QUOTE DW2017 007)

It is the responsibility of the purchasing manager to then create the red line BOM and add it to the Red Line folder within the contract folder.

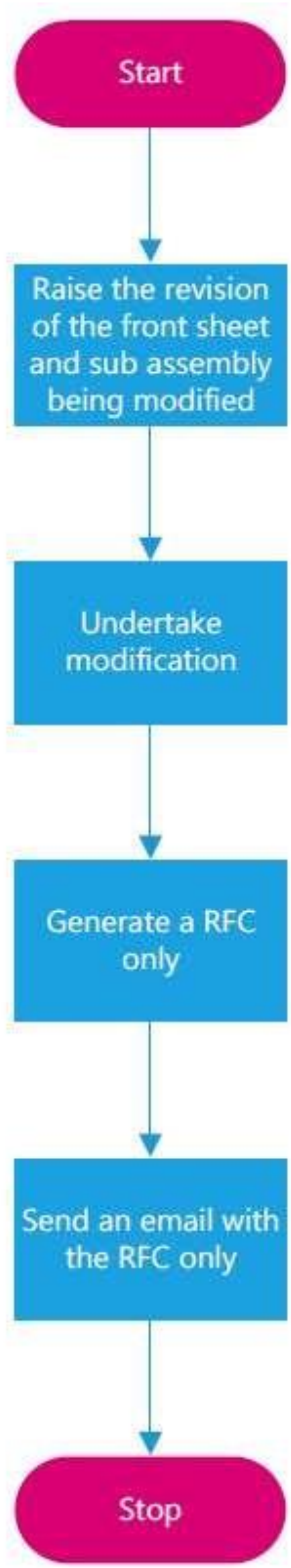
3. Ensure that the email clearly communicated that it is a red line BOM that is required.

4, Appendices

4.1, Document First Issue Flow Diagram



4.2, Document Modification Flow Diagram



4.3, User Error modifications Flow Diagram

7 SOP071 – Design Risk Management

SOP071 - Design Risk Management

Document Number:	SOP071
Process Owner	
Description:	Design Risk Management

	Print Name	Sign	Date
Originator:			
Reviewed by:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
Draft	Initial Issue		

Glossary of terms and abbreviations

Term or abbreviation	Definition
DFMEA	Design Failure Mode Effects Analysis
PFMEA	Process Failure Mode Effects Analysis
Responsible Person	This is the person given the responsibility for ensuring that the technical or engineering document is produced (or modified) in order to meet a specific business need.
RPN	Risk Priority Number

Contents

1, Purpose

The purpose of the following document is to describe how to identify potential designs risks at the outset of a project. Utilising the below assessment method will identify risks and assist in deciding if the project should continue or if undertaking a mitigation strategy will suffice.

The following document should be read in conjunction with:

- F234- DFMEA Template
- F241 - Risk Ranking and Filtering Template
- F242 – PFMEA Template

2, Risk Ranking and Filtering Introduction

The following sections describes the Risk Ranking and Filtering process.

2.1, What is a Risk Ranking and Filtering Guide?

A Risk Ranking and Filtering guide is an aiding document used prior to conducting a Failure Mode Effect Analysis (FMEA), this can either be design or process specific. The document is used to quickly highlight any potential risks that may pose as a threat to the overall product/design. This is done by allocating Failure Modes to their assigned category and evaluating their possible risks by their categorised Risk Priority Number (RPN) as opposed to individually.

2.2, Why perform a Risk Ranking and Filtering Guide?

The purpose of performing a Risk Ranking and Filtering Guide is to reduce the workload required from a FMEA. This initial assessment only entails a brief evaluation for each filter rather than an in-depth analysis. From this, attention can be focused on the specific design criteria that warrants further action rather than the entirety. Consequently, the process is efficient rather than laborious.

3, How to perform a Risk Ranking and Filtering guide

The Initial review of the Risk Ranking and filtering guide is an independent process that in most cases will involve the input of a design engineer or if needed a manufacturing engineer. If a follow up review is necessary, then the participation of additional personnel i.e. sales and finance can be sought. The format of the sheet is designed so that it can be filled out swiftly and is completed as follows:

3.1, Design Criteria

This field is predetermined and comprises of the filters that are to be assessed. These filters are the categorised risks that are devised of the individual Failure modes.

3.2, Scoring

The Scoring System is based on a 1-10 scale, with 1 being a Low-level risk and 10 being high. The scoring fields are also conditioned to follow a traffic light colour system, with red indicating a high-level risk, amber a medium level risk and green a low-level risk.

3.2.1, Occurrence

"Occurrence" is a ranking number associated with the likelihood that a failure mode and its associated cause will present itself in the item being analysed. This is measured on known or lack of data of the item and thus has a direct relationship with the item's history.

3.2.2, Detection

"Detection" is a ranking number used to consider the likelihood of identifying a failure mode/cause before it reaches the end-user/customer.

3.2.3, Severity

"Severity" is a ranking number selected based on the impact or danger to the end user/customer. This figure is given by the most serious effect for any given failure mode.

3.2.4, Risk Priority Number (RPN)

This is the measure used for assessing the risk identified by the design criteria. The RPN values range from 1 (absolute best) to 1000 (absolute worst) and this is generated from the product from the three previously stated rankings:

Occurrence * Detection * Severity

3.2.5, Comments

This is an additional field used to store any relevant information in relation to the design criteria.

3.2.6, Further Action

This is prompted by the value of the RPN. If the RPN is greater than the agreed limit, then either a DFMEA or PFMEA is essential.

3.2.7, Design Failure Mode Effect Analysis (DFMEA)

DFMEA is a methodical approach used for identifying potential risks introduced in a new or changed design of a product/service.

3.2.8, Process Failure Mode Effect Analysis (PFMEA)

PFMEA is a methodical approach used for identifying risks on process changes.

4, Introduction to a Design and a Process Failure Mode Effects Analysis (DFMEA and PFMEA)?

A Design Failure Mode Effects Analysis (DFMEA) and a Process Failure Mode Effect Analysis (PFMEA) are used as tools to identify potential failure modes and their causes. They should be used by the company Engineers when introducing a new product/design or fundamentally changing an existing one. The specific risks that require an analysis should have been identified by undertaking a Risk Ranking and Filter analysis. The following document will describe how to undertake the analysis and the procedure surrounding this work.

5, What is a DFMEA and PFMEA?

"A DFMEA is a methodical approach used for identifying potential risks introduced due to a new or changed design of a product/design. Alternatively, a PFMEA is a methodical approach used for recognising any potential failure modes resultant of process changes. Both the Design and Process FMEA initially identifies design functions, failure modes and their effects on the customer with corresponding severity ranking / danger of the effect. The causes and their mechanisms of the failure modes are then identified. High probability causes, indicated by the occurrence ranking, may drive action to prevent or reduce the cause's impact on the failure mode. The detection ranking highlights the ability of specific tests to confirm the failure mode / causes are eliminated. The Design and Process FMEAs also tracks improvements through Risk Priority Numbers (RPN) reductions. By comparing the before and after RPN, a history of improvement and risk mitigation can be chronicled" (Quality-One, 2024).

6, Why perform a DFMEA and PFMEA?

"Risk is the substitute for failure on new / changed designs and processes. It is a good practice to identify risks on a program as early as possible. Early risk identification provides the greatest opportunity for verified mitigation prior to program launch.

Risks are identified on designs and processes, which if left unattended, could result in failure. The DFMEA and PFMEA is applied when:

- There is a new design / process with new content.
- There is a current design / process with modifications, which also may include changes due to past failure.

- There is a current design / process being used in a new environment or change in duty cycle (no physical change made to design)" (Quality-One, 2024).

7, How to perform a DFMEA and PFMEA?

The Design and Process FMEAs are an iterative process and should be completed in sections at different times within the design timeline of the project, not all at once. The forms are completed in the following sequence:

7.1, Item / Function

The Item / Function column permits the Design Engineer to describe the item that is being analysed. The item can be a complete system, subsystem, or component. The function is the "Verb – Noun" that describes what the item does. This should include the part number and the change level of the item / Function. There may be many functions for any one item.

7.2, Requirement

The requirements, or measurements, of the function are described in the second column. The requirements are provided by sales in the Project Launch Document (See: WI155 - Introduction to Project Launch Document). The requirement must be measurable and should have test methods defined. If requirements are poorly written or non-existent, design work may be wasted. The first opportunity for recommended action may be to investigate and clarify the requirements to prevent wasted design activity.

7.3, Potential Failure Mode

List each potential failure mode for the specific part and part function. The assumption is made that the failure could occur but will not necessarily occur. A review of past FMEAs test reports, quality, warranty, durability, and reliability concerns on similar components is a recommended starting point.

Failure Modes are the anti-functions or requirements not being met. There are 5 types of Failure Modes:

- Full Failure
- Partial Failure
- Intermittent Failure
- Degraded Failure

- Unintentional Failure

7.4, Potential Effects of Failure

Assuming the failure mode has occurred, describe the effects of the failure in terms of what the customer might notice or experience. Many effects could be possible for any one failure mode. All effects should appear in the same cell or grouped next to the corresponding failure mode. These should be stated in terms of the system performance. Examples of typical descriptions or failure effects are shown below:

- Noise
- Erratic Operation
- Inoperative
- Unstable
- Intermittent Operation
- Small
- Operation Impaired

7.5, Classification

"Classification refers to the type of characteristics indicated by the risk. Many types of special characteristics exist in different industries. These special characteristics typically require additional work, either design error proofing, process error proofing, process variation reduction or mistake proofing. The Classification column designates where the characteristics may be identified for Process FMEA Collaboration. This section is not required for all FMEA analysis" (Quality-One, 2024).

7.6, Potential Causes / Mechanisms of Failure

"Causes are defined for the Failure Mode. The causes should be determined at the physics-level. The causes at a component level can be related to the material properties, geometry, dimensions, interfaces with other components and other energies which could inhibit the function. These can be derived from pre-work documents such as Boundary (or Block) Diagrams, Parameter (P) Diagrams and Interface Analysis. Causes at the system level are cascaded as failure modes in more detailed analysis. Geometry and dimensions are cascaded (waterfall) into special characteristics, which can be transferred to the Process FMEA. Use of words like bad, poor, defective and failed should be avoided as they do not define the cause with enough detail to make risk calculations for mitigation.

Examples of causes are:

- Material properties (inadequate strength, lubricity, viscosity, etc.
- Material geometry (inadequate position, flatness, parallelism, etc.)
- Tolerances or stack ups
- Interfaces with mating components
- Physical attachment / clearance
- Energy transfers (heat vibration, peak loads, etc.)
- Material flow or exchange (gas, liquid)
- Data exchanges (signals, commands, timing, etc.)" (Quality-One, 2024).
- Assembly error
- Incorrect torque
- Incorrect Heat Treatment
- Poor Weld

7.7, Current Design Controls Prevention

"The prevention strategy used by an engineering team when planning and completing a design / process has the benefit of lowering occurrence or probability. The stronger the prevention, the more evidence the potential cause can be eliminated by design / process. The use of verified design standards, proven technology (with similar stresses applied) and computer-aided engineering (CAE) are typical Prevention Controls" (Quality-One, 2024). In this section list all the current controls which are intended to prevent the cause(s) of failure from occurring or are intended to detect causes of failure or the resultant failure mode.

Current controls (Engineering Specifications, quality control systems, etc.) are those that have been or are in place for the same or similar design. The initial occurrence and detection rankings will be based on these controls. The controls listed should be directly related to prevention or detection of specific causes of failure.

Do not assume that any current controls will be implemented unless they are detailed in the specification, are standard industry practice, are used on similar designs, or have been verified by the affected activity. If any other specific control measures are necessary, they should be listed under the recommended action (Column 7.13).

It is the responsibility of the design engineer to obtain verification of all current quality control systems listed on the FMEA from the affected manufacturing, assembly or supply activities. The design engineer should obtain copies of the pertinent process flow charts and inspection sheets on similar parts as an aid in the FMEA development.

For an all new design, the current controls may be very limited or non-existent. However, the engineer may use planned controls if they have been approved by the appropriate activity.

7.8, Current Design Controls Detection

"The activities conducted to verify design safety and performance are placed in the Current Design Controls Detection column. The tests and evaluations intended to prove the design is capable are aligned to the causes and failure modes identified with the highest risks. Specific tests must be identified when risks are in the highest severity range (9-10) or the high criticality, non-safety combinations. Examples of Design Controls Detection are:

- Design Reviews
- Verification Test Methods
- Bogey Test to 1 Life
- Test to Failure
- Degradation Testing" (Quality-One, 2024).

7.9, Occurrence (OCC)

The Occurrence ranking is an estimate based on known or lack of data. When estimating the occurrence ranking, the following two probabilities should be considered:

1. The probability that the potential cause of failure will occur. For this probability all current controls which are in place to prevent the cause of the failure from occurring on the designated item must be assessed.
2. The probability that once the failure has occurred, it will result in the indicated potential failure mode. For this estimate, it must be assumed that the cause of failure and failure mode are not detected before the product reaches the customer.

The engineer should mentally combine these two probabilities when estimating the occurrence ranking.

The following Occurrence Ranking should be followed to ensure consistency:

- "1: Prevented causes due to using a known design standard
- 2: Identical or similar design with no history of failure
- This ranking is often used improperly. The stresses in the new application and a sufficient sample of products to gain history are required to select this ranking value.
- 3-4: Isolated failures
- Some confusion may occur when trying to quantify "isolated"
- 5-6: Occasional failures have been experienced in the field or in development / verification testing

- 7-9: New design with no history (based on a current technology)
- 10: New design with no experience with technology

Actions may be directed against causes of failure with a high occurrence. Special attention must be placed on items with a Severity of 9 or 10. These severity rankings must be examined to assure that due diligence has been satisfied" (Quality-One, 2024).

7.10, Severity

(The Severity of each effect is selected based on the impact or danger to the end user / customer.

The severity ranking is typically between 1 through 10 where:

2-4: Annoyance or squeak and rattle; visual defects which do not affect function.

5-6: Degradation or loss of a secondary function of the item studied.

7-8: Degradation or loss of the primary function of the item studied.

9-10: Regulatory and / or Safety implications

The highest severity is chosen from the many potential effects and placed in the Severity Column. Actions may be identified to change the design direction on any failure mode with an effect of failure ranked 9 or 10. If a recommended action is identified, it is placed in the Recommended Actions column of the DFMEA / PFMEA" (Quality-One, 2024).

7.11, Current Design Controls Detection (DET)

"Detection Rankings are assigned to each test based on the type of test / evaluation technique with respect to the time it is performed. It is ideal to perform tests (on high-risk items) as early in the design process as is possible. Testing after tools are completed is called Product Validation (PV) and is used to supplement Design Verification (DV) tests. PV tests may be used to save test time and resources on low-risk items. There is often more than one test / evaluation technique per Cause-Failure Mode combination. Listing all in one cell and applying a detection ranking for each is the best practice. The lowest of the detection rankings is then placed in the detection column.

Typical Detection Rankings can be found below:

1: Failure prevented through Design Solution, Design Standard, Standard Materials, etc.

2: Use of Computer Aided Engineering (CAE) highly correlated to real world user/stress profiles

3: Test to Failure with measurement of output tracking degradation (performed before Design Freeze (DV))

4: Test to Failure (DV)

5: Bogey Test, test to pass to 1 life and suspend the test (DV)

6: Test to Failure with measurement of output tracking degradation (performed after Design Freeze (PV))

7: Test to Failure (PV)

8: Bogey Test, test to pass to 1 life and suspend the test (PV)

9: Use of CAE, but not yet correlated to real world stress profiles

10: Cannot evaluate, no test available or current tests do not excite the cause / failure mode

Actions may be necessary to improve testing capability. The test improvement will address the weakness in the test strategy. The actions are placed in the Recommended Actions Column" (Quality-One, 2024).

7.12, Risk Priority Number (RPN)

"The Risk Priority Number (RPN) is the product of the three previously selected rankings, Severity * Occurrence * Detection. RPN thresholds must not be used to determine the need for action. RPN thresholds are not permitted mainly due to two factors:

- Poor behaviour by design engineers trying to get below the specified threshold.
- This behaviour does not improve or address risk. There is no RPN value above which an action should be taken or below which a team is excused of one.

- "Relative Risk" is not always represented by RPN" (Quality-One, 2024).

7.13, Recommended Actions

"The Recommended Actions column is the location within the DFMEA and PFMEA that all potential improvements are placed. Completed actions are the purpose of the DFMEA and PFMEA. Actions must be detailed enough that it makes sense if it stood alone in a risk register or actions list. Actions are directed against one of the rankings previously assigned. The objectives are as follows:

- Eliminate Failure Modes with a Severity 9 or 10
- Lower Occurrence on Causes by error proofing, reducing variation or mistake proofing
   - Lower Detection on specific test improvements" (Quality-One, 2024).

7.14, Responsibility and Target Completion Date

"Enter the name and date that the action should be completed by. A milestone name can substitute for a date if a timeline shows the linkage between date and selected milestone" (Quality-One, 2024).

DFMEA and PFMEA Section

7.15, Actions Taken and Completion Date

“List the Actions Taken or reference the test report which indicates the results. The Design FMEA should result in actions which bring higher risks items to an acceptable level of risk. It is important to note that acceptable risk is desirable and mitigation of high risk to lower risk is the primary goal” (Quality-One, 2024).

7.16, Re-Rank RPN

“Using the new conditions the fields 7.16, 7.17 and 7.18 are to be populated as before. This will generate a new (re-ranked) RPN, which is then to be compared with the original RPN. A reduction in this value is desirable. Residual risk may still be too high after actions have been taken. If this is the case, a new action line would be developed. This is repeated until an acceptable residual risk has been obtained” (Quality-One, 2024).

8 SOP072 – Design Change control

SOP072 - Design Change Control

Document Number:	SOP072
Process Owner	
Description:	Design Change Control

	Print Name	Sign	Date
Originator:			
Checked			
Process Owner			
Process Owner			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	First Issue		

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
DTN	Document Transmittal Note
LTR	Lifetime Records
Responsible Person	Is the person given the responsibility for ensuring that the technical or engineering document is produced (or modified) in order to meet a specific business need.
Technical and engineering document	May be any document which contains technical, engineering, or other related information intended to be shared with or communicated to others, or to record information as a business record. This could include both physical documents, such as FDS's, drawings, calculations, technical reports, etc. as well as electronic documents, such as word-processed document files, PDFs, CAD drawing files, etc.

1, Purpose

The purpose of this procedure is to instruct any persons involved in an engineering project the process of identifying and recording design changes to an approved technical drawing or engineering document. This procedure addresses the requirements of BS EN ISO 9001:2015 Section 7.5.3 ‘Control of documented information’.

Upon completion of a design when the status of the document has been advanced to an approved status, then this baseline design must be controlled. This will require the management of subsequent design changes or design queries thus ensuring that a controlled and consistent approach is taken to maintaining the baseline design. This document is specific to all projects within the company.

2, Process

Upon completion of a Machine/Cell sub-section, all drawings and Bills of Material’s (BOMs) should be issued to procurement as and when they are checked and approved. Once the BOM and all Drawings are issued the BOM should be converted to a frozen state, detailed in procedure SOP069. If any changes are required on a frozen BOM, the following steps should be followed.

2.1, Submit a design change proposal

This Procedure is based on design change control being completed as PDF red line drawings. The records will form part of the audit trail to support quality improvements this evidence must be recorded in the contract folder specific to the order under the relevant section. See below for an example of the route for the design change control folder for a TFW contact.

Y:\Contracts\T70??? – Customer name\12. Project Status and Reporting\10. As-Built 'Red Book'\10.4. Red Line Drawings

Once a project or work package starts up the Project Manager or Responsible Person shall establish administrative arrangements that:

- Define arrangements for the communication of approved design changes to the relevant persons.

The originator of the design change proposal will be a Production Engineer and they shall:

- Identify the project or work package against which the design change proposal is proposed
- Identify the reason(s) that have initiated the requirement for the design change proposal being raised and identify supporting references where applicable – see section 2.2.
- Provide a description of the design change proposal with several supporting drawings and documents as required to define the change.
- Provide a provisional indication of the equipment that is affected – see section 2.3.
- Identify the Drawings and documentation affected – see section 2.3.
- Submit the design change proposal to the responsible person – see section 2.4

2.2, Identify Reasons for the Design Change Proposal

The reasons for a design change proposal can be from one or more sources or drivers during detail design, document production, fabrication, assembly, or commissioning. There may be one or more reasons varying from minor modifications during assembly to substantial changes that may affect function. Therefore, the design change proposal originator shall identify the reason for the proposed change supported by reference(s) or marked-up documents where required.

Typical reasons are listed (but not limited to):

- Results of underpinning development work.
- Design Reviews.
- Changes to the Engineering Substantiation.
- Errors / Inconsistencies identified in Approved Documentation / Drawings.
- Changes to Fabrication / Assembly Methodology.
- Changes to Testing / Commissioning.
- Resolution of fault observations that require Design Changes.
- Project Scope Change.
- Project Variation Note.
- Manufacturing Change.
- Changes to Engineering Orders.

2.3, Identify Affected Equipment

The Production Engineer shall clearly identify the equipment that will be affected by the design change by populating the required form “F437 – Design Change Control Report”, clearly stating the following:

- Project (if not stated on the drawing).
- General Assembly Drawing stating current revision. Detail Drawings stating current revision.

2.4, Accepting the Design Change Proposal

The Production Engineer will contact the relevant person (generally the lead engineer), share the populated F437 document, marked up red line drawings and discuss reasons for change and the affected equipment. The relevant person on the project will review the proposal to confirm understanding of the cumulative effect of design changes on the design and project. The relevant person can then sign and date the documents to say they approve it, thus allowing the originator of the design change to continue their work. Upon acceptance of the design change, the Production Engineer is required to store the marked-up drawing, BOM, or engineering document in the Red Line Drawings Folder detailed in section 2.1.

Actions:

- Production Engineer – Discuss changes, Mark up changes in red.
- Relevant person – Sign, date, and print name.
- Production Engineer – Sign, date, and print name. Add documents to the “Red Line Drawings Folder”.

If for any reason the responsible engineer does not accept the design change proposal a technical meeting is required with the relevant parties to discuss the reasons behind this decision and to find a solution that best addresses the issue identified.

2.5, Updating the Technical Documentation

Upon completion of the project, all data captured through this process and stored in the Red Line Drawings Folder will be updated in Vault and Visibility to ‘as-built’ status. The BOMs will be marked in the comments box as “As-Built”, as detailed in section 2.

2.6, Procuring goods on a Frozen BOM

If for any reason an oversight has occurred and parts are missing from a frozen BOM that need procurement, then the following steps should be taken.

1. Ensure the parts are in visibility so that they can be added to the BOM when appropriate.

2. Email the purchasing manager requesting the parts are added to the BOM stating the sections, quantity and description as below:

K05792-4100

1-off - 219504 - CALIBRATION PLATE 10mm

K05792-4500

4-off - F1235-00997 - Ø22 (M20) WASHER DIN 9021 – BZP

K05792-4262

1-off - M1064-00013 - NORBAR TORQUE TRANSDUCER #Q5091 - SEE QUOTE
1-off - M1064-00006 - TTT INSTRUMENT (SEE QUOTE DW2017 007)

It is the responsibility of the purchasing manager to then create the red line BOM and add it to the Red Line folder

9 SOP073 - HOW TO RESOLVE ENGINEERING TECHNICAL QUERIES, CONCESSIONS AND NCR'S

SOP073 - How to Resolve Engineering Technical Queries, Concessions and NCR's

Document Number:	SOP073
Process Owner	
Description:	How to Resolve Engineering Technical Queries, Concessions and NCR's

	Print Name	Sign	Date
Originator:			
Process Owner			
Process Owner			
Process Owner			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
Producer	Is the person (or team of people) appointed by the Responsible person to produce (i.e. prepare, draft, create, or modify, etc.) the technical or engineering document
Responsible Person	Is the person given the responsibility for ensuring that the technical or engineering document is produced (or modified) in order to meet a specific business need.
Technical and engineering document	May be any document which contains technical, engineering, or other related information intended to be shared with or communicated to others, or to record information as a business record. This could include both physical documents, such as FDS's, drawings, calculations, technical reports, etc. as well as electronic documents, such as word-processed document files, PDFs, CAD drawing files, etc.
Technical Query (TQ)	A request for clarification of technical or engineering information typically contained in drawings, specifications, contract documents and the like.
Non-Conformance Report (NCR)	Product or service that does not conform to stated requirement (generally expressed within the Engineering Standards, specifications and drawings).
Concession	A retrospective request to accept a deviation from specification e.g. manufacturing non-conformance. Where an existing non-conformance (defect) with the requirements has been identified, a request for a concession (generally to accept "as-is") can be made as an alternative to re-work. A non-conforming product may be subject to certain conditions restricting its use. Concessions should only be considered where there are genuine technical difficulties in meeting the requirement. They should not be used to condone poor quality workmanship.

1, Purpose

This Procedure must be used for the resolution of any technical and engineering queries and deviations from specification. These typically include the physical and functional attributes of equipment as described in standards, drawings, specifications, manufacturing and construction records, inspection and test criteria and spares requirements. The procedure applies throughout the equipment lifecycle, design, manufacture, assembly, commissioning, and maintenance activities.

The purpose of this procedure is to assist those involved using technical and engineering documents to receive authoritative direction on the interpretation of such information. Whenever there is doubt or ambiguity in the Engineering or Technical information or it is possible that a product or service may not meet the design intent, this practice should be used to resolve the situation. The procedure provides permission to deviate from requirements in the form of a concession, as well as providing clarification in the form of a technical query.

Triggers for this process that can invoke a design input include, validation and verification of construction work, fault observations, supply chain queries, changes to conditions for acceptance and general requests for clarification. quality and approach to the delivery of these documents is followed within the company.

NOTE: This procedure does not include design change. Where a design change is required, the appropriate process is initiated in accordance with either SOP072 - Design Change Control or SOP116 - Conducting Design Change Control (Nuclear).

2, Process

2.1 Identify Responsibilities

The procedure is applicable to Manufacturing, Projects and Engineering Operations both internally and interfacing with the supply chain. Therefore, it is a prerequisite that a protocol for communications must be established. The protocol should cover document control in accordance with Company Practices including the tracking and distribution of documents and data capture.

NOTE: Project Managers must establish arrangements within their Projects.

2.2, Raise a Technical Query (TQ), Concession's and Non-Conformance Report (NCR).

Engineering and technical issues for resolution can be raised by anyone using such information. Originators should raise their issue on the relevant form and identify the initial request as either a query or a deviation request.

When concessions are being raised, specific reference must be made in the request to the document and issue in question. Such requests should be discussed with the relevant responsible person, and the relevant specialist if appropriate, at the earliest opportunity.

The contents should be clear and concise, explaining what the request is and, for a concession, providing a clear justification why it is needed. Where applicable the request should explain the relationship to interfacing equipment such that the impact of the request is fully understood. This section should also identify where possible any previous requests that might relate to the same equipment to enable the cumulative impact of concessions to be evaluated.

Any solutions proposed by the originator should be included and the request then forwarded to the responsible person for resolution.

Any item which could fail in service must be quarantined to prevent its inadvertent use. For items currently in use, consideration must be given to the ongoing safe operation of the equipment.

The originator shall clearly identify the equipment by clearly stating the following:

- Project (if not stated on the drawing)
- General Assembly Drawing stating current revision
- Detail Drawings stating current revision
- Any other Engineering Documentation in question eg specifications or procedures.

2.3, Distribution of Documentation

TQ's, NCR's and Concessions will be received by the relevant, the company nominated contact. The nominated contact shall undertake the relevant checks to ensure the validity of the documents, checks should include registration and titles that accurately reflect contents in order to assist with its resolution and data capture. The nominated contact may reject the document at this stage and return it to the originator if information is missing or clarity is required.

If the documents are acceptable, they then may be issued to the relevant responsible person to review and resolve the request. The nominated person will distribute the document in accordance with the agreed protocol and to any additional recipients, requesting responses as required.

2.4, Resolving the Documentation

The responsible person must assess the information and reasoning presented in the document submitted and then respond accordingly.

If the request involves a change to the design intent or the design baseline or whether there is any potential impact on safety or the environment. Safety in this context includes compliance with conventional safety legislation e.g. Control of Major Accident Hazards or machinery safety. If the answer to any of these aspects is ‘Yes’ or ‘Not Sure’, then the proposal must be treated as a ‘Design Change Proposal’ in accordance with either SOP072 - Non-Nuclear Design Change Control or SOP116 - Conducting Design Change Control (Nuclear).

Examples that should be raised as a Design Change would be: material, dimensional, functional or form changes that would affect compatibility now or in the future, i.e. Design intent changed and requires the design baseline updating and would be required for replacements or repeat orders.

Examples that could continue to be progressed through this process would be, to correct errors, add missing information, incorporate clarifications. No design intent change or substitutions, or direct material substitutions, dimensional, functional, form changes that would not affect compatibility now or in the future, e.g. for replacement and repeat orders.

The responsible person is responsible for completing the form, ensuring suitable justification for the decision, and return to the originator. The response must be distributed to the relevant recipients with additional recipients added as required. Responses concerning Engineering Standards, specifications or processes should be copied to the document owner.

If for any reason the responsible engineer does not accept the design change proposal a technical meeting is required with the relevant parties to discuss the reasons behind this decision and to find a solution that best addresses the issue identified.

2.5, Updating the Technical Documentation

When required, the relevant documents are updated (see examples in stage 2.4). This could be simple correction, incorporation of information to provide clarification or adding missing information.

10 SOP117 – Design Review AWS & HMP

SOP117 - Design Review AWS & HMP

Document Number:	SOP117
Process Owner	
Description:	Design Review AWS & HMP

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
LFE	Learning from Experience
Formal Review	A formal review may be called to input to business governance processes (Assurance) or assist the work in the development of a good and cost-effective design solution (Assistance). These reviews require an independent Chairman.
Informal Review	A review, with or without independence, which does not form part of the Governance process. Short duration with a small number of participants.

1, Purpose

Design reviews are an important activity in assisting studies, tasks and projects to develop design engineering quality and in assuring that design maturity is appropriate to progress through the relevant stages of the company Toll Gate Process. This process aims to avoid rework by providing timely advice and assurance.

This procedure applies to all studies, projects and tasks that include design engineering content and should be applied pragmatically in accordance with risk-based principles, e.g. accounting for scale and complexity. This includes engineering substantiation work.

It is important that formal and informal design reviews are recorded via the company Design Quality Process and are categorised correctly so that the resulting business Key Performance Indicators provide an accurate picture of design engineering maturity.

Note: This Procedure has been written to generally align with BS EN 61160: 2005.

2, Process

2.1, Overview

This procedure covers formal reviews on all work that includes design engineering. It is important that the number and scope of reviews is proportionate to the scale, complexity and risk of the work in accordance with risk-based principles.

No design is too small to be reviewed, but in some circumstances, such as minor tasks, modified existing designs, and so on, the review may be brief and only involve a small number of people. This procedure should be interpreted in a manner appropriate to the review and stage.

Each design review shall have a clear and stated objective, i.e. a question (or number of questions) to be answered at the end of the review.

Design Review's should not carry out checking activities but should confirm that appropriate principles have been applied and that correct activities and good practice have been carried out.

The reviews shall be undertaken in the following order to ensure efficiency and relevance at each stage as the design progresses:

1. Concept Review
2. Production Review
3. Manufacturing Review

+ Informal Reviews – As required throughout.

2.2, Design Review Attendees

Every review should consider the need for reviewers who:

- Have appropriate competencies, experience, specialism and engineering expertise (e.g. subject experts, supply chain, technical specialists).
- Are a source of Learning from Experience (LFE).
- Are independent peers to the design team.
- Are independent from the project or task under review (are objective).
- May need to influence the design but who are not designers (e.g. operators, quality, manufacturers).
- Represent Assembly, Manufacturing and Commissioning (As Required).

The review team may include reviewers who are independent from the project but not the programme area and reviewers who are entirely independent of the programme. This make up of review team can be effective by providing diverse experience and utilising individuals who are efficient in sharing best practice and lessons learned.

Where the work is being carried out in partnership with contractors or suppliers who are involved in the design, they may attend to support the Responsible Engineer. Although it is important that all relevant views are represented, every effort should be made to keep the number of individual attendees as low as possible, to enable an efficient meeting to be held.

Where practicable all attendees of a review should have carried out enough pre-work to be familiar with the project, with the purpose of the review and with any required detailed information. This is to minimise the time taken in the review bringing people to a common level of understanding.

2.3, Concept Review

A concept review shall be undertaken with the relevant company personnel present, where required an independent company employee shall be present to provide an unbiased opinion from those involved with the project. All reviewers shall possess appropriate skills, knowledge and experience of the equipment or systems under consideration.

The Concept Review shall be undertaken by reviewing the 3D General Assembly Model.

Reviews should be scheduled a minimum of 1 week in advance.

All actions shall be recorded on the relevant section of the Design Review Template. Any actions shall be investigated and addressed accordingly by the responsible person.

See Document Template F233 – Design Review Template.

2.4, Design for Assembly Review

A Design for Assembly Review shall be undertaken with the relevant company personnel present, where required an independent company employee shall be present to provide an unbiased opinion from those involved with the project. All reviewers shall possess appropriate skills, knowledge and experience of the equipment or systems under consideration.

The Production Review shall be undertaken by reviewing the preliminary General Assembly drawings.

Reviews should be scheduled a minimum of 2 weeks in advance and all materials identified for design review should be issued at least one week before the review.

All actions shall be recorded on the relevant section of the Design Review Template. Any actions shall be investigated and addressed accordingly by the responsible person.

See Document Template F233 – Design Review Template.

2.5, Design for Manufacture Review

A Design for Manufacture Review shall be undertaken with the relevant company personnel present and identified Manufacturing representative shall be present to provide an unbiased opinion from those involved with the project. All reviewers shall possess appropriate skills, knowledge and experience of the equipment or systems under consideration.

The Manufacturing Review shall be undertaken by reviewing the preliminary Manufacturing Drawings.

Reviews should be scheduled a minimum of 3 weeks in advance and all materials identified for design review should be issued at least 2 weeks before the review.

All actions shall be recorded on the relevant section of the Design Review Template. Any actions shall be investigated and addressed accordingly by the responsible person.

See Document Template F233 – Design Review Template.

3, Informal Design Reviews

It is feasible that during the life of a project informal reviews or “Engineering Discussions” will take place outside of the formal design review procedure. Informal reviews are common in the early stages of a products lifecycle and a two-person team can conduct an informal review. It is important that although informal these discussions are captured to evidence the design development. When undertaking an informal review, the “F243 – Engineering Discussion Template” should be used.

4, References

- BS EN 61160: 2005 – Design Review

11 WI154 - Introduction to Learning From Experience (LFE)

WI154 - Introduction to Learning from Experience

Document Number:	WI154
Process Owner	
Description:	Introduction to Learning From Experience (LFE)

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

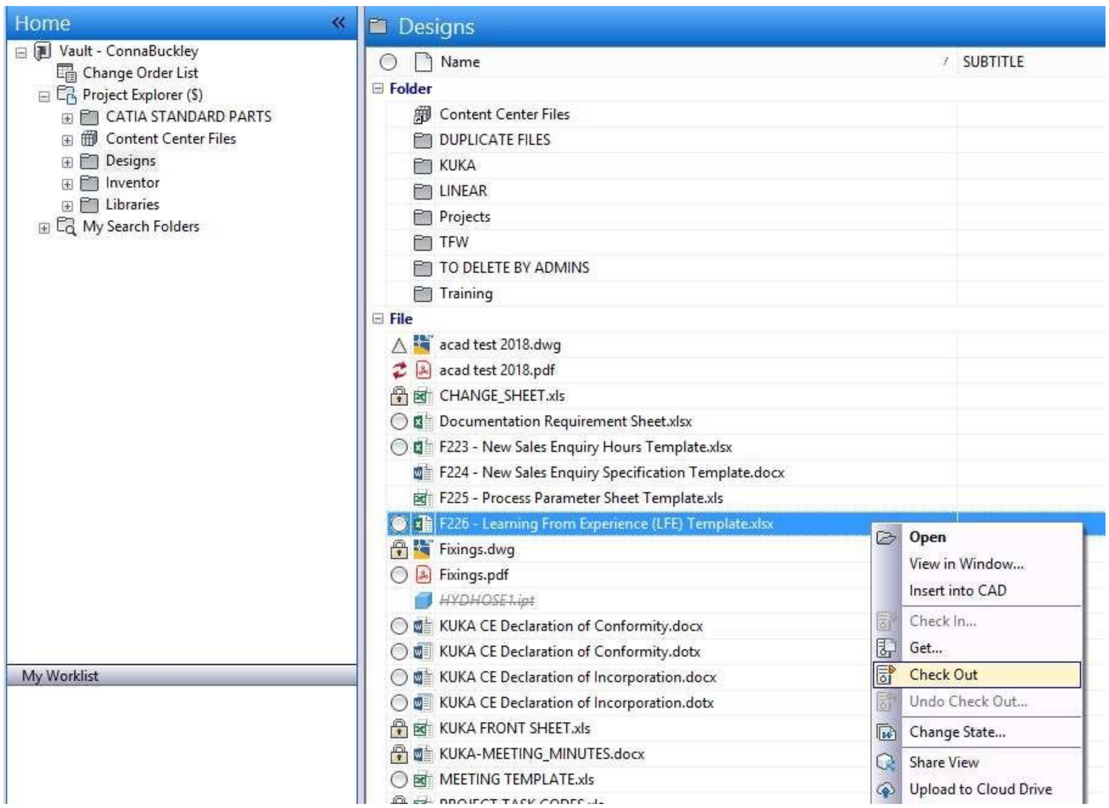
1, Description

To continuously improve as a company by enhancing systems and equipment designed and provided by the company, or removing any issues previously encountered on similar projects, learning from experience (LFE) is crucial. The ‘F226 - Learning from Experience (LFE) Template’ document allows for information from previous projects to be easily located.

The ‘F226 - Learning from Experience (LFE) Template’ document is stored within the document management system Vault at the top level as shown below.

To view or add to the ‘F226 - Learning from Experience (LFE) Template’ from inside Vault the following steps must be followed:

1. In the project explorer select ‘Designs’, right click ‘F226 - Learning from Experience (LFE) Template’ and select get (for reference) or check out (for data entry).



2. From the Index table on the ‘Index’ tab, Navigate to the required section you wish to view or add information to.

   Note: If a Tab has not been created for the relevant section add one as required. Please do not duplicate sections.

INDEX
Robots
Nuclear - Associated Equipment
Nuclear - Nut Runner
Nuclear - Grabs
Nuclear - Swab Gripper
Nuclear - Hole Driller
Nuclear - Shear Tool
Nuclear - Datum Tool
Nuclear - Controls
Nuclear - Hydraulics
Nuclear - Pneumatics
Automation - Grippers & Tooling
Automation - Conveyor
Automation - Turntable
Automation - Positioners
Automation - Guards
Automation - Shutter Doors
Automation - Cell Safety
Automation - Controls
FW - Single Ender
FW - Double Ender
FW - Chuck
FW - Chuck Tooling
FW - Clamp Tooling
FW - Shear Tooling
FW - Clamps
FW - Head Assembly
FW - Base Assembly
FW - Flash Removal
FW - Marking Unit

3. If entering any data, on the desired section, complete the table with the required project information for future reference.
    1. Enter the Project Number in ‘Project Number’
    2. Enter the Project Title in ‘Project Title’
    3. Provide a brief description of the Project in ‘Project Description’
    4. Provide a description of any issues / problems / Improvements in the ‘Description’ column.
    5. Provide a description of any actions taken to resolve the problem in the ‘Action’ column. If no actions were taken for whatever reason i.e project timescales please state so.
    6. Add any recommendations for future reference in the ‘Recommendations’ column.
    7. Enter the responsible person / persons names in the ‘Responsible Person’ column. This will allow for any users in the future to discuss the comments.
    8. Enter the date the information was recorded in ‘Date’ Column.
    9. Enter any reference documents in the ‘Reference Documents’ column. This could be, Drawings, Design Reviews, Meeting Minutes etc. which can be accessed through Vault.

Project Number:		Project Title:				
Project Description:						
Action Number	Description	Action	Recommendations	Responsible Person	Date	Reference Documents
1						
2						
3						
4						

4. Upon completion of data entry, save the file and check the document back into Vault for other users to use / view, using the ‘Check in’ Command.

12 WI155 - Introduction to Project Launch Document

WI155 - Introduction to Sales Form AWS001

Document Number:	WI155
Process Owner	
Description:	Introduction to Project Launch Document

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01			
02			

Glossary of terms and abbreviations

Term or abbreviation	Definition
Responsible Person	Is the person given the responsibility for ensuring that the technical or engineering document is produced (or modified) in order to meet a specific business need.
Producer	Is the person (or team of people) appointed by the Responsible person to produce (ie. prepare, draft, create, or modify, etc.) the technical or engineering document.

Contents

1, Description

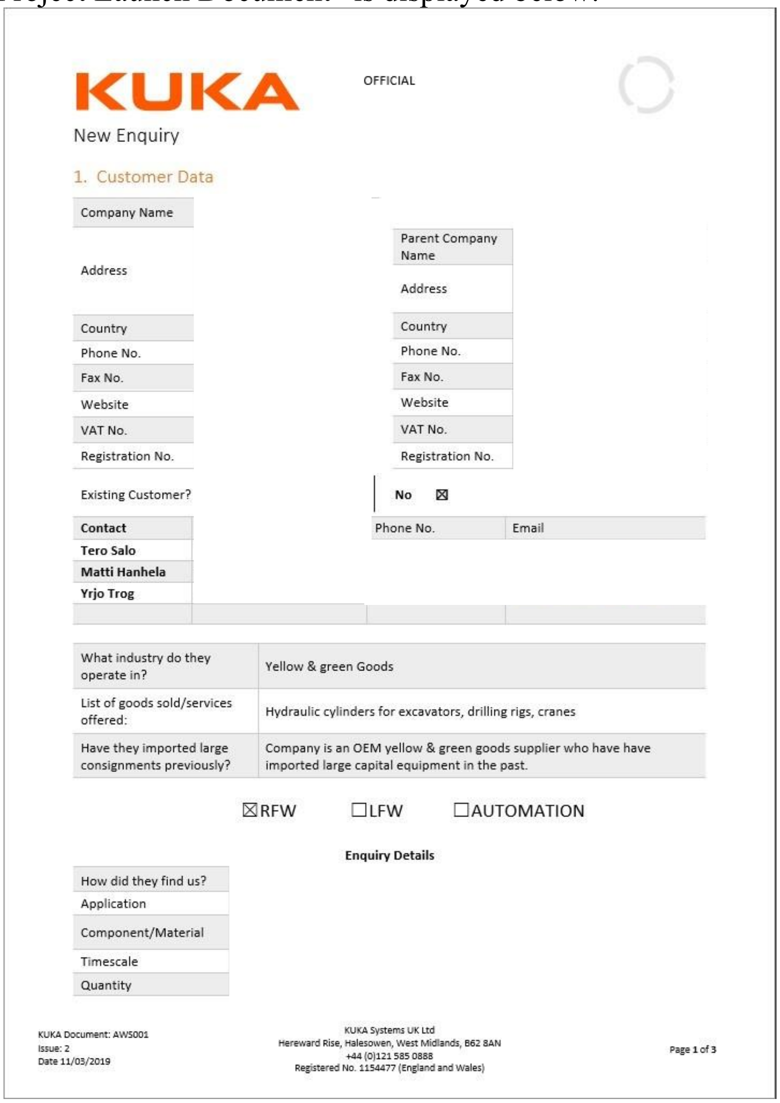
The Project Launch Document (AWS001) from an engineering perspective is a file created by the sales department which details each section of the project detailing the customer’s specification. This document should have enough detail to enable the Engineering department to start the design process.

If there is insufficient or missing information preventing a producer from undertaking their work, the responsible person for that order should be informed as soon as the issue is identified, at the latest during the during a weekly progress review.

This weekly update will enable the responsible person to pursue outstanding information and adjust their plans for resource to suit.

The ‘F276 - Project Launch Document’ is available to access within a file location like Y:\Contracts\Contract No – Contract Name\01.0 RFQ_SALES_ENQUIRY.

An example of a “Project Launch Document” is displayed below.



KUKA

OFFICIAL

New Enquiry

1. Customer Data

Company Name		Parent Company Name	
Address		Address	
Country		Country	
Phone No.		Phone No.	
Fax No.		Fax No.	
Website		Website	
VAT No.		VAT No.	
Registration No.		Registration No.	
Existing Customer?		No ☒	

Contact		Phone No.	Email
Tero Salo			
Matti Hanhela			
Yrjo Trog			

What industry do they operate in?	Yellow & green Goods
List of goods sold/services offered:	Hydraulic cylinders for excavators, drilling rigs, cranes
Have they imported large consignments previously?	Company is an OEM yellow & green goods supplier who have have imported large capital equipment in the past.

☒RFW ☐LFW ☐AUTOMATION

Enquiry Details

How did they find us?	
Application	
Component/Material	
Timescale	
Quantity	

KUKA Document: AWS001
Issue: 2
Date 11/03/2019

KUKA Systems UK Ltd
Hereward Rise, Halesowen, West Midlands, B62 8AN
+44 (0)121 585 0888
Registered No. 1154477 (England and Wales)

Page 1 of 3

13 WI156 - Introduction to Sales Risk Register

WI156 - Introduction to Sales Risk Register

Document Number:	WI156
Process Owner	
Description:	Introduction to Sales Risk Register

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Glossary of terms and abbreviations

Term or abbreviation	Definition
Responsible Person	Is the person responsible for ensuring that the product being designed is produced (or modified) in order to meet a specific business or customers' requirement.

Contents

1, Description

The Sales Risk Register from an engineering perspective is a file created by the sales department which documents risks to the project and actions to manage the risk. The Sales Risk Register is essential to the successful management of risk and should be read by all company Engineers undertaking work on a project. If any additional risks are identified they should be communicated to the responsible person on the project. The responsible person should then log the risk on the register and identify actions to respond to the risk. The document revision should then be raised, and the document should be circulated to all relevant personnel from Sales, Projects and Engineering.

The Sales Risk Register is available to access within a file location like Y:\Contracts\Contract No - Customer\05.0 CONTRACT_ACCEPTANCE\05.4 SALES_RISK_REGISTER. A hard copy should also be available to view within the project folder.

An example of a "Sales Risk Register" is displayed below.

Risk Register

Project Manager TBA	TBA
Project Number:	tfw 004027.9
Project Name:	AX5DE PLUS AUTOMATION
Date of Last Assessment (DD/MM/YY):	03/09/2018

										Current Risks - Assessment			Proposed action	Residual Risk - After Treatment				Current Status
Risk ID	Initiation Date	Risk Category	Risk Description	Cause "If..."	Effect "Then......"	Approx Exposure (£K)	Risk Response	Risk Owner	Risk Originator	Probability	Impact	Ranking		Probability	Impact	Ranking	Approx Revised Exposure (£K)	
1	03/09/18	Project	Late delivery issues	Current capacity loading	Penalty up to 5% for late delivery	TBC	Avoid		CR Nicholls	3	4	12		2	4	8	TBC	
2	03/09/18	Technical/Design	COMPLICATED AUTOMATION LAYOUT	Design capability and possiblity	PROBLEMS AT PASS OFF - LATE DELIVERY	TBC	Mitigate		CR Nicholls	4	5	20		2	5	10	ZERO	
4	03/09/18	Technical/Design	WELD ORIENTATION ISSUES	Design capability and possiblity	FAILURE TO GET FIRST TIME PASS OFF	TBC	Avoid		CR Nicholls	3	4	12		1	4	4	TBC	
5	03/09/18	Technical/Design	POOR CLAMPING OF AXLE SPINDLES	MARKING THE SPINDLE BEARING AREA	FAILURE TO GET FIRST TIME PASS OFF	TBC	Avoid		CR Nicholls	2	3	6	Software to raise a warning of worn tooling after a number of welds	1	3	3	TBC	
6	03/09/18	Technical/Design	BAD WELD GEOMETRY	POOR CLAMPING OF CHUCK	FAILURE TO GET FIRST TIME PASS OFF	TBC	Avoid		CR Nicholls	2	3	6	Software to raise a warning of worn tooling after a number of welds	1	3	3	TBC	
7	01/11/18	Technical/Design	SQL Database	Unknown Quantity / Issue	Time and Resource contribution	TBC	Mitigate		N MCCarthy	3	4	12				0		
8	01/11/18	Technical/Design	Automation - Picking of Axle tubes with magnet & Vision system	Incorrect or inability to pick parts	Failure to get passoff	TBC	Mitigate		N MCCarthy	2	4	8				0		
9	01/11/18	Technical/Design	Automation - Picking of Axle spindles with Vision system	Incorrect or inability to pick parts	Failure to get passoff	TBC	Mitigate		N MCCarthy	3	5	15	Pre-plan to look at focal lengths / Vision trials			0		
10	01/11/18	Technical/Design	Tipping of parts on output stillage when loading one part on wooden dividers	Robot will be unable to load second part	Failure to get passoff	TBC	Mitigate	Gigant	N MCCarthy	4	5	20	Include caviate in order aknowledgment & FDS that Stillage must be safe for unloading of components	1	5	5		
11	23/07/19	Technical/Design	Access to robot control cabinets	Unable to access as inside cell	Poor access for maintenance, commissioning etc		Avoid		Ian Walker	5	4	20	Look to relocate cabinets outside gaurdline	1	1	1		
12	23/07/19	Technical/Design	Vision system for spindle pick up	vision system fails to find spindles	system stops		Avoid		Ian Walker	2	5	10	failure, procedure for manual recovery to be in	1	5	5		
13	23/07/19	Technical/Design	Robot collission with crane / hoist	Crane not at home.	Collission		Transfer		Ian Walker	2	5	10	Interlock	1	1	1		
14	23/07/19	Technical/Design	Access via sliding door to wooden divider bin	Poential man access into working cell	Operator safety comprimised		Avoid		Ian Walker	5	5	25	Redesign concept to use a chute or similar to pass dividers throught the guard - bin to be located outside fence	1	1	1		
15	23/07/19	Technical/Design	Tubes on infeed stillage move	Incorrect pickup	Cell stop		Transfer		Ian Walker	3	5	15	Design of dividers to ensure repeatible pickup position.	1	1	1		
16	23/07/19	Procurement	Robot delivery	Delay specifying robot	Unable to order robots in time		Avoid		Ian Walker	3	5	15	Robot delivery currently forecast at 13 weeks. Schedule delivery to suit	1	1	1		
17	23/07/19	Procurement	Conveyor delivery	Delay specifying conveyor	Unable to order conveyor in time		Avoid		Ian Walker	3	5	15	Schedule delivery to suit	1	1	1		
18	23/07/19	Technical/Design	Robot programmer resource	Due to workload resource may not be available	Delay to project delivery		Avoid		Ian Walker	4	5	20	Order robots as absolute accurate - consider off line programming	1	1	1		
19	23/07/19	Technical/Design	Robot payload (spindle and tube)	Weight of SAF and BPW grippers high	KR340 overloaded		Avoid		Ian Walker	5	5	25	change to KR500 - still requires feedback from KUKA Germany	2	1	2		

14 WI157 - Introduction to Sales Cost Sheet (SCS) MIKA

WI157 - Introduction to Sales Cost Sheet (SCS) MIKA

Document Number:	WI157
Process Owner	
Description:	Introduction to Sales Cost Sheet (SCS) MIKA

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Glossary of terms and abbreviations

Term or abbreviation	Definition
Responsible Person	Is the person given the responsibility for ensuring that the technical or engineering document is produced (or modified) in order to meet a specific business need.

Contents

1, Description

The MIKA cost sheet from an engineering perspective is a file created by the sales department which details each section of the project taken from the customer's specification. This will identify the design hours allocated to each of the tasks for the project. The MIKA cost sheet acts as a basis for work to be distributed within the department. The responsible person for the project will use this information to plan and allocate the correct resource for the task.

In the event the hours allocated to the task have been underestimated for any reason such as the complexity of the task not being fully understood or an unforeseen issue arises, this will be captured by a responsible person within the department during a weekly progress review with the producer. In this progress review the responsible person should identify the following:

- Current task and predicted finish date.
- Future tasks and predicted finish date.
- Estimated availability.

This weekly update will enable the responsible person to adjust their plans for resource to suit. The MIKA cost sheet is available to access within a file location like Y:\Contracts\Contract No - Customer\05.0 CONTRACT_ACCEPTANCE\05.5 SALE_COST_SHEET. A hard copy should also be available to view within the project folder.

An example of a MIKA cost sheet is displayed below, to view the project tasks and design hours allocated to the job navigate the tabs at the bottom of the excel sheet and select 'MACHINE COST TEMPLATE'.

VIZ TASK	TASK DESCRIPTION	UPDATED DESCRIPTION (IF APPLICABBLE)	EST COST	MIKA REF/COST TYPE	HOURS	COST	COMMENTS
2000	SALES						
2100	PROJECT PLANNING		7,500.00	1	150	50.00	
2200	ORDER PROCESSING			2			
2250	ORDER PROCESSING EXTERNAL		0.00	3			
2400	TRAVEL COSTS		6,000.00	4			
2450	TRAVEL COSTS - DESIGN			10			
2500	OTHER COST OF SALES			47			
2900	COMMISSIONS			48			
Sub Totals			13,500.00				

VIZ TASK	TASK DESCRIPTION	UPDATED DESCRIPTION (IF APPLICABBLE)	TOTAL EST COST	DESIGN LABOUR								
					INTERNAL				EXTERNAL			
4000	CELL			TOTAL HOURS	MIKA REF / COST TYPE	HOURS	COST	TOTAL	MIKA REF / COST TYPE	HOURS	COST	TOTAL
402A	HEAD ASSEMBLY	Based on using the Edbro head	53,239.76	50.00								
402B	PNEUMATICS		1,616.70	10.00								
402E	HEAD LINEAR ENCODER		1,762.95	10.00								
403A	BASE ASSEMBLY	Based on using the l base	15,596.12	80.00								
403B	SWARF CHUTE		0.00									
404A	BACK STOP ASSEMBLY		35,633.62	80.00								
404B	BACKSTOP ENCODER		0.00									
404C	TIE BAR ASSEMBLY (EXTERNAL)		27,364.76	50.00								
404D	SLIDING DOLLY		0.00									
404E	EXPANDING BUNG		0.00									
404F	SLIDING CARRIAGE		0.00									
405A	HYDRAULICS		55,273.27	100.00								
405B	AUTOMATION HYDRAULICS		0.00									
405C	HYDRAULIC INSTALLATION		8,156.25									
406A	HEAD BEARING LUBRICATION		3,895.90	20.00								
406B	SLIDEWAY LUBRICATION		4,608.40	20.00								
406C	MANUAL LUBRICATION		378.36	8.00								
407A	3 JAW CHUCK		42,727.26	50.00								
407B	2 JAW CHUCK		0.00									
407C	CHUCK FIXTURE 3 JAW DRAWBAR OPERATED CHUCK		0.00									
407D	COLLET CHUCK		0.00									
407F	6 JAW CHUCK		0.00									
407G	ROTARY DISTRIBUTOR ASSEMBLY		0.00									
407S	CHUCK SWITCHING		1,503.75									
408A	SELF CENTERING CLAMP		33,264.76	50.00								
408B	CLAMP POSITIONER		0.00									
408C	ROLLER STEADY - MACHINE		8,539.31	40.00								

FRONT SHEET | MACHINE COST TEMPLATE | MACHINE INITIAL TIMING PLAN | PROJECTED CASHFLOW | MACHINE TIMING TEMPLATE

Note: If an additional project task is required for any reason, the appointed project manager should be informed of this requirement

15 WI158 – Design Risk Assessment Work Instruction

WI158 - Design Risk Assessment Work Instruction

Document Number:	WI158
Process Owner	
Description:	Design Risk Assessment Work Instruction

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01			
02			

Contents

1, Description

A Design Risk Assessment is required to comply with the requirements of the EU Machinery Directive (2006/42/EC). The regulations require the designer to carry out a risk assessment of their design, eliminate hazards and risks by using the hierarchy of risk control and record details of remaining hazards in the form of a Residual Risk Register (See WI159 - Residual Risk Register Work Instruction). To produce a Design Risk Assessment, the producer shall follow the following steps:

1. Using the DRA Template (See F228 – DRA Template). Please complete the front sheet with relevant project specific information.

F228 - DRA Template

KUKA project number	
Project title	
Description	
Customer / Employer	
Client	

Doc. Number		Issue	
Author		Date	
Department			

	Print Name / Position	Signature	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By			

2. Read through the instructions stated on the relevant tabs.

3. Work through each of the sections answering each question appropriately 'Comply', 'Not Comply' or 'Not Applicable' and then add a supporting comment, if necessary, in the relevant sections.

Section 1.	1.1.2: Principles of safety integration						Contract No =
Question 1	Is machinery designed and constructed so that it is fitted for its function and can it be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the conditions foreseen but also taking into account any reasonably foreseeable misuse thereof? The aim of measures taken must be to eliminate any risk throughout the foreseeable lifetime of the machinery including the phases of transport, assembly, dismantling, disabling and scrapping.						
Comply		Not Comply		Not Applicable		Verification	

ANSI B11.TR3.2000 & BS EN ISO 12100:2010	ANSI B11.TR6.2010 & BS EN ISO 13849-1:2008

STATION #	Type or Group of Hazard	Operation mode	Hazard Description	Potential Consequences	Initial Assessment: Severity of Injury	Frequency of Exposure	Possibility of Avoidance	Hazard Risk Number	Risk level	Action Required	After Reassessment: Severity of Injury	Frequency of Exposure	Possibility of Avoidance	Hazard Risk Number	Risk level	Further Action Required	Action Requires SRP/CS	Assessment: Severity of Injury	Frequency of Exposure	Probability of Avoidance	Performance Level required	Description Of SRP/CS (Safety Related Parts Of Control System)	Safety function (description to be populated here and tested at safety buy-off)
	Mechanical Hazards	Operation						0	Negligible					0	Negligible						n/a		
	Mechanical Hazards	Set-up						0	Negligible					0	Negligible						n/a		
	Mechanical Hazards	Maintenance						0	Negligible					0	Negligible						n/a		

Page	7	of	213	OFFICIAL © 2020 KUKA Systems UK Ltd Registered office: Hereward Rise, Halesowen, West Midlands, B62 8AN Tel: +44 (0) 121585 0888

16 WI159 - Residual Risk Register Work Instruction

WI159 - Residual Risk Register Work Instruction

Document Number:	WI159
Process Owner	
Description:	Residual Risk Register Work Instruction

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01			
02			

Contents

1, Description

A ‘Residual Risk’ is the amount of risk or danger associated with an action or event remaining after natural or inherent risks have been reduced by risk controls.

Upon completion of a Design Risk Assessment (See WI158 - Design Risk Assessment Work Instruction), any remaining risks that have been identified must be recorded in the ‘F230 - Residual Risk Register Template’. A ‘F230 - Residual Risk Register Template’ is required to comply with the requirements of the Construction (Design Management Regulations 2007).

To produce a ‘F230 - Residual Risk Register Template’, the producer shall follow the following steps:

1. Populate the front sheet with the required information, Document Number, Revision Date, Producer name etc.

2. Populate the Introduction section with the project title and provide a brief description of the equipment.

1 Introduction

The purpose of this document is to collate the residual risks identified during the design risk assessments of the [Project], such that the residual risks can be taken into account when preparing further documentation, when carrying out future risk assessments and to comply with the requirements of the Construction (Design Management) Regulations 2007.

2 Description of Equipment

3. Populate each of the required fields shown below, this information should be taken from the Design Risk Assessment.

Residual Risk Register:

Identified In Document No.	System Reference	Hazard Ref. No.	Description of Hazard	Hazard Type	Suggested Control Measures	Residual Risk
						L
						M
						H

17 WI160 – Introduction to Toll Gates

WI160 - Introduction to Toll Gates

Document Number:	WI160
Process Owner	
Description:	Introduction to Toll Gates

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01			
02			

Contents

1, Description

The Tollgate procedure is detailed in 'P10 - Design Procedure'. To avoid duplication and potential error this source document should be read to understand this procedure.

The "SOP10 - Design Procedure" is saved in:

Vault:\Project Explorer\Designs\1.Procedures\SOP10 – Design Procedure

&

V:\Iso9000 2000\OPERATING PROCEDURES_____________@@@@\New BMS Procedures\P11 Product Realisation\P11_Product

18 WI161 – Introduction to Emails

WI161 - Introduction to Emails

Document Number:	WI161
Process Owner	
Description:	Introduction to Emails

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

The use of emails is an effective way to communicate with customers, suppliers and colleagues as it acts as a piece of evidence to clarify what was and wasn't said between two individuals. When communicating through emails it's important to populate the subject area to the following format:

By following the format outlined above, a substantial amount of time can be saved for the recipient when reading the email as it clearly identifies the project, task and purpose for the email. Furthermore, conforming to this format is beneficial for traceability and filing.

Note: When sending emails consideration should be given to the recipients of the email, are all the relevant parties involved? Is the content of the email relevant to all parties?

19 WI162 – Introduction to the Front Sheet

WI162 - Introduction to Front Sheet

Document Number:	WI162
Process Owner	
Description:	Introduction to Front Sheets

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01			
02			

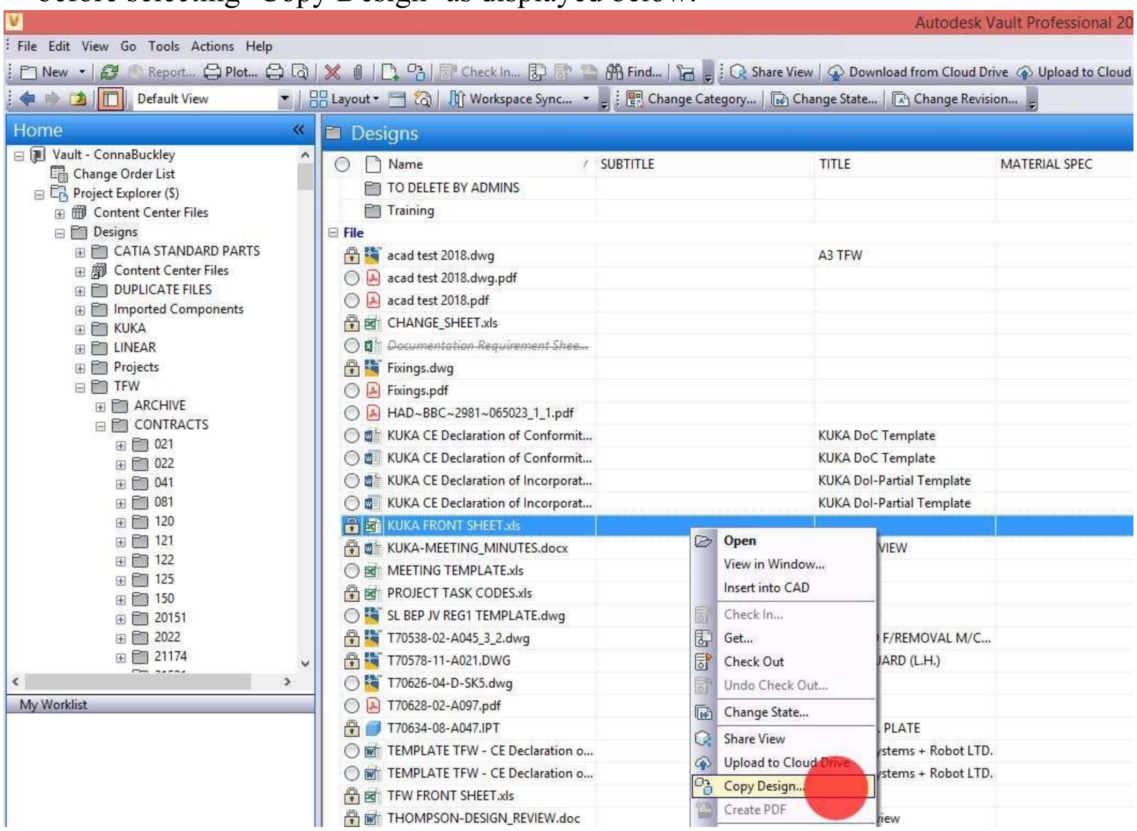
Contents

1, Description

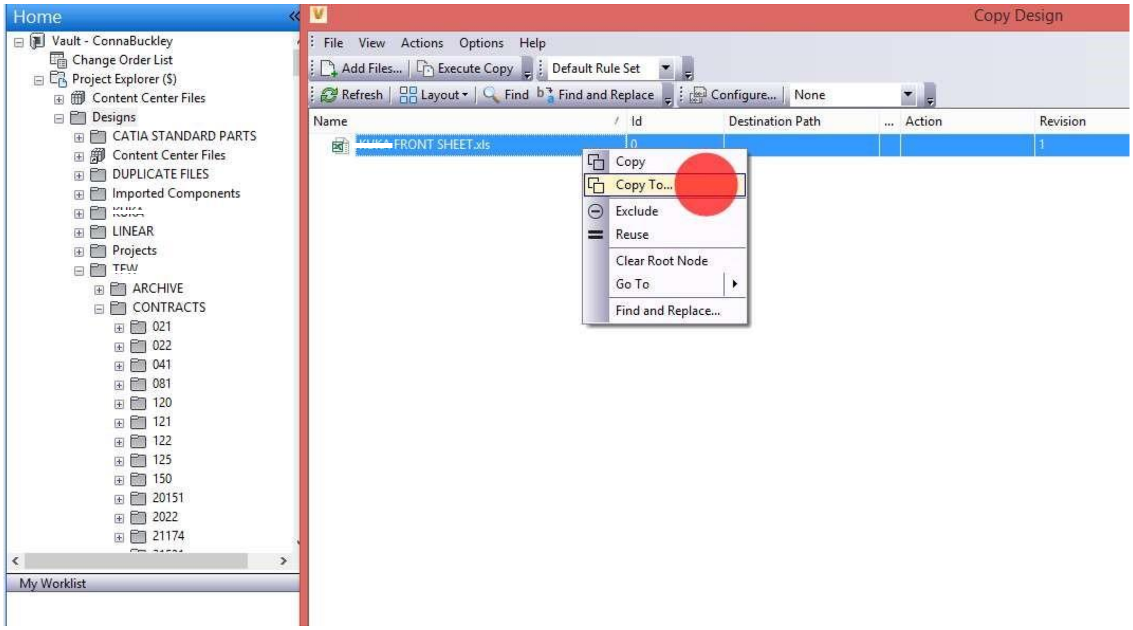
All projects require a ‘F231 - Front Sheet Template’, this work instruction details how to create a ‘F231 - Front Sheet Template’. The ‘F231 - Front Sheet Template’ acts as a point of reference for the engineering department to see what is yet to be issued and what has been issued and when. The ‘F231 - Front Sheet Template’ is stored within the document management system Vault inside the relevant contract folder.

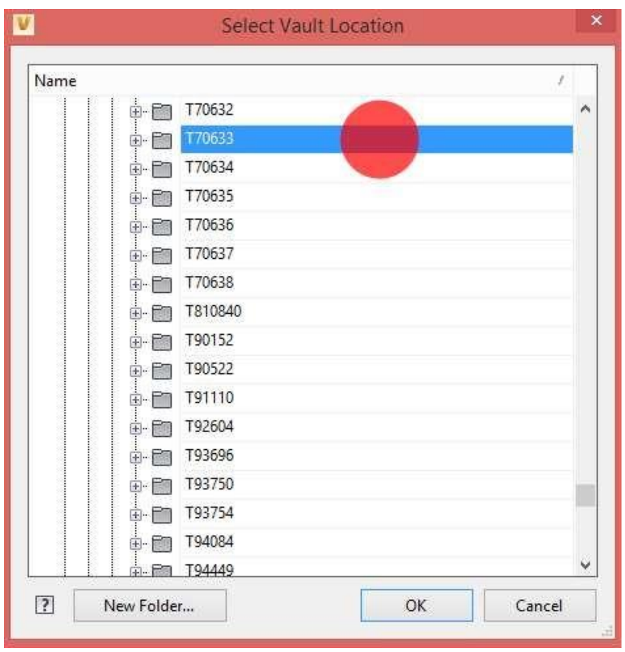
To create a front sheet inside Vault the following steps must be followed:

1. In the project explorer select ‘Designs’, right click ‘F231 - Front Sheet Template.xls’ before selecting ‘Copy Design’ as displayed below.

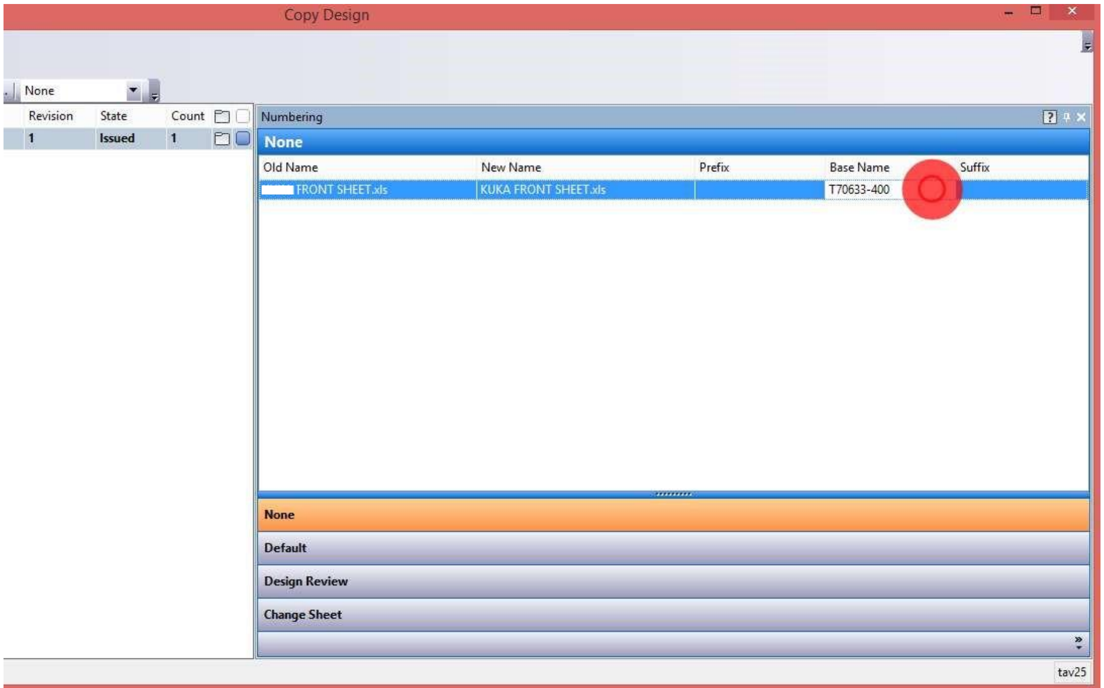


2. Right click ‘F231 - Front Sheet Template.xls’ and select ‘Copy To…’ before proceeding to store it in the relevant Project location inside Vault as shown below.

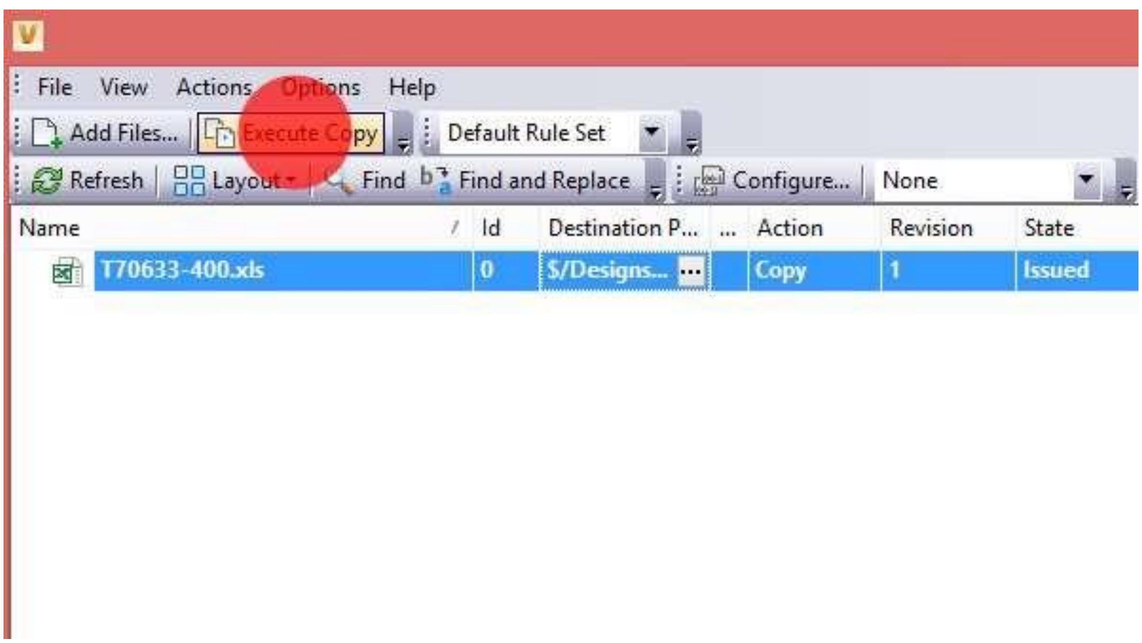




3. Proceed to remove the ‘Prefix’ automatically generated by Vault and enter an appropriate ‘Base Name’. The standard format ‘Base Name’ for a Front Sheet is ‘CONTRACT NUMBER-400’.



4. Select ‘Execute Copy’ as illustrated below. This excel sheet will now be accessible within the location previously selected inside Vault.



5. Open the Excel file created upon completion of the previous steps, the sheet should be populated in a similar manner to what’s shown below. The front sheet should be populated in accordance with the MIKA sheet created by the sales department, (See WI157 - Introduction to Sales Cost Sheet (SCS) MIKA). The Front Sheet should be updated as and when sections of the project are issued.

Thompson Friction Welding

CUSTOMER:

PROJECT TITLE AX5DE TRAILER AXLE FRICTION WELD M/C.

CONTRACT No. T70633

TO DO LIST

ASSEMBLY	ASSEMBLY No.	Based On No.	ISSUED	% COMPLETE	
HEAD ASSEMBLY	402-A	T70626	07/02/2019	100	

ISSUE	DATE	MOD No.	ISSUE	DATE	MOD No.	ISSUE	DATE	MOD No.
1		FIRST ISSUE						

SECTIONS FULLY ISSUED

SECTIONS PART ISSUED WITH COMMENTS

PRE ISSUED ON LLP FORM

APPD	FRONT SHEET	SHT 1	T70633-400
DRAWN		OF 2	

2, Tollgates

The front sheet template has a tab that include the deliverables for each of the tollgates. Some of the tollgate deliverables are internal documents for Engineering only and some are to be included as deliverables for the business tollgates. This is clearly shown on Tab 2 of the template.

KUKA Systems

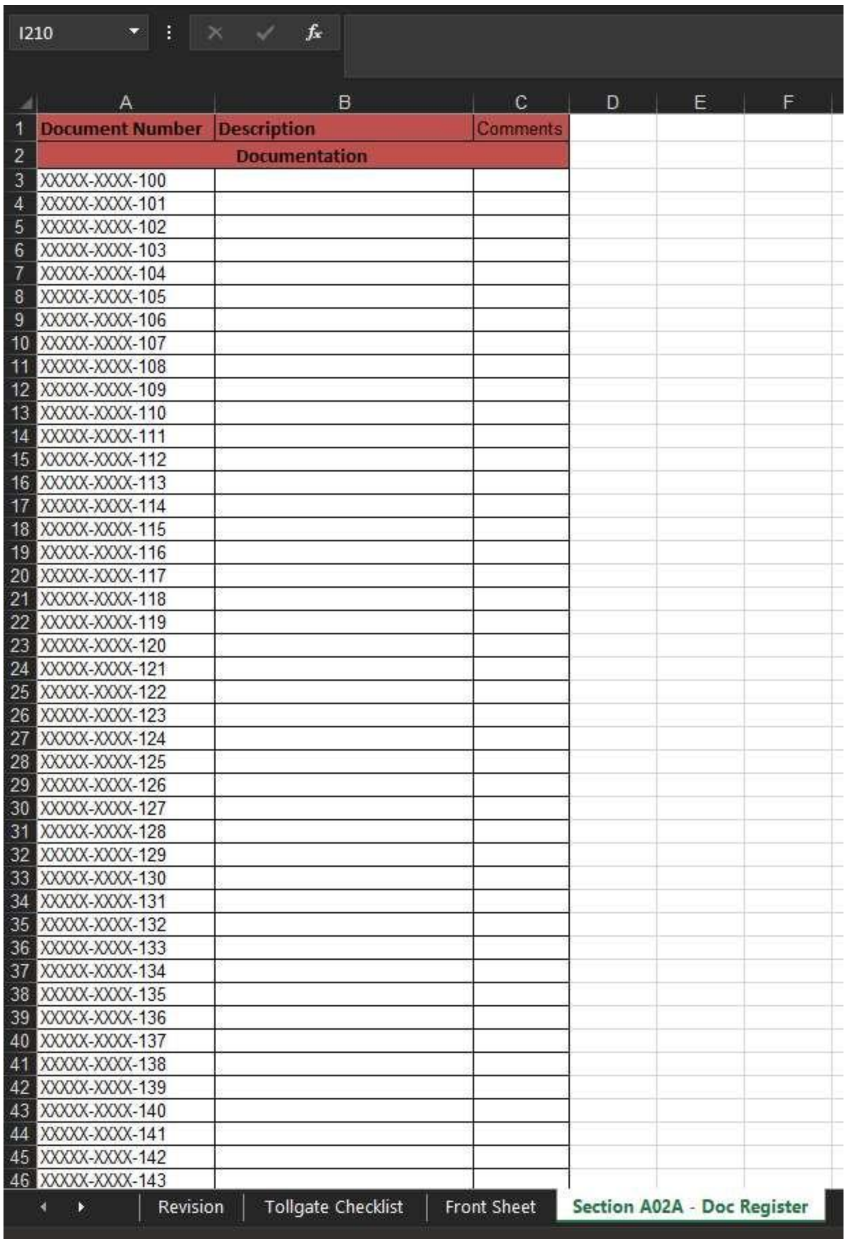
CONTRACT No.			0	
CUSTOMER			0	
PROJECT DESCRIPTION			0	
No	No	Internal Tollgate Deliverable	External Tollgate Deliverable	Completed
Tollgate A	1	New Sales Enquiry Specification Generated (No Non-standard machine elements) (F224)	New Sales Enquiry Specification Generated (Non-standard machine elements listed) (F224)	
	2	Learning From Experience (LFE) Template Reviewed (F226)		
	3	New Sales Enquiry Hours Generated (F223)		
	4	Process Parameters Sheet Generated (F225)		
Tollgate B	5		Concept Design (WI197)	
	6	Risk Ranking and Filtering Template (F241)		
Tollgate 3.1	7	Design Risk Assessment (DRA) Generated (Draft) (F228)		
	8	Residual Risk Register (RRR) Generated (Draft) (F230)		
	9	Design Brief Generated (F413)		
Tollgate 3.2	10	Peer Design Reviews Undertaken (If Required) (F233)		
	11	Peer Design Review Quesionnaire (If Required) (F419)		
	12	Design Failure Mode Effect Analysis (DFMEA) Undertaken (If Required) (F234)		
	13	Process Failure Mode Effect Analysis (PFMEA) Undertaken (If Required) (F242)		
Tollgate 3.3	14	Production Design Reviews Undertaken (If Required) (F233)		
	15	Design Risk Assessment (DRA) (Approved) (F228)		
	16	Residual Risk Register (RRR) (Approved) (F230)		
	17	Paint Specification Issued (F409 If Standard paint spec)		
Tollgate 3.4	18	Manufacturing Design Reviews Undertaken (If Required) (F233)		
	19	Lifting Plan Issued (F235)		
	20	Switch List Issued (F411)		
Tollgate T4	21		Design Risk Assessment Issued (F228)	
	22		Residual Risk Register Issued (F230)	
	23		Risk Ranking and Filtering Template Issued (F241)	
	24		All Checked and Approved Drawings Issued	
	25		Frozen Bills Of Materials (BOMs) Issued	
	26		Issue Spare Parts List	
	27	Front Sheet Check Undertaken		
Tollgate 5	28		Pass Of Critera Issued (F421)	
	29		Testing and Commissioning Strategy Issued (F420)	
Tollgate 6	30		Declaration of Conformity / Incorporation Issued (F236 or F237)	
	31	Front Sheet Closed (F231)		

F231 - Front Sheet Template SHT 2 OF 3

All documents created should be saved within Vault under the contract file. Additionally, it is the responsibility of the Lead Engineer on the contract to ensure that the relevant documents are generated and saved as required for each of the tollgates.

3, Document Register

The front sheet contains a document register that should be adhered to, and all documents created must be added to this register. Each machine section has a tab, and each tab should be populated with the relevant documents for that section including, calculations, General Arrangement drawings etc (See WI205 – Document Naming and Numbering Convention Work Instruction)



Document Number	Description	Comments
Documentation		
XXXXX-XXXX-100		
XXXXX-XXXX-101		
XXXXX-XXXX-102		
XXXXX-XXXX-103		
XXXXX-XXXX-104		
XXXXX-XXXX-105		
XXXXX-XXXX-106		
XXXXX-XXXX-107		
XXXXX-XXXX-108		
XXXXX-XXXX-109		
XXXXX-XXXX-110		
XXXXX-XXXX-111		
XXXXX-XXXX-112		
XXXXX-XXXX-113		
XXXXX-XXXX-114		
XXXXX-XXXX-115		
XXXXX-XXXX-116		
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XXXXX-XXXX-137		
XXXXX-XXXX-138		
XXXXX-XXXX-139		
XXXXX-XXXX-140		
XXXXX-XXXX-141		
XXXXX-XXXX-142		
XXXXX-XXXX-143		

20 WI163 – Introduction to Timesheets

WI163 - Introduction to Timesheets

Document Number:	WI163
Process Owner	
Description:	Introduction to Timesheets

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

Timesheets are maintained in the engineering department to record the hours and projects each employee has worked on throughout the month. The primary function of timesheets from an engineering perspective is to enable the sales and projects departments to revisit past data with the aim of being able to accurately cost and plan future projects, thus it's important to input data as accurately as possible.

The following excel spreadsheet is available to assist in recording timesheet data for the working month prior to entering onto Visibility. This template is circulated by the accounts department annually.

KUKA SYSTEMS UK LTD
HEREWARD RISE, HALESOVEN, WEST MIDLANDS.

TIME SHEET

NAME:

MONTH:

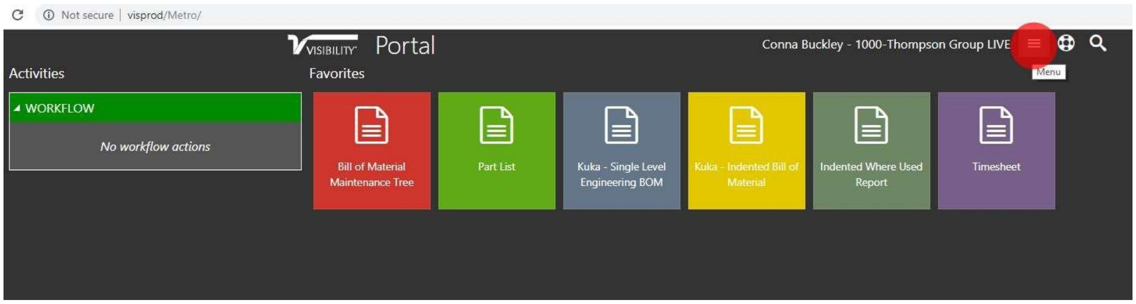
Week		Day	Start	Finish	Lunch	Hrs	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10										093 University / Training	094 All Holiday	095 Sick	096 Meetings / Administration	098 Waiting Time	Total	Check	Std Hrs	Surplus / Deficit
31	1	Thu	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	2	Fri	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	3	Sat																																
	4	Sun																																
	5	Mon	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	6	Tue	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	7	Wed	08:30	17:00	01:00	7.50																										error	7.5	-7.5
32	8	Thu	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	9	Fri	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	10	Sat																																
	11	Sun																																
	12	Mon	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	13	Tue	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	14	Wed	08:30	17:00	01:00	7.50																										error	7.5	-7.5
33	15	Thu	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	16	Fri	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	17	Sat																																
	18	Sun																																
	19	Mon	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	20	Tue	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	21	Wed	08:30	17:00	01:00	7.50																										error	7.5	-7.5
34	22	Thu	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	23	Fri	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	24	Sat																																
	25	Sun																																
	26	Mon	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	27	Tue	08:30	17:00	01:00	7.50																										error	7.5	-7.5
35	28	Wed	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	29	Thu	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	30	Fri	08:30	17:00	01:00	7.50																										error	7.5	-7.5
	31	Sat																																
		TOTAL																															165	-165

Signed

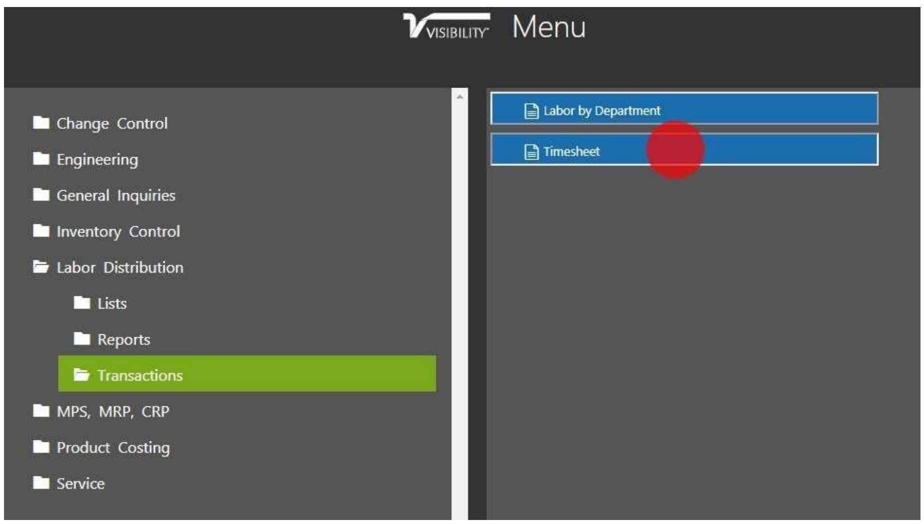
Authorised

To record your data inside Visibility the following steps must be followed:

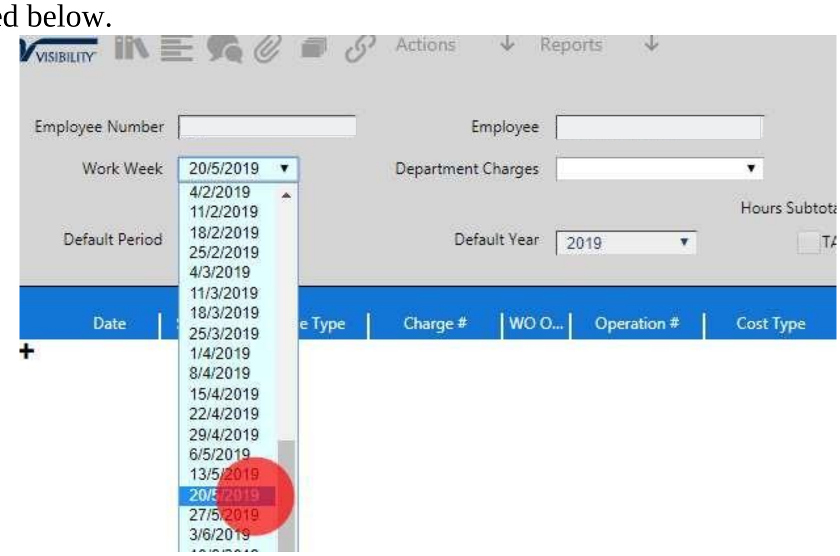
1. Upon logging into visibility select ‘Menu’ at the top of the page as shown below.



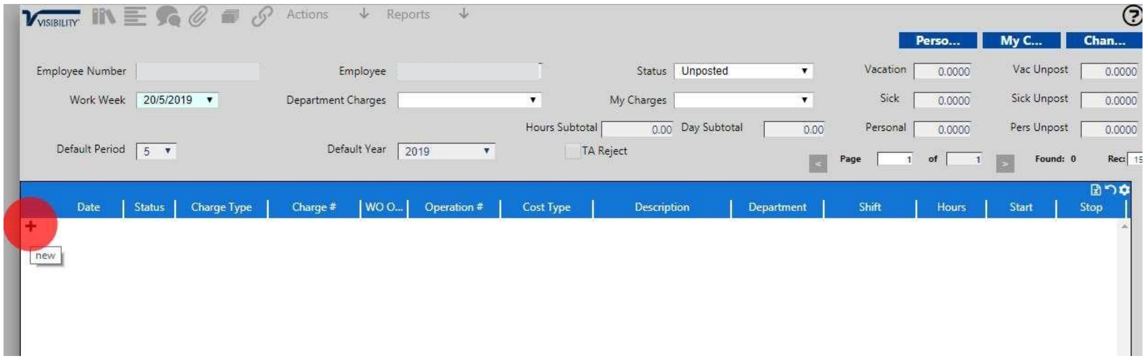
2. Navigate the menu as displayed below before selecting ‘Timesheet’.



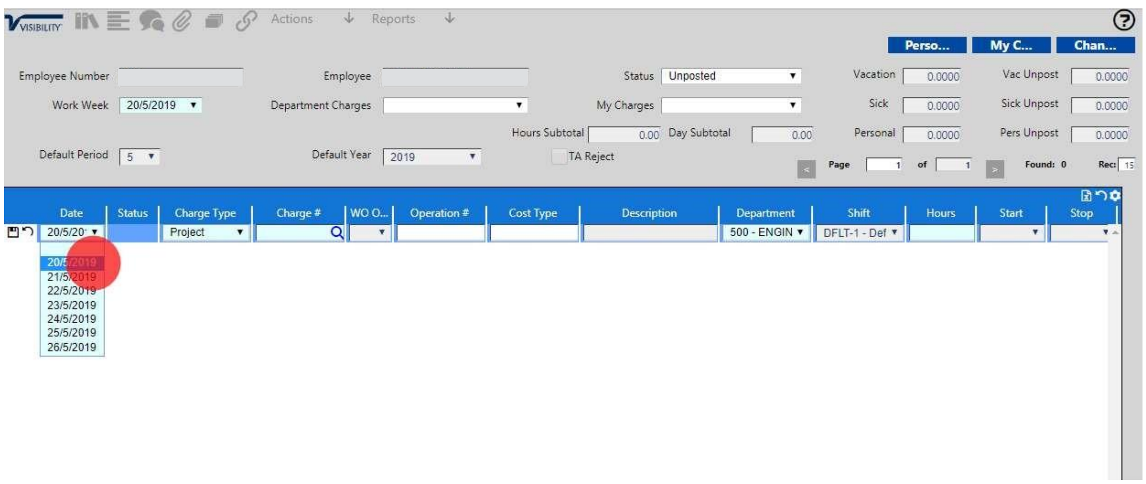
3. Before adding an entry to the timesheet, first select the appropriate ‘Work Week’ as displayed below.



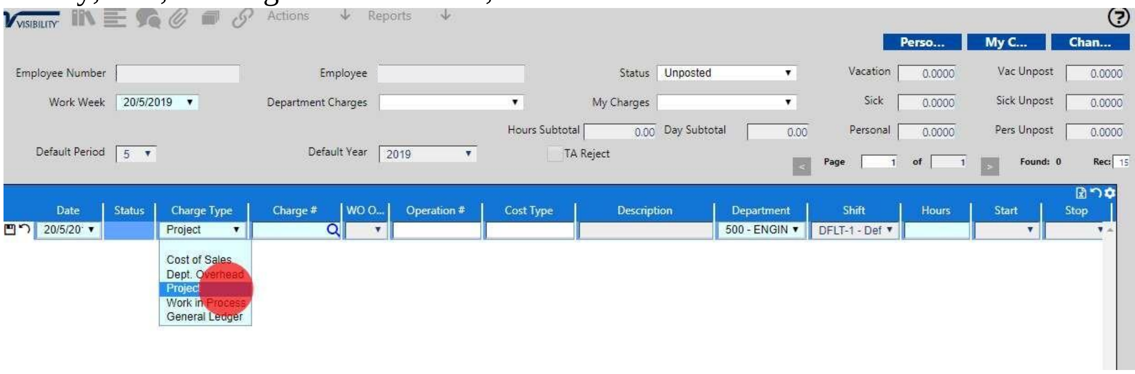
4. To add an entry to the timesheet, select the plus on the left-hand side of the screen as shown below.



5. Upon adding an entry to the time sheet, you should select a specific 'Date' for that working week as demonstrated below.

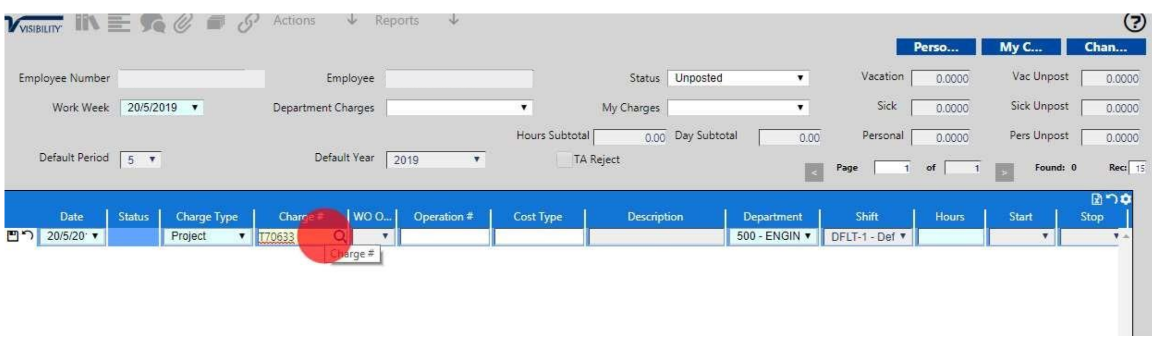


6. Select a charge type as displayed below. Engineering have one of two options for this drop down menu, those being 'Project' or 'Department Overhead'. 'Project' should be selected when the task you have been working on is for a specific contract that is 'active'. 'Department Overhead' should be selected for instances such as training/university, holiday, sick, meetings/administration, etc.



7. The next step is to enter the 'Charge #' as shown below. If 'Project' was selected in the previous step proceed to enter the allocated contract number. If 'Department Overhead' has been selected in the previous step, choose the appropriate code from the following 5 codes:

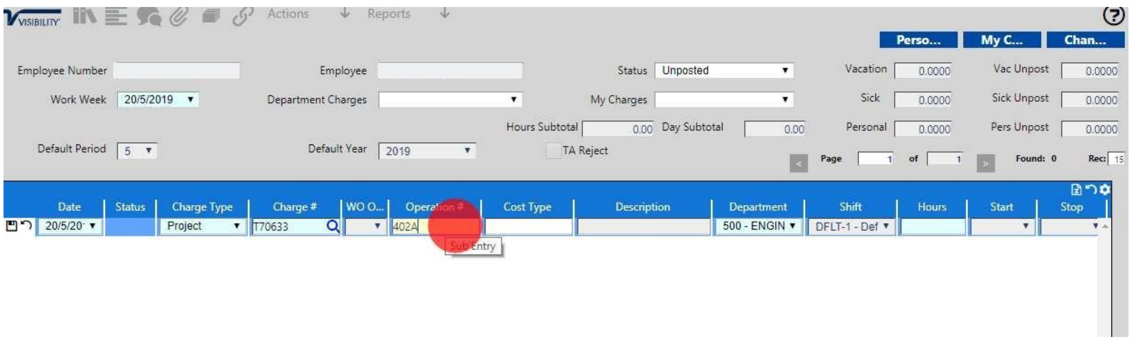
- S093 – Training/University
- S094 –Holiday
- S095 – Sick
- S096 – Meetings/Administration
- S098 – Waiting Time.

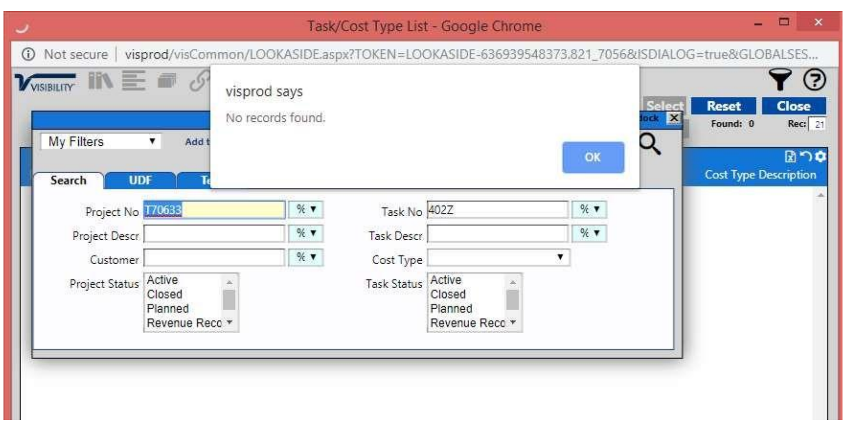


Note: If 'Department Overhead' was selected at step 6 the next step isn't necessary.

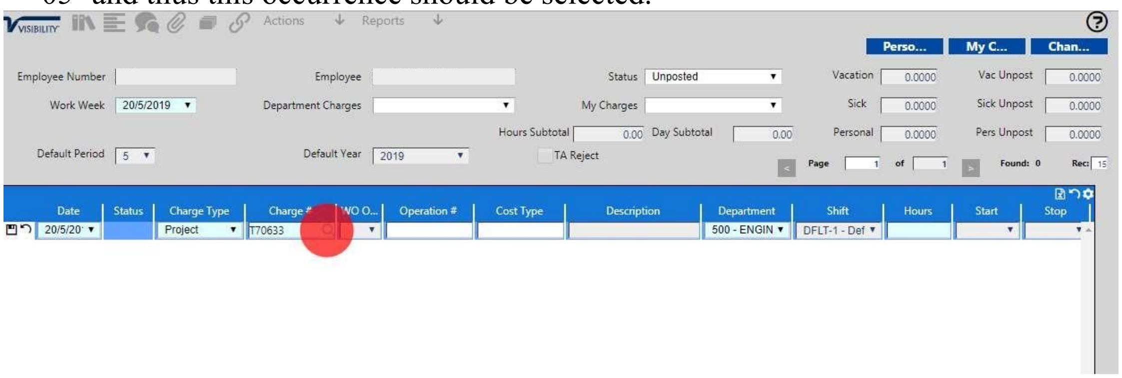
8. The next step is to enter the 'Operation #' as shown below. This code identifies specific task / section of the project work has been carried out for. For example, '402A' refers to the head assembly.

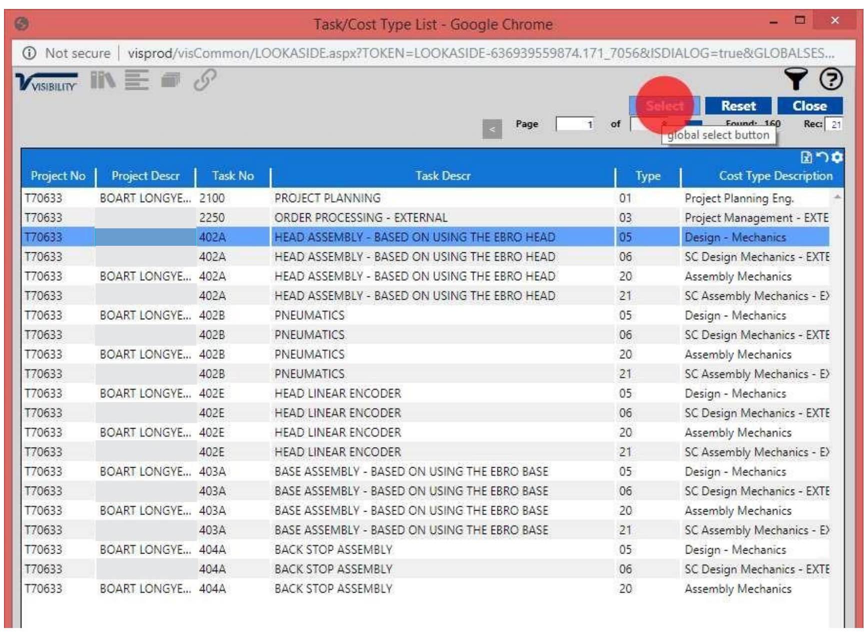
   Note: The code enter should NOT contain any hyphens i.e. 402-A. If the code entered prompts the following window it symbolises that an 'Operation #' hasn't been created for that task / section. If this is the case then contact the relevant person in the Accounts department with a request for the task / section to be created, with approval of your line manager and request for them to create the required 'Operation #'.



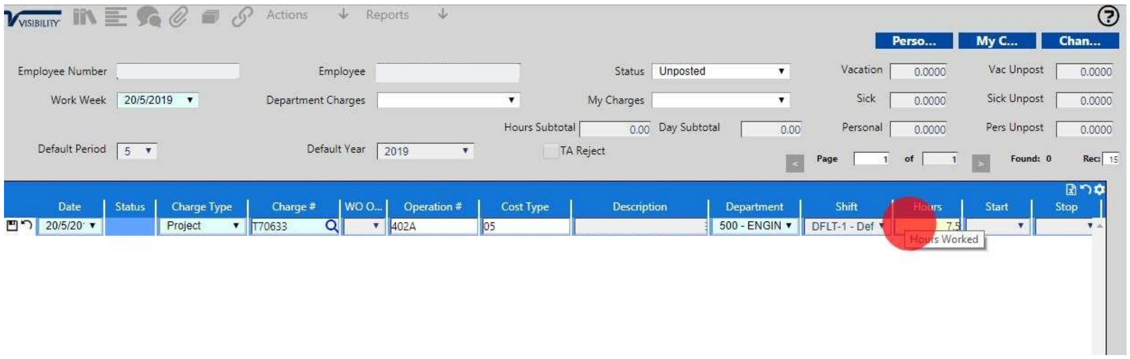


Note: ‘Operation #’ can be selected from various ‘Operation #’ created for that specific ‘Charge #’ generated by accounts. To do this click the magnifying glass within the ‘Charge #’ field as shown below which will prompt the following window. It’s important to note that each ‘Operation #’ will have several occurrences due to the various cost types throughout the business. Within the Engineering department the designated cost type is ‘05’ and thus this occurrence should be selected.

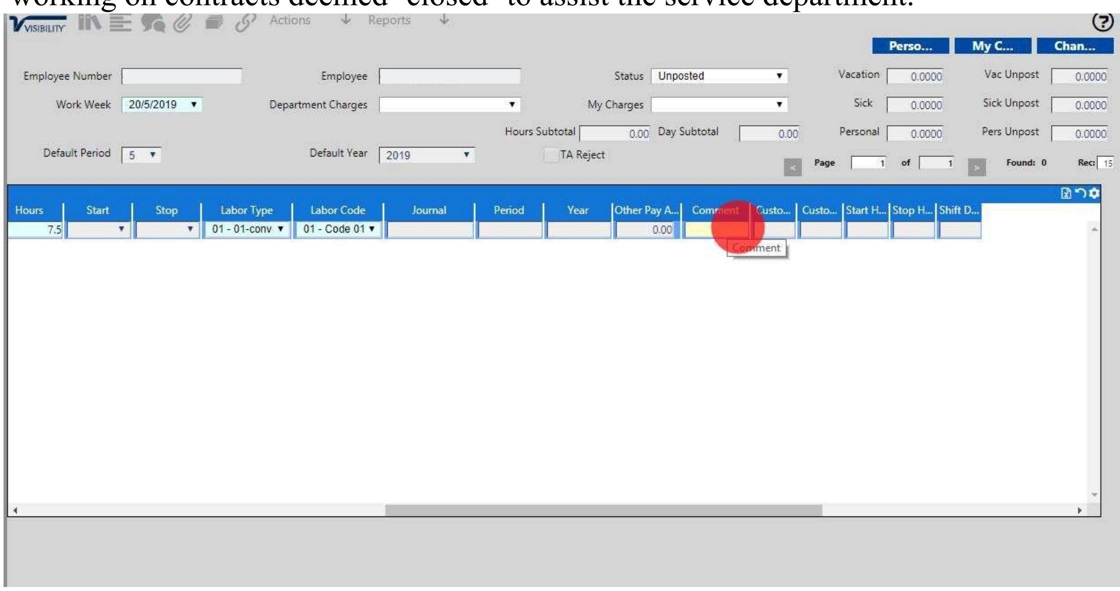




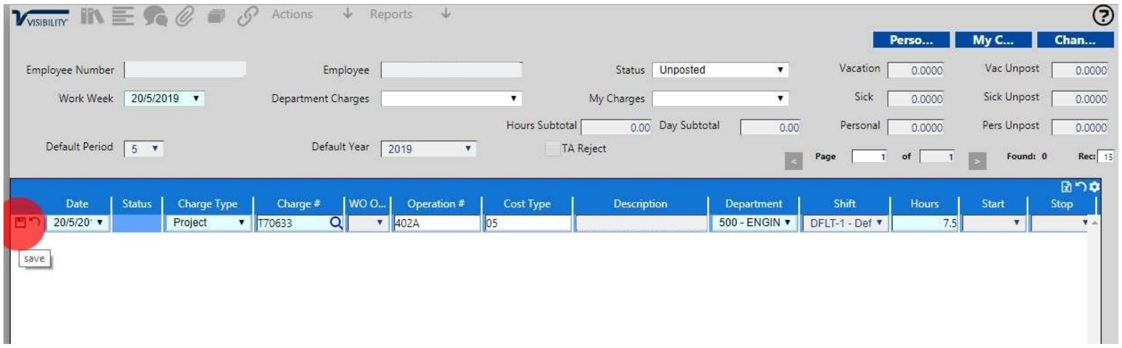
9. Enter the ‘Hours’ worked on that job as shown below. The time spent on the job can be recorded to the nearest 15-minute interval which is represented by 0.25.



10. The penultimate step is optional but is of particular use when using generic ‘Charge #’ such as S093, S096 and S098 which can be ambiguous and may require further details. The comments section can be used to briefly describe what tasks have been undertaken e.g. working on contracts deemed ‘closed’ to assist the service department.



11. Upon completion of the previous steps and all the required fields have been populated, save the entry as demonstrated below.



12. Repeat the steps outlined above for all required entries for the month.

13. Upon completion of the monthly timesheet, the time sheets will be approved by the line manager and issued to the Accounts Department. Whilst this process is taking place it's important NOT to post any further entries into the timesheet for the upcoming month until instructed to do so by the Accounts Department via an email.

21 WI164 – Setting Procedure for AutoCAD and Inventor

WI164 - Setting Procedure for AutoCAD & Inventor

Document Number:	WI164
Process Owner	
Description:	Setting Procedure for AutoCAD & Inventor

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

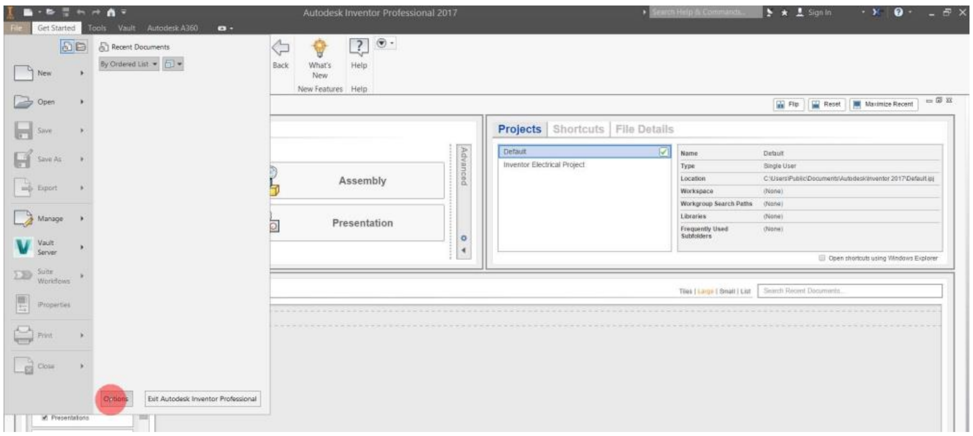
Issue	Amendment	Author	Date
01	Initial Issue		

Contents

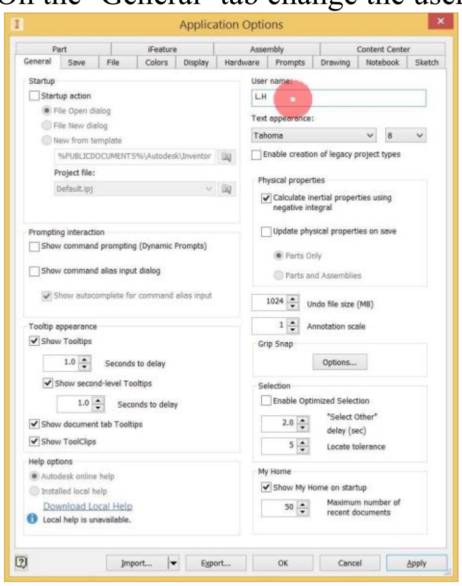
1, Inventor

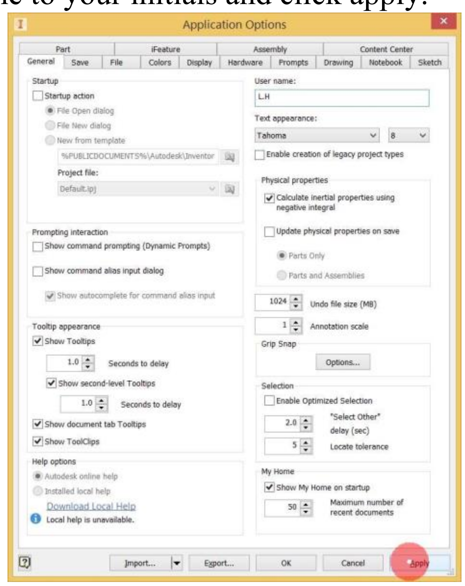
1.1, Initial Settings & Display Settings

1. Navigate to “File > Options”.

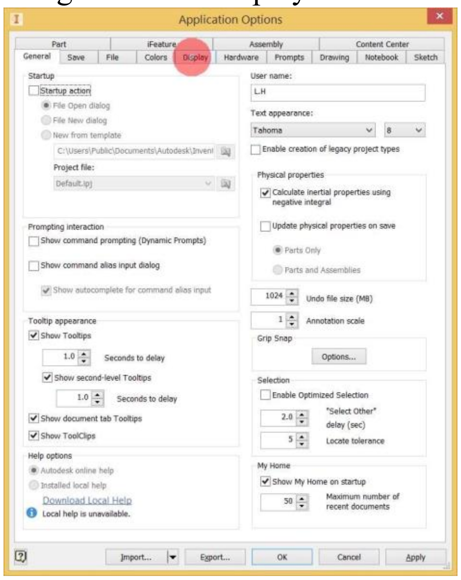


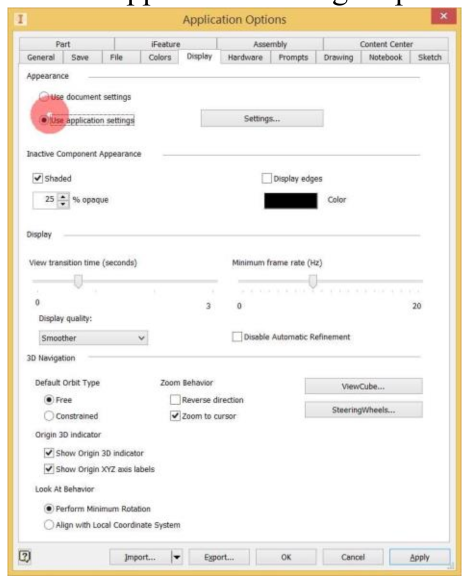
2. On the ‘General’ tab change the username to your initials and click apply.



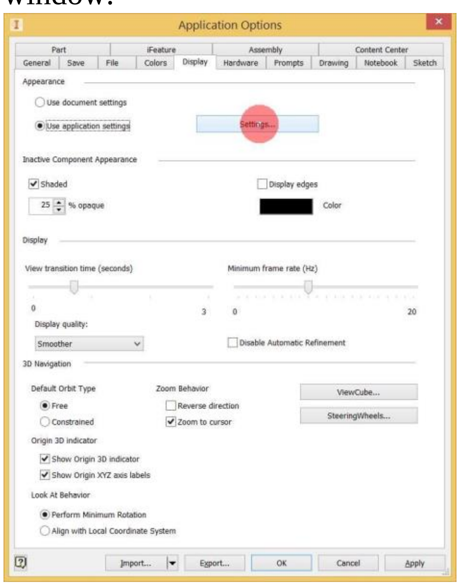


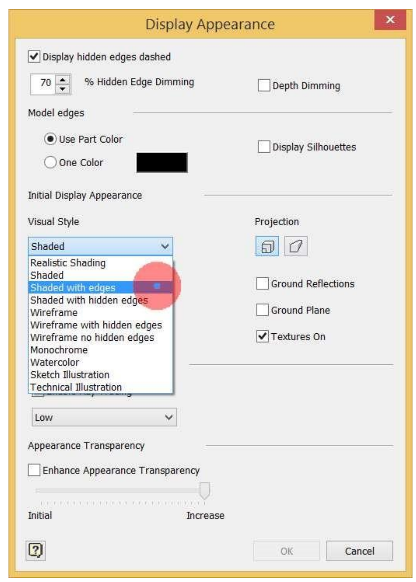
3. Navigate to the ‘Display’ tab and select the ‘Use application settings’ option.



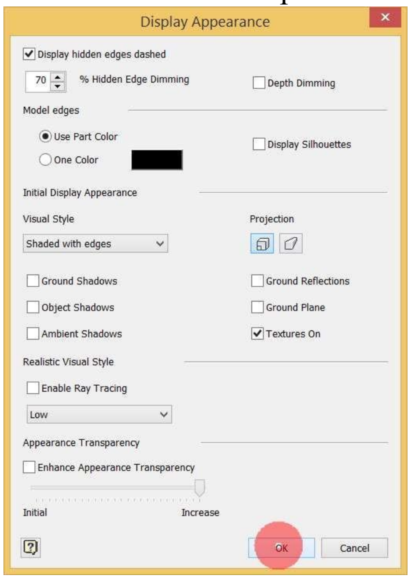


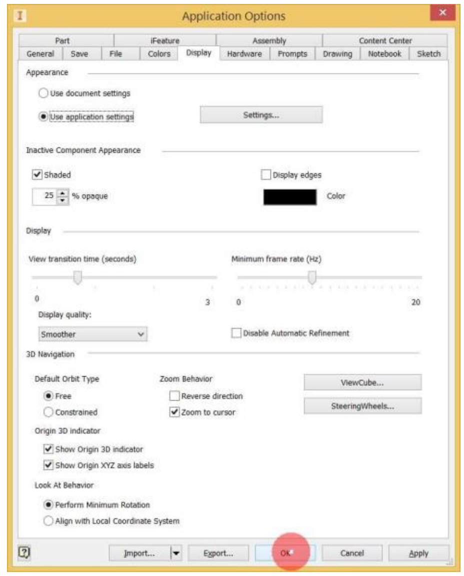
4. Click ‘Settings…’ and select ‘Shaded with edges’ from the drop down menu in the new window.





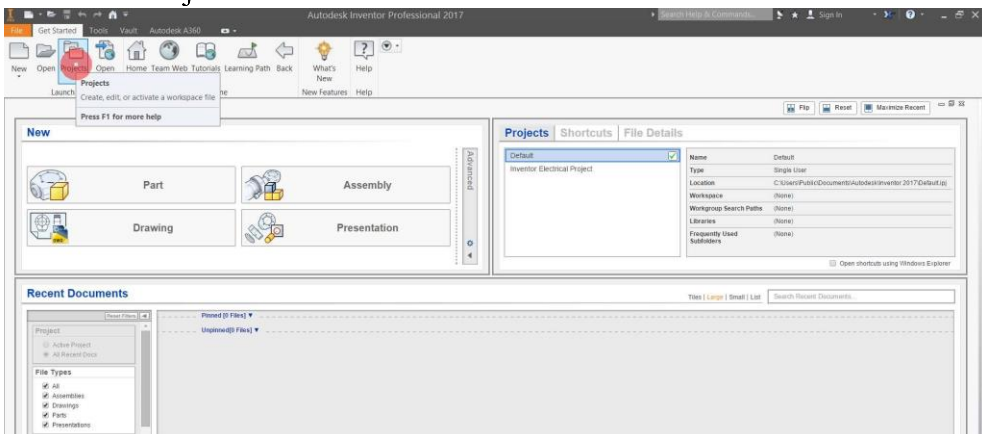
5. Select ‘OK’ on both open windows.



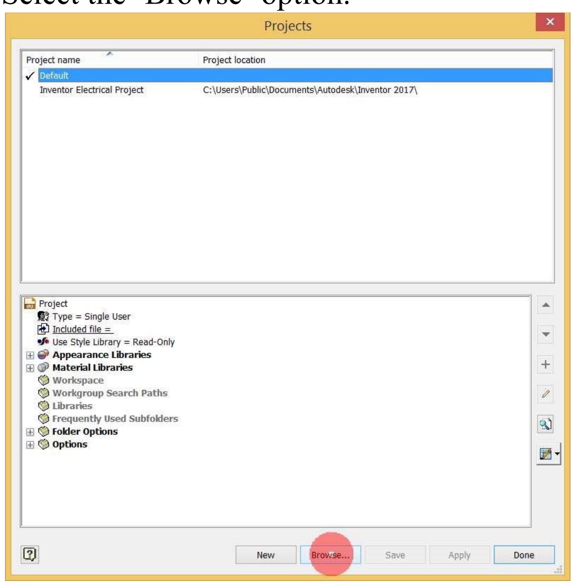


1.2, Setting a Project Folder

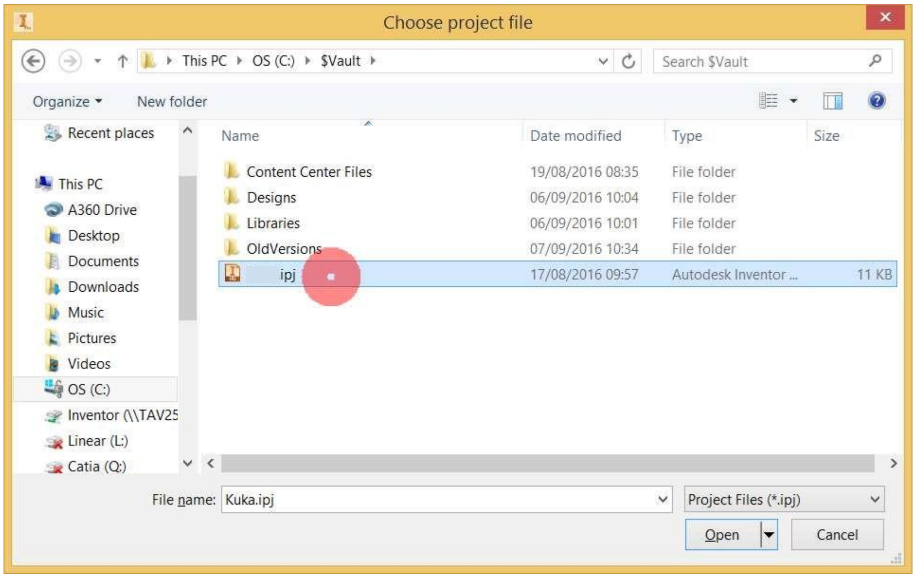
1. Select the ‘Projects’ button.



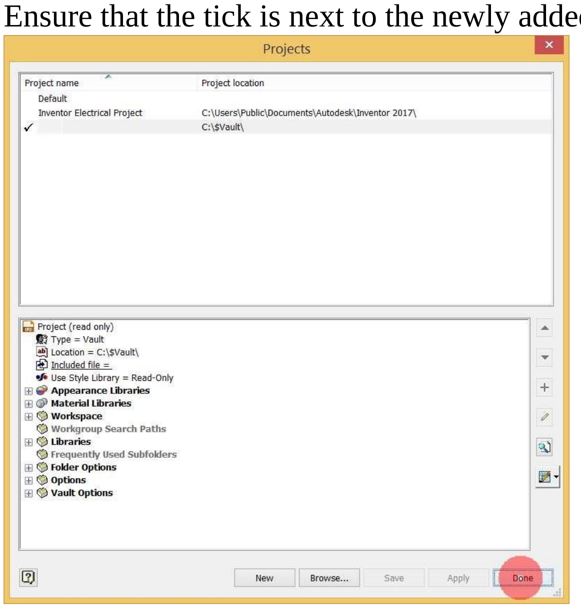
2. Select the ‘Browse’ option.



3. Navigate to “This PC > OS (C:) > $Vault” and select and open the ‘company.ipj’ file.



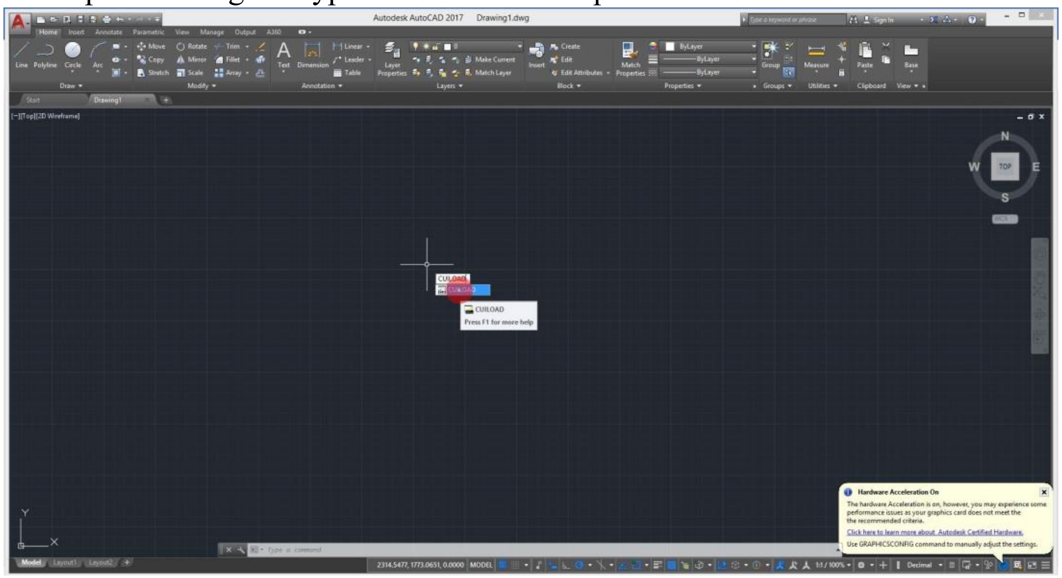
4. Ensure that the tick is next to the newly added project file and select done.



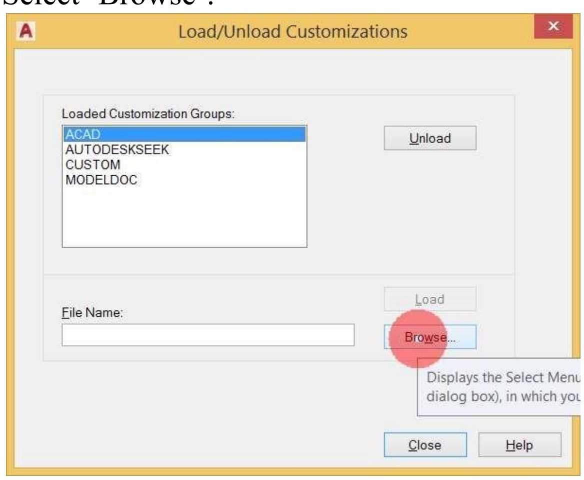
2, AutoCAD

2.1, Adding the Vault Tab to the Ribbon

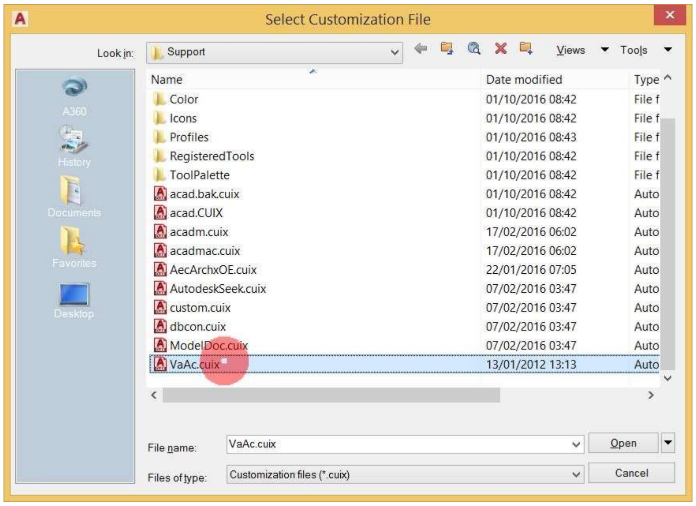
1. In an open drawing file type ‘CUILOAD’ and press enter.



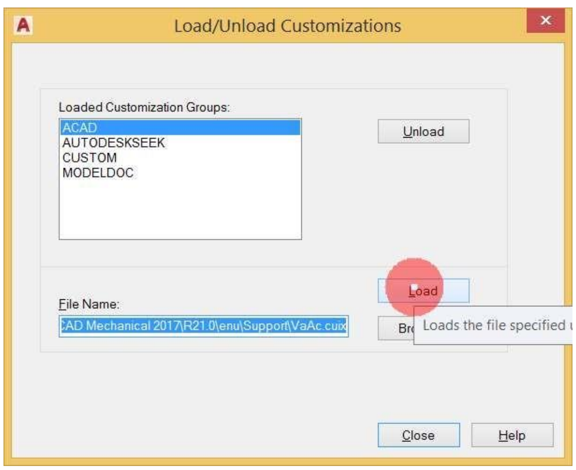
2. Select ‘Browse’.

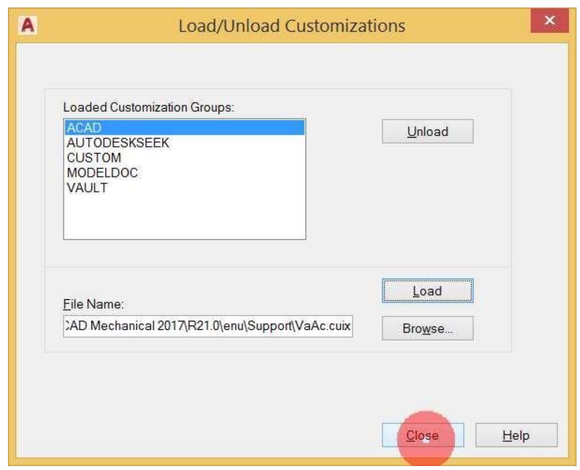


3. Select the ‘VaAc.cuix’ file and press open.

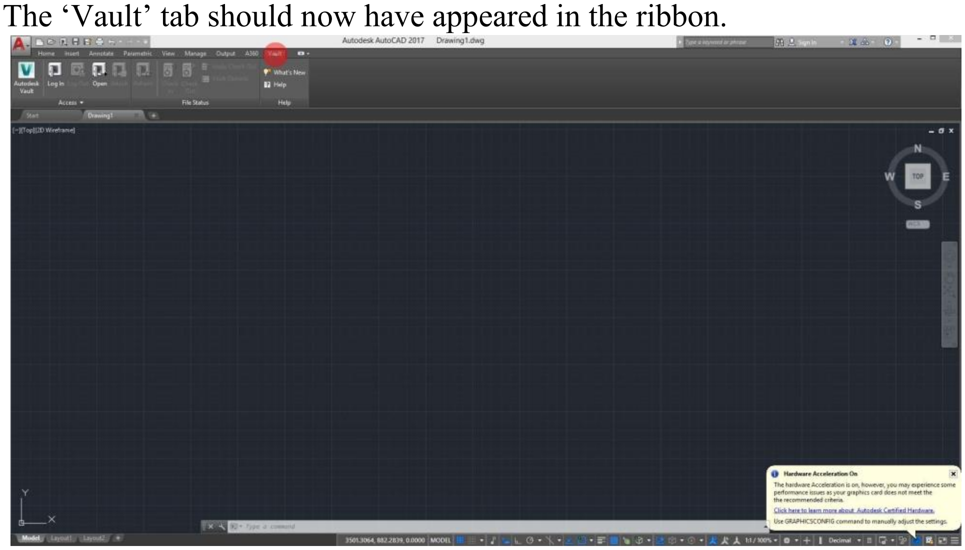


4. Select ‘Load’, if this is successful the work ‘Vault’ will appear in the upper box. Close the window.





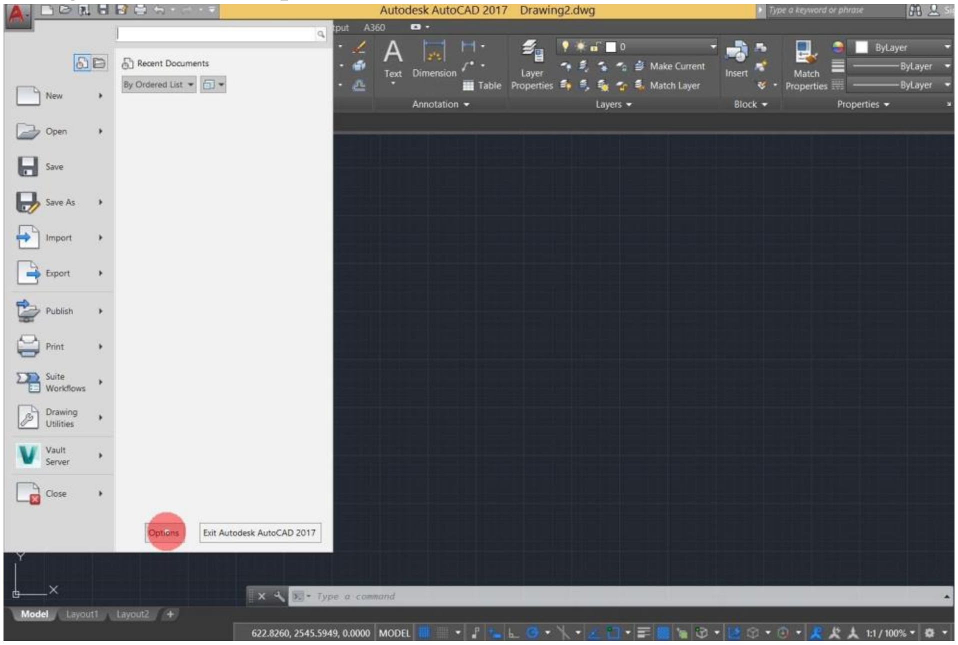
5. The ‘Vault’ tab should now have appeared in the ribbon.



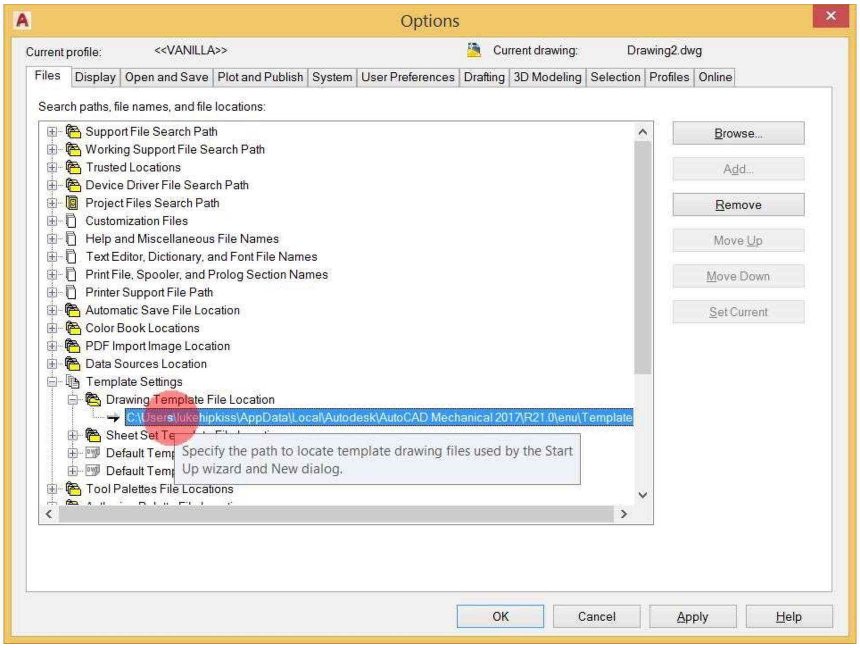
2.2, Setting the Template files location

1. Open a new file.

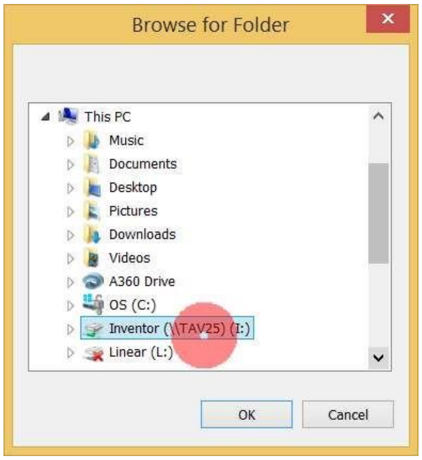
2. Navigate to “File > Options”.

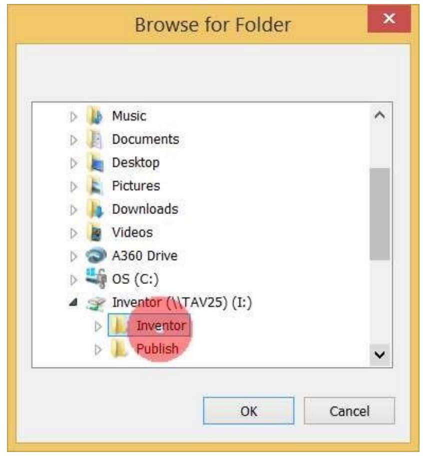


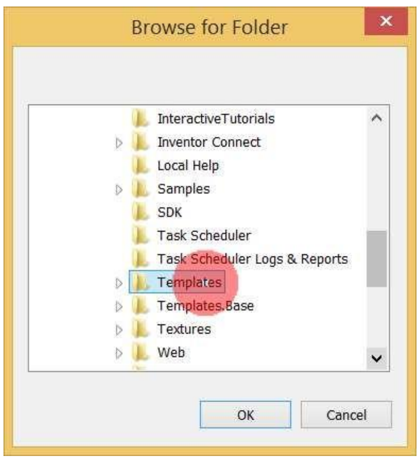
3. On the ‘Files’ tab navigate to “Template Settings > Drawing Template File Location” and double click on the file path.

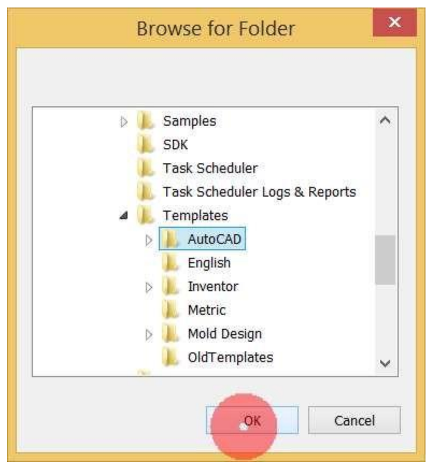


4. Next navigate to “Inventor (\\TAV25) (I:) > Inventor > Templates > AutoCAD” and select ‘OK’ whilst this folder is highlighted.

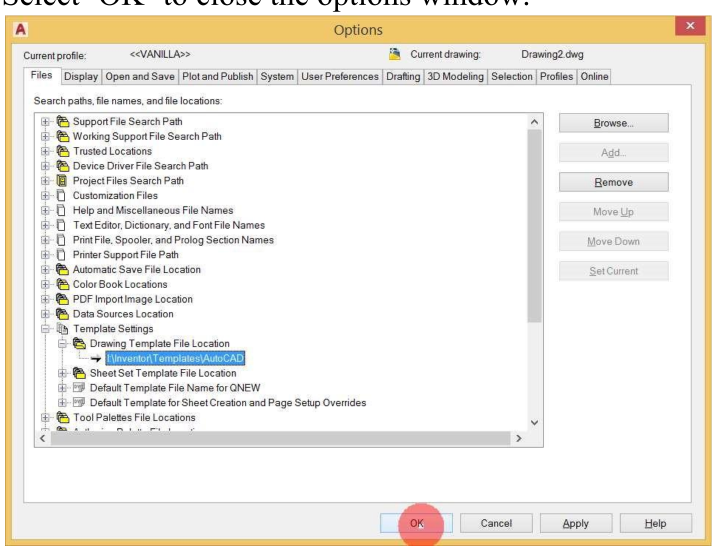








5. Select ‘OK’ to close the options window.



22 WI165 – Working with Vault and Inventor

WI165 - Working with Vault and Inventor

Document Number:	WI165
Process Owner	
Description:	Working with Vault and Inventor

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

1.1, Introduction to Vault

Autodesk Vault is the document management software used at the company. The documents stored in the Vault are held under revision control and the system records when documents have been modified throughout their life cycle to ensure full traceability of any changes made to the files. The system also ensures that there are no duplicate file names meaning that drawing numbers should remain unique. All file types can be stored inside the Vault system and have the revision control applied.

Whilst the Vault system can work with all file types, the interaction between these files and the Vault system is limited with non-cad files along with cad files that are not native to Autodesk software (e.g. Catia, Solidworks, etc.). For these files the Vault system works in a similar way to windows explorer with that additional feature of revision control. For native Autodesk files the Vault system will ensure that links are maintained upon returning files to Vault by ensuring the files are checked in through the appropriate software package.

1.2, Introduction to Inventor

Autodesk Inventor is a 3D parametric modelling software package and is the primary design software package used at the company. The software is used to create 3D models of components from which 2D drawings are created which will then be used to manufacture the parts. The software is also used for the creation of assemblies and G.A drawings. Inventor also contains tools which allow for stress analysis, interference analysis, tube and pipe run creation, frame generator (allows placement of standard sections to a skeleton) and content center which contains a store of standard components (e.g. fasteners, pipe fittings)

1.3, Working Inside Vault

1.3.1, Logging into Vault

Upon opening the Vault software, a log in window will appear. In this window you will fill in your username and password. In addition to this ensure that the Server and Vault are entered correctly as displayed in Figure 7.

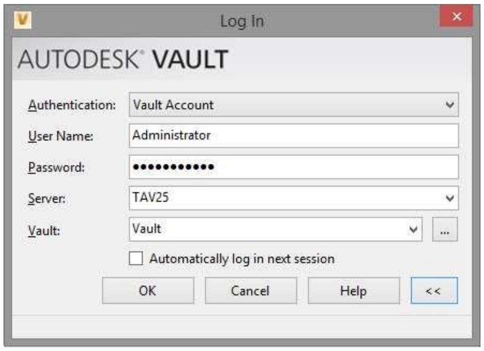


Figure 7: Vault Login Window

When you log into Vault for the first time you will be greeted with a pop-up message as displayed in Figure 8. This message indicates where on your local drive files will be stored when they are brought down from the Vault server.

Figure 8: Vault Working Folder Window

1.3.2, Finding Files inside Vault

Once you have logged in you will enter the Vault at the ‘Project Explorer ($)’ level which is the top level of the Vault folder structure. From this level you can navigate through the folder structure to the desired contract folder. The path to get to the contract folder varies for TS and AWS projects detailed below.

- TS Project - ‘Project Explorer ($)\Designs\TS\CONTRACTS\######’
- AWS Project - ‘Project Explorer ($)\Designs\AWS\CONTRACTS\######’

From this location you can navigate to the desired file.

An alternative way of finding the correct file is by searching for it. The search bar is located at the top right of the main view (see Figure 9).

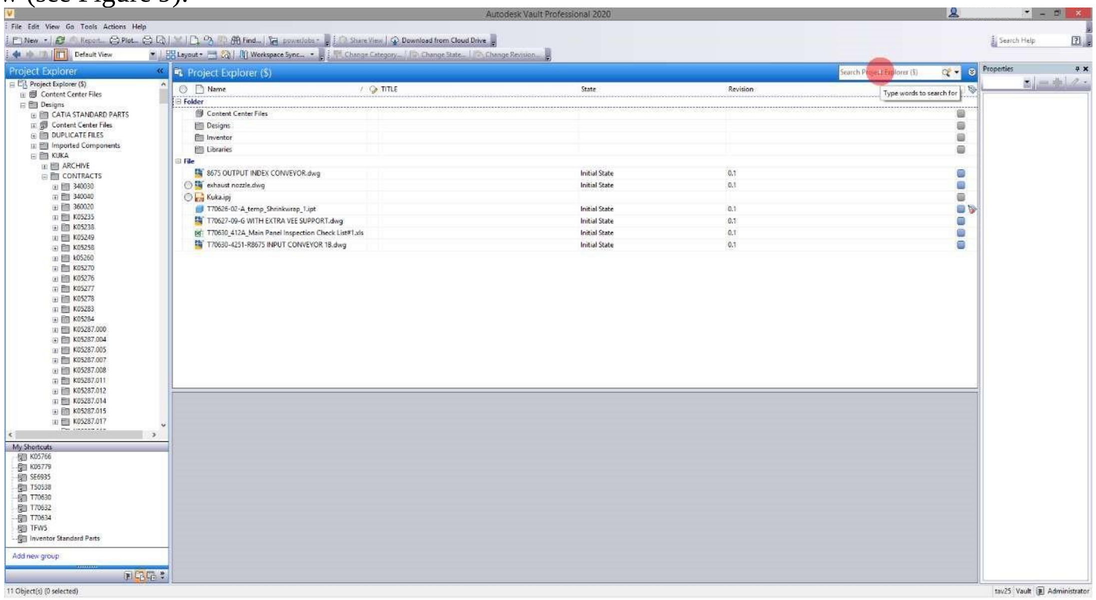


Figure 9: Vault Search Bar Location

Into this bar you can enter the desired filename or parts of the filename if the full name is not known. This search function will search through all properties associated with a file. If you wish to narrow the search to only interrogate specific properties, select the double down arrow located to the right of the search bar (see Figure 10).

This opens further options for the search tool (see Figure 11). In these options you can search specific properties such as the Title, who created it, if it is checked out, etc.

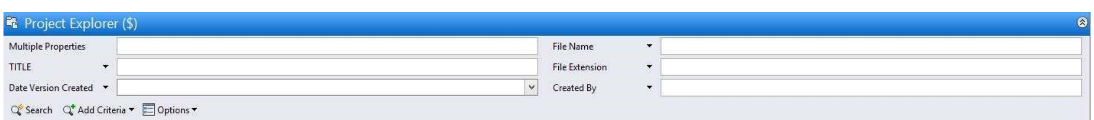


Figure 11: Vault Expanded Search Options

1.3.3, Adding Files into the Vault

In order to add new files into the Vault they must first be created outside the Vault system. It is important that any files created are saved in the correct location – the corresponding local folder to the desired place in Vault. For example, if the file needs to be placed in the 'TFW5' contract folder inside the Vault then the file should be saved in the following location, 'C:\$Vault\Designs\TFW\CONTRACTS\TFW5'.

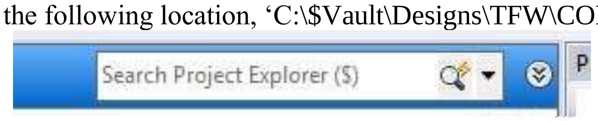


Figure 10: Vault Search Bar

For native CAD files the parts must then be checked in through the software (see section below). However, for non-native CAD files and non-CAD files they will be added to the Vault differently. These files are added by the drag and drop method. Navigate to the desired destination folder in the Vault browser and navigate to the file in windows explorer. Then drag the desired file into the Vault. Once this is done an add files pop up window will appear (Figure 12). Select ‘ok’ and the file will be added

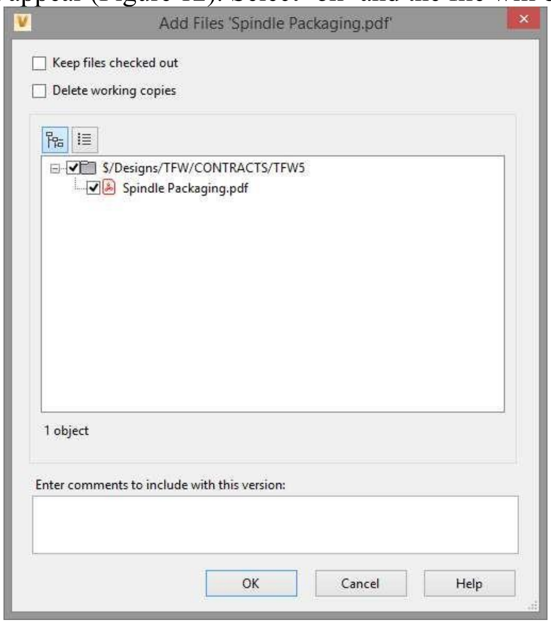


Figure 12: Vault Add Files Window

into Vault.

1.3.4, Creating Files Inside Vault

Whilst many files are created outside and then added into the Vault, there is one method of using the Vault to create new files. This is by using the copy design process. The first step is to find the file that you wish to copy. This can be any form of file inside the Vault. If an assembly file is selected, then all

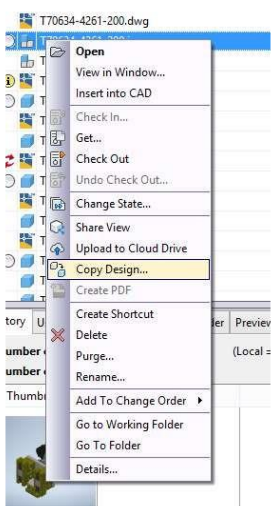


Figure 13: Right Click Menu - Copy Design

the part files inside the assembly can also be copied at the same time. Once you have navigated to the file, right click and select copy design from the right click menu (Figure 13).

This will bring up the copy design window. In the window select the files that you want to copy and right click and select ‘copy to’ (Figure 14). Alternatively, you can select ‘copy branch to’ which will select all items at lower levels in the tree.

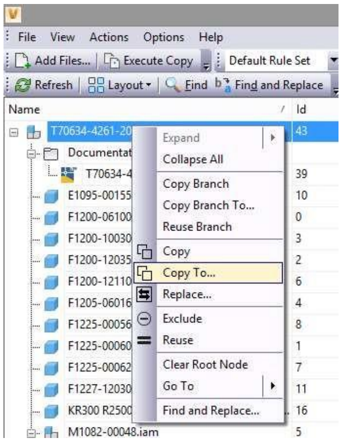


Figure 14: Copy Design Right Click Menu – Copy To

Then select the destination folder of your new files (Figure 15).

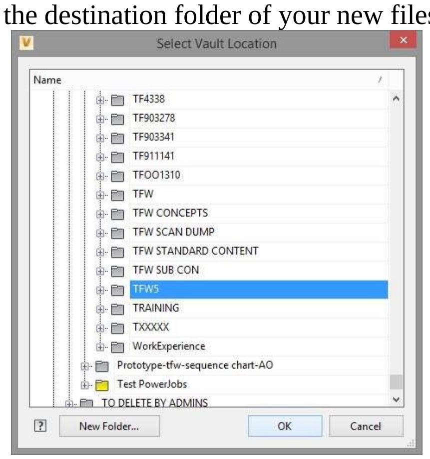


Figure 15: Copy to Location Selection Window

The files that will be copied will now be emboldened in the main panel (Figure 16).

Rename the new files in the numbering panel (Figure 17). You can change the base names individually or you can do a find and replace, which can be found by right clicking in the numbering panel, whichever is preferable.

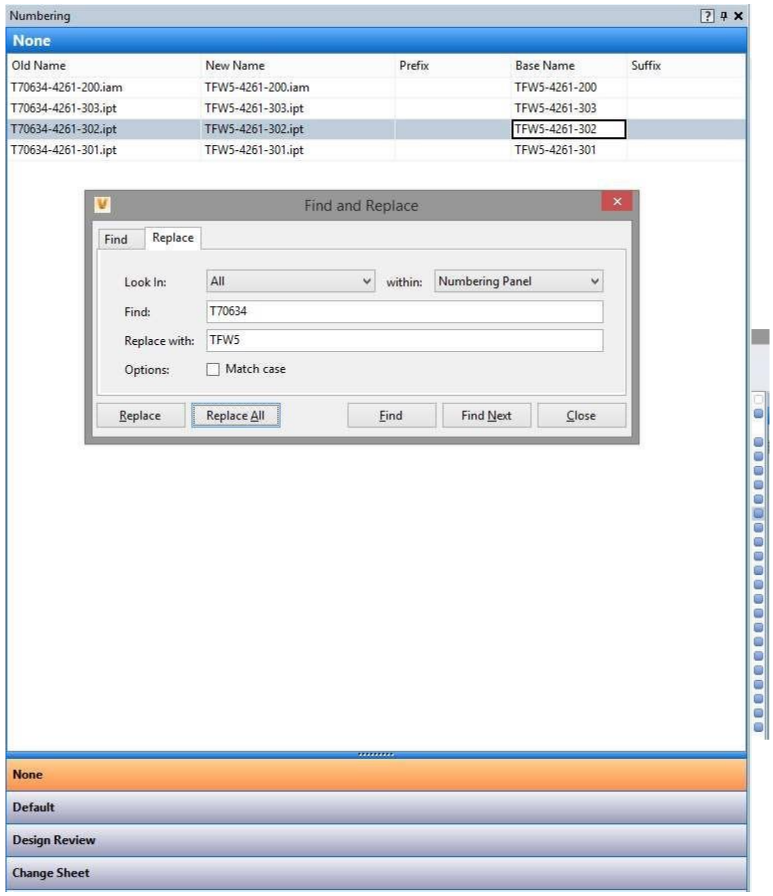


Figure 17: Copy Design Numbering Panel - Renaming Files

The main panel will now show the new name of the file. Check this to ensure it is correct. If there are any parts which have been selected to copy and do not need copying, right click on the parts in the main panel and select reuse (Figure 18).

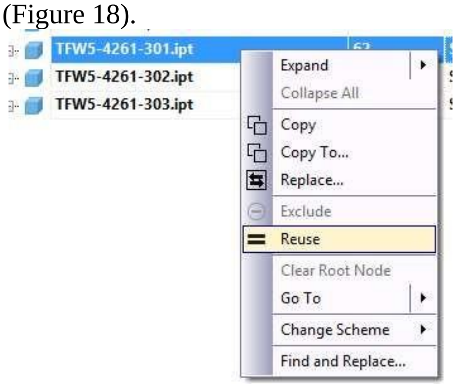


Figure 18: Copy Design Right Click Menu - Reuse

Once you have checked the parts and ensured that they are correct you can then execute the copy. To do this select the execute copy button at the top of the copy design window (Figure 19). If there are any drawings associated with the models, then these will also be copied and given the same filename as the model file.

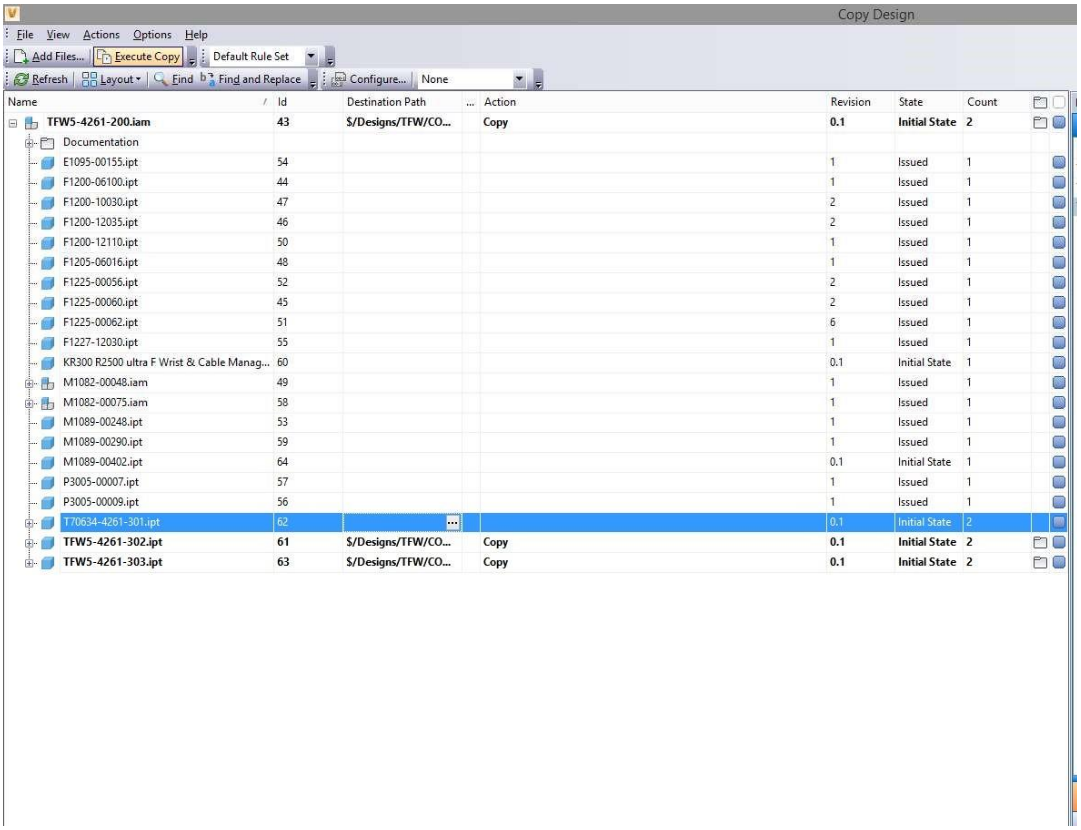


Figure 19: Vault Main Panel - Execute Copy

Your new files will now be in the selected Vault location.

1.3.5, Editing/Viewing File in Vault

Navigate to the desired file as in section 0. You can then open the desired file by either double clicking the file or right clicking on the file and selecting open from the right click menu. If this file is not issued a pop-up window will appear asking if you want to check out the file (Figure 20).

If you are opening the file for viewing purposes only select ‘No’, if you need to edit the file select ‘yes’.

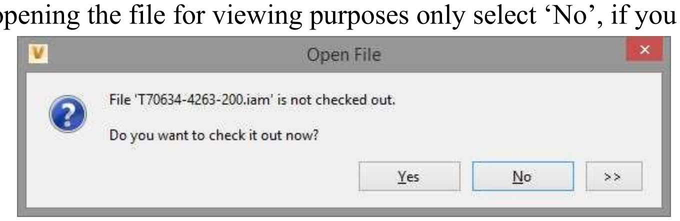


Figure 20: Vault Check Out Window

If you have checked the file out, you must check the file back in to Vault once you have finished editing it. When checking in Autodesk CAD data it must be done through the associated software package (see section 1.4). If the file in question is non-native CAD or non-CAD data, then the file will be checked in through the Vault browser. This is done by right clicking on the file and selecting check-in from the right click menu (Figure 21).

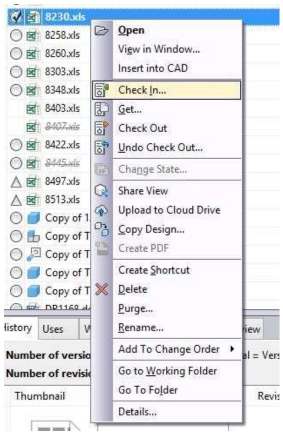


Figure 21: Vault File Right Click Menu

A popup window (Figure 22) will then appear showing the file which will be checked in. You can select the 'delete working copies' option which will remove any copies of the file from your 'C' drive, this will allow you to ensure that the storage space on the drive does not get too full. Once the settings are

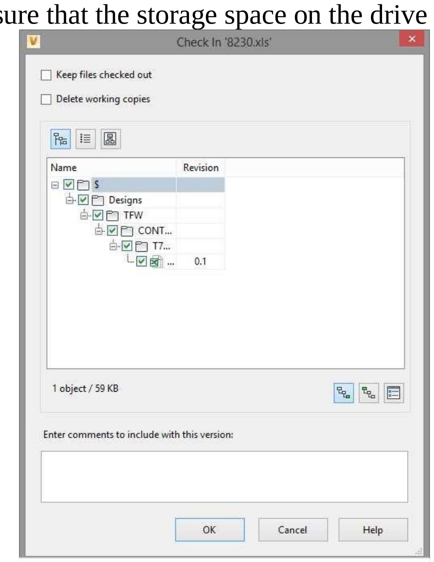


Figure 22: Vault Check In Window

complete select ok and the file will be checked into Vault.

If you have checked out a file and edited it but you do not wish to save the changes to the file you can select the 'undo check out' option. This will also have a pop-up window similar to the check in option. If this option is selected the file will revert to the state it was in prior to your modifications.

Once you have finished modelling and drawing the files will then be sent through the issuing process. See company Procedure 'SOP068 - Issuing Documents - Vault'.

1.4, Working Inside Inventor

1.4.1, Logging into Vault Inside Inventor

Open the Inventor software and navigate to the 'Vault' tab in the ribbon. Then select 'Log In' (Figure 23).

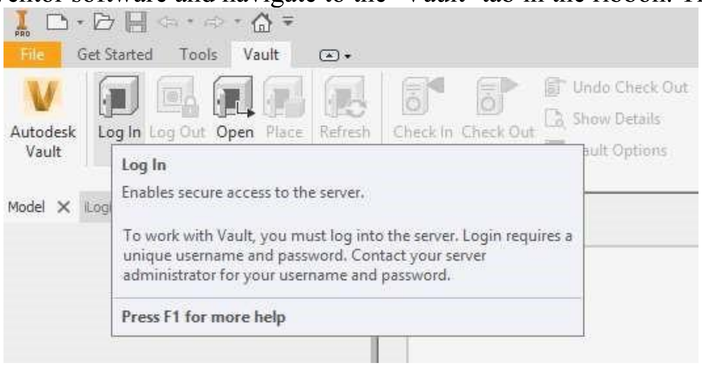


Figure 23: Inventor Vault Tab - Log In

A log in window will then appear. In this window you will fill in your username and password. In addition to this ensure that the Server and Vault are entered correctly as displayed in Figure 24.

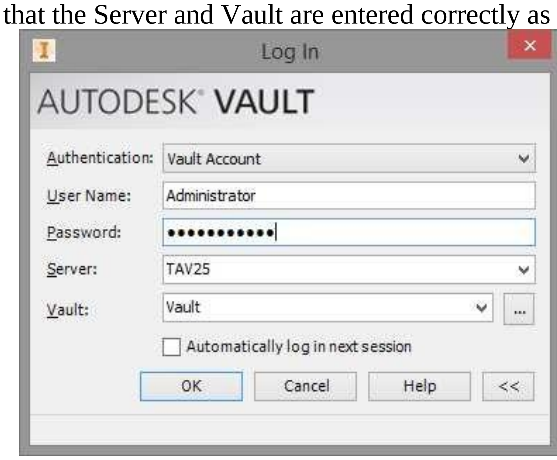


Figure 24: Inventor Vault Log In Window

Select 'ok' and you will now be logged into Vault inside Inventor.

1.4.2, Creating Files Inside Inventor

Any new CAD files (models or drawings) will be created through the CAD software. To do this inside Inventor, for either model or drawing, select 'file' then 'new' (Figure 25).

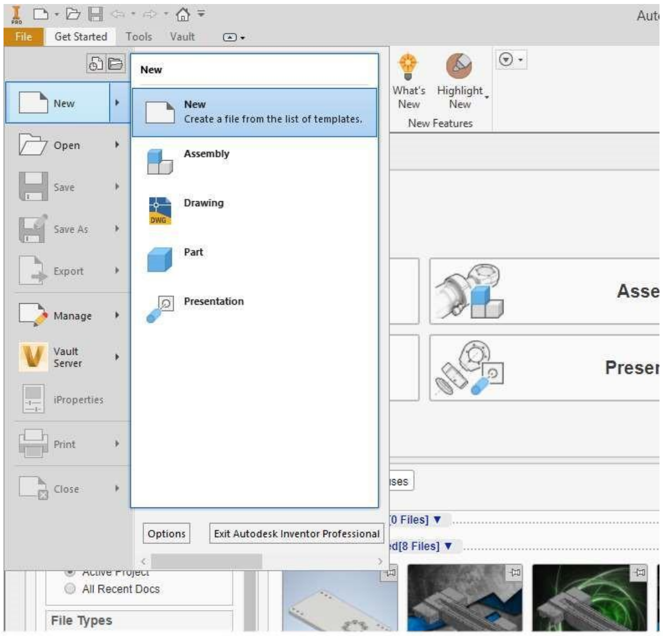


Figure 25: Inventor File Menu - New File

Once new is selected a pop-up window will appear allowing you to select a template file. Ensure that you select a template from the inventor folder as shown in Figure 26.

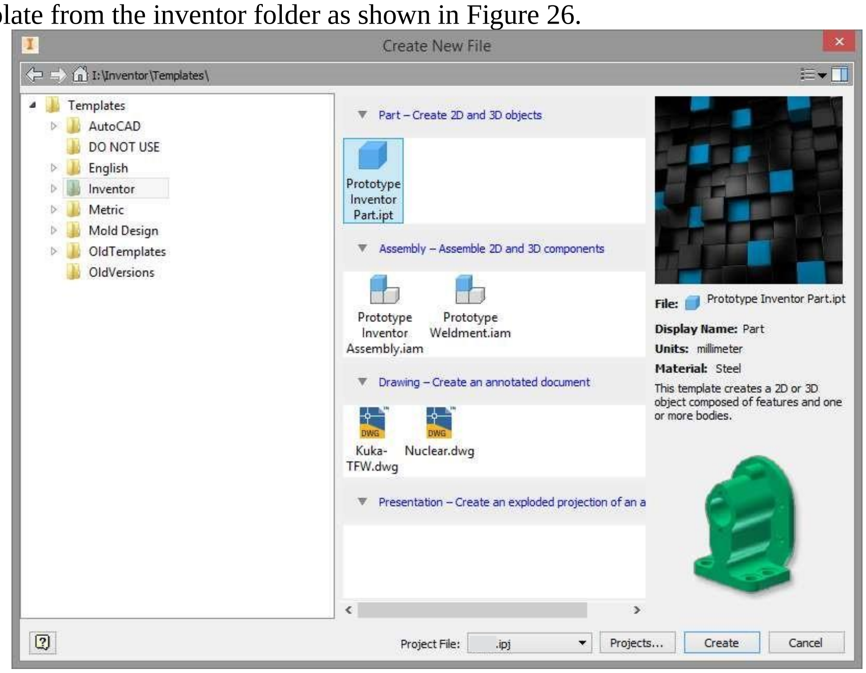


Figure 26: Template Selection Window

Once you have selected a template select ‘create’ and a new file will be opened. A pop-up window will appear in which you must fill in the relevant information for the file (Figure 27). This includes the Title, Material and Treatment. You will not be able to fill in the part number in this window, this will be completed in the next step. Once the relevant information is inputted, select ‘update’ and then ‘done’.

Figure 27: iProperty Window

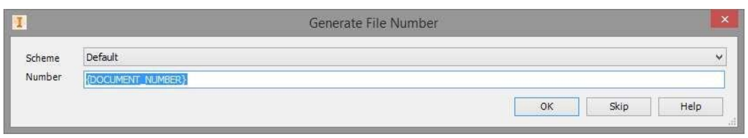


Figure 28: File Number Creation Window

The next step is to save the file. Navigate to file then save. A pop-up window will appear (Figure 28). In this window input the part number of the file to be created and select ‘ok’.

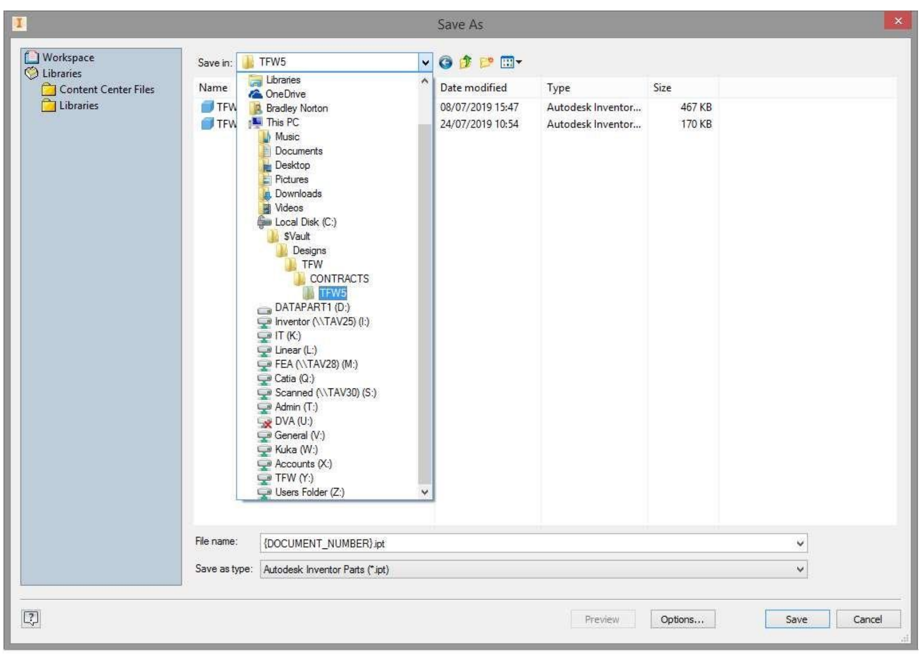


Figure 29: Inventor Save Window

Next navigate to the correct destination folder in your local workspace in the save window (). The destination path will begin with the following ‘C:\$Vault\Designs\.......’ once the folder is correct, check that the file name is as desired and select ‘save’.

1.4.2.1, Inventor File Types

Inventor can be used to create various different files depending upon the components which will be created. For certain types of components specific files must be used. The list below details the different files.

- Sheet Metal Components (e.g. covers) – Sheet Metal IPT File
- Fabrications – Weldment IAM Flie
- Standard Sections (e.g. box section) Fabrication – Frame Generator – Weldment IAM File

1.4.2.1.1, Sheet Metal IPT File

To enter the sheet metal environment, create a new IPT file and navigate to the environments tab on the ribbon. From here select convert to sheet metal (Figure 30).

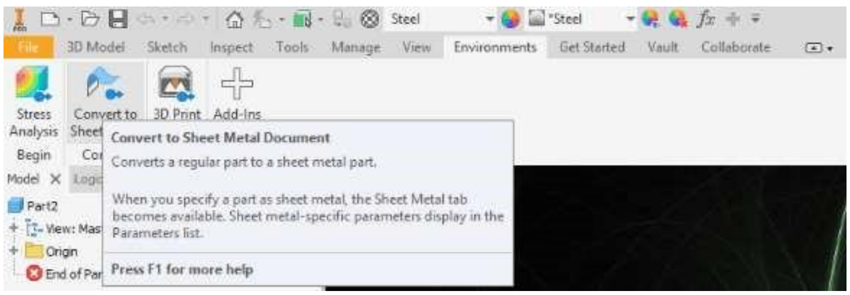


Figure 30: Environments Tab - Convert to Sheet Metal

When in the sheet metal environment select the ‘sheet metal defaults’ button to set the material thickness. This will bring up a pop-up window (Figure 31). In this window you can set both the thickness and the rule used to add in the excess bend material when creating a flat pattern.

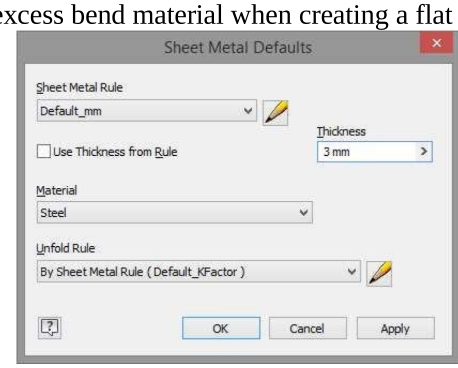


Figure 31: Sheet Metal Defaults

You can then begin sketches and create the part file. For further details on sheet metal refer to the inventor help pages or request further training.

1.4.2.1.2, Weldment IAM File

A weldment file can be selected from the template selection window when creating a new part (see Figure 26 in section 0). In this file type individual plates are modelled using standard part files in their pre-fabrication condition, assembled together inside the weldment, welded and then machined. This allows for the easy creation of a cutting list. The individual plates will be named as the weldment part number followed by –A, -

B, -C, etc. (e.g. TFW5-05-C001-A). For further details on weldments refer to the inventor help pages or request further training.

1.4.2.1.3, Frame Generator

Some weldments will require the use of frame generator to input forms of standard sections. The first step to using frame generator is to create a part file which contains a skeleton, this is a series of lines onto which the sections will be added. The skeleton file should be saved as the part number followed by –SKELETON. (e.g. TFW5-05-C001-SKELETON). This skeleton file will then be placed inside a weldment.

Frame generator is accessible from the design tab inside a weldment file (Figure 32).

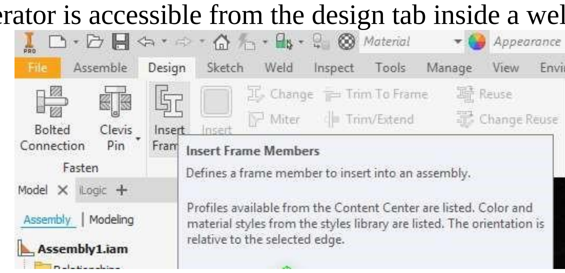


Figure 32: Inventor Design Tab - Insert Frame

The frame generator window will appear, select the desired section, and select the lines of the skeleton on which you will place the section. Then select OK. If this is the first insertion of frame parts in the assembly file, then you will be asked to save the frame and the automatically generated reference file associated with it. For the frame save it as the part number followed by –Frame 00001 and for the skeleton save the part number followed by –Skeleton 00001 (Figure 34).

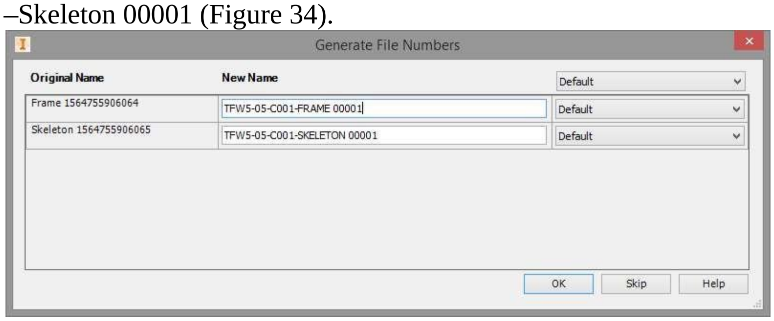


Figure 34: Frame & Skeleton Numbering

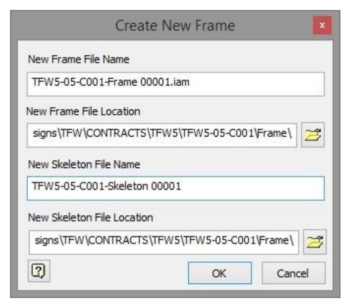


Figure 33: Frame & Skeleton Save Location

Select ‘ok’ and a new window will appear (Figure 33). The file path will be the same as the original part with some additional folders, one will be the part number and the second will be entitled ‘frame’ if this is the case select ‘ok’.

You will next have to save the members of the box section. These will be saved as follows – part number followed by the standard and size of the box section, followed by 00001, 00002, etc. This can be seen in Figure 35.

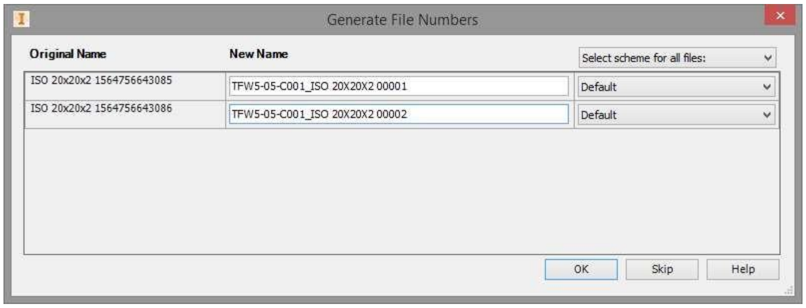


Figure 35: Frame Member Numbering

Once you have selected ‘ok’ another window will appear (Figure 36). Modify the display names to match that of the file name and ensure that it is saving in the same location as the 2 previous files.

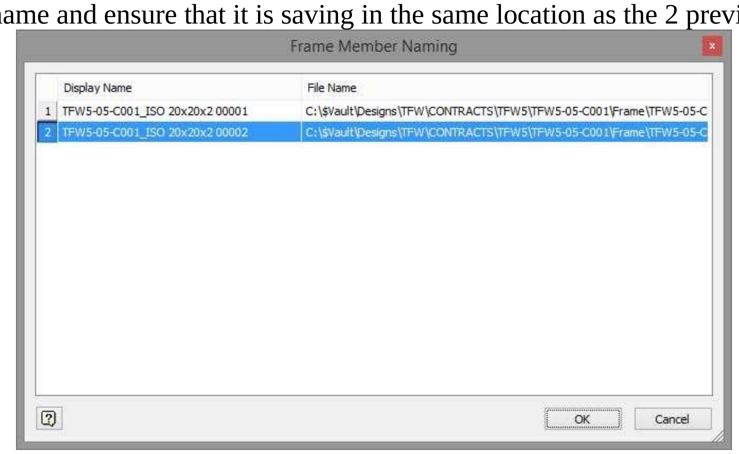


Figure 36: Frame Member Save Location

Once this is done select ‘ok’ and the frame members will be inside the weldment. Save the weldment file and the frame will also be saved. For further details on frame generator refer to the inventor help pages or request further training.

1.4.3, Adding Files to the Vault from Inventor

Once you have finished modifying a file it must be placed into vault, whether for the first time or to return the file that is being modified. This process is called checking in. To check a file into vault you must first ensure that it has been saved. Then select check in from the vault tab in the ribbon (Figure 37). The select ‘ok from the pop-up window.

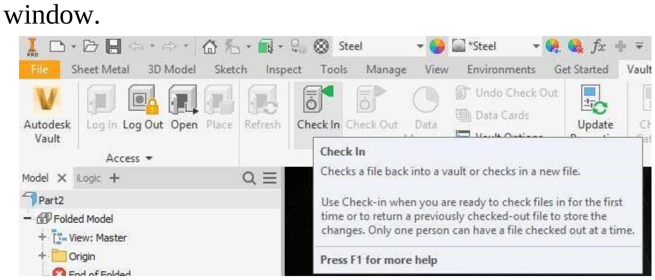


Figure 37: Inventor Vault Tab - Check In

23 WI166 – Introduction to Engineering Change Log

WI166 - Introduction to Engineering Change Log

Document Number:	WI166
Process Owner	
Description:	Introduction to Engineering Change Log

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

The engineering change log is a tool used to record any problems on projects that have been built or are being built that weren't corrected at that instance through the undertaking of a modification. The engineering change log is a useful source of information to refer to when producing new designs as it's often the case that existing designs are copied over from job to job.

By using this tool not only can improvements be incorporated within any new design, but it also prevents past errors being carried over from job to job. The excel sheet is accessible via the file path W:\Engineering Change Log and is called 'Engineering Change Log.xlsx'. Upon opening the excel file you will be prompted to enter a password. The password to enable access to the engineering change log is 'CHANGELOG'.

The engineering change log can be used for two purposes, the first being to record any issues encountered that won't be corrected at that instance.

To record an issue, populate columns 'Date', 'Contract', 'Drawing Number', 'Issue', 'Request Number', 'Comment/Action Requested', 'Drawing or Image' and 'Raised by' with the appropriate data as demonstrated below.

Date	Contract	Drawing Number	Issue	Request Number	Comment/Action Requested	Drawing or Image	Raised by
01/09/2018	ALL 60 TON TIE BAR MACHINES.	N/A.	N/A.	123	PROVISION MUST BE MADE TO ALLOW THE TIE BARS TO BE TAKEN OFF THE BASE ON STRIP DOWN CURRENTLY WE HAVE THE CAPSCREWS HOLDING THE TWO ITEMS TOGETHER HIDDEN UNDERNEATH THE LINEAR RAILS !!! THIS MAKES IT A MAJOR STRIP DOWN IF WE HAVE SHIPPING CONSTRAINTS.	N/A.	J. Bart.
01/09/2018.	ALL LONG TIE BAR ASSEMBLIES. (EG: PERFORATOR)	N/A.	N/A.	124	PROVISION MUST BE MADE TO ALLOW THE TIE BARS TO BE SPLIT (AS IN THIS CASE 6 SEPARATE ITEMS). WITHOUT HAVING TO MAKE IT INTO A MAJOR STRIP DOWN BY HAVING TO REMOVE ALL THE ROLLER STEADIES AND BACKSTOP JUST SO WE CAN REMOVE THE RAILS. CAN WE PLEASE HAVE THE TIE BARS AND RAILS SPLIT IN THE SAME PLACE PLEASE ?	N/A.	J. Bart.
18/09/2018	T70624. (F/W HOLLAND). DRAW BAR	T70624-07-B	1	125	PROBLEMS WITH TIR IN BUILD BETWEEN THE ROTARY CYLINDER AND THE DRAW BAR. PLEASE SEE REQUEST NUMBER 99 FOR GKN DRAWBAR UPDATED / MODIFIED DRAWING IN THE CHANGE LOG IMAGES FOLDER. WE NOW HAVE THE SAME PROBLEM FOR F/W HOLLAND.	N/A.	J. Bart.
06/10/2018	T70628 (SINO TRUCK). DIE HOUSING.	T70628 - 16 - A007.	1	126	ENGINEERING DRAWING SHOWING TWO DIFFERENT DATUM B's PLEASE SEE STEVE FELTONS NOTES SHOWN ON THE DRAWING IN THE CHANGE LOG DRAWING AND IMAGES FILE.	PLEASE SEE T70628 DIE HOUSING DRAWING IN THE ENGINEERING CHANGE LOG DRAWING AND IMAGES FILE.	J. Bart.
08/11/2018	T70621 (FAW) BASE	T70621-03-A001 (SHT. 1 & 2)		127	ADD (2x) M8 x 20 DEEP SLIDE KEYWAY MOUNTING HOLES TO BASE (1 EACH END) AND REPOSITION EXISTING (2X) M8 x 20 DEEP TAPPED HOLES CURRENTLY SHOWN AT 300mm FROM MACHINE CENTERLINE TO 270mm FROM MACHINE CENTERLINE (SEE T70621-03-A001 SHT. 1). ADD (2x) KEY T70630-03-A020 TO PARTS LIST IF KEYS ARE REQUIRED TO BRIDGE SLIDE SPLIT LINES.	FOR TYP. SEE BASE AX5DE-BA-03-A003	K EVANS
07/05/2019	T50538 (BPW Robots) TOOLING	T70591-413-A	2 & 4 !!	128	Ref Int dim 117.730 / 117.700 grid ref D/E -8/9 , Largest Taper Dia is needed & was requested to assist Finish Machining, 15th Apr. Largest Taper Dia was quoted at 128.5 [Incorrect as this was retrieved from Iss 2] S/B 122.3 Dia from Iss 4. BOTH issues 2 & 4 are available on Vault Should this be possible ?	T70591-13-A048	G.Evans

The second purpose of the engineering change log is to document a response to the 'Comment/Action Requested' raised. When responding to a 'Comment/Action Requested' it's important to be as descriptive as possible through populating the 'Engineering Response', 'Drawing Number', 'Issue', 'Action Taken', 'Requested for Change Number', 'Actioned By', 'Signed Off' and 'Date'. Upon responding to a 'Comment/Action Requested' its good practise to highlight the associated columns to signify precautions have been to taken to prevent the same issues arising on future contracts as demonstrated below.

Comment/Action Requested	Drawing or Image	Raised by	Engineering Response	Drawing Number	Issue	Action Taken	Request for Change Number	Actioned By	Signed Off	Date
ASSEMBLY DRAWING PLEASE ? ESPECIALLY AS RIGID PIPE IS CALLED FOR.										
THE ITEM MANUFACTURED TO THIS DRAWING WAS INCORRECT ! AND TO BE PERFECTLY HONEST ITS QUITE EASY TO SEE WHY. TO STOP THIS HAPPENING AGAIN CAN WE HAVE THE VIEW CHANGED PLEASE TO SHOW THAT INFACT THE FLANGE FACE ISN'T 475MM O.D. AND 399MM I.D. AS WHAT WAS MANUFACTURED ! THANK YOU.	T40550-11-A006	J. Bart.								
ITEM 144 (BEARING BLOCK) AND ITEM 146 (SPINDLE) THERE DOESN'T APPEAR TO BE ANY CIR-CLIPS CALLED UP IN THIS ASSEMBLY TO HOLD THE SPINDLE IN PLACE !	T70619-02-A	J. Bart.								
WE ARE STILL SHOWING ON OUR DRAWINGS 0.10 / 0.18MM END FLOAT ON THE HEAD ASSEMBLY DETAILS !	T70619-02-A	J.Bart.								
CAN WE USE A BALL NOSED CUTTER TO MACHINE THE OIL / GREASE GROOVES IN ITEMS SUCH AS THIS PLEASE ? IT IS VERY DIFFICULT AND TIME CONSUMING TO BREAK THE SHARP RAZOR LIKE EDGES ON THESE HARDENED GROOVES. IDEALLY WE SHOULD ALSO BE DOING THIS SAME OPERATION ON ALL OF OUR DX MATERIAL.	041-08-E028 REAR SIDEPLATE.	J. Bart.								
TOOL HOLDER LOCATION POCKETS 102MM (REF DIMENSION) REQUIRES A PARALLEL DIMESION IN BOTH PLANES PLEASE. IE: ACROSS THE 102 DIMENSION, AND DOWN THE POCKET DEPTH 15MM (a) BELL MOUTHING IN THIS SLOT IS ALSO AN ISSUE HERE !	T70595-16-B013.	J. Bart.								
CAN WE HAVE A COUPLE OF " SHARP CORNER STRESS RAISERS " REMOVED PLEASE ? 133MM WIDE SLOT ON THE TOP OF THE DRAW BACK ARM AND TO A LESSER EXTENT THE 74MM WIDE SLOT ON THE UNDERSIDE OF THE DRAWBACK ARM.	T70539/08-A002	J. Bart.	3mm RADII ADDED TO UPPER SLOT. 1mm RADII ADDED TO LOWER SLOT. THIS MOD HAS BEEN ADDED ATP ALL OTHER DRAWBACK ARMS OF SIMLIAR DESIGN. M CORNS	T70539-08-A002	6	DRAWINGS UPDATED FOR FUTURE CONTRACTS	7086	AS		27.1.17
COULD WE HAVE A NOTE ON THE DRAWING REQUESTING THAT 0.20 / 0.25MM IS LEFT ON THE SHAFT DIAMETER AND IN THE BORE UNTIL THE KEYWAY IS FINISHED CUT ? THIS IS BECAUSE THE KEYWAY BING PUT IN LAST IS MAKING THE COMPONENT OVAL 0.05 / 0.06MM	T70604 - 02 - A220	J. Bart.								

Upon completion of the change log it’s important to save any changes and close the spreadsheet promptly. This is because the engineering change log works in such a way that once someone has it open all other employees are only able to view it in a read only format and are unable to edit the spread sheet as shown below.

24 WI167 – Introduction to Change Requests

WI167 - Introduction to Change Requests

Document Number:	WI167
Process Owner	
Description:	Introduction to Change Requests

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

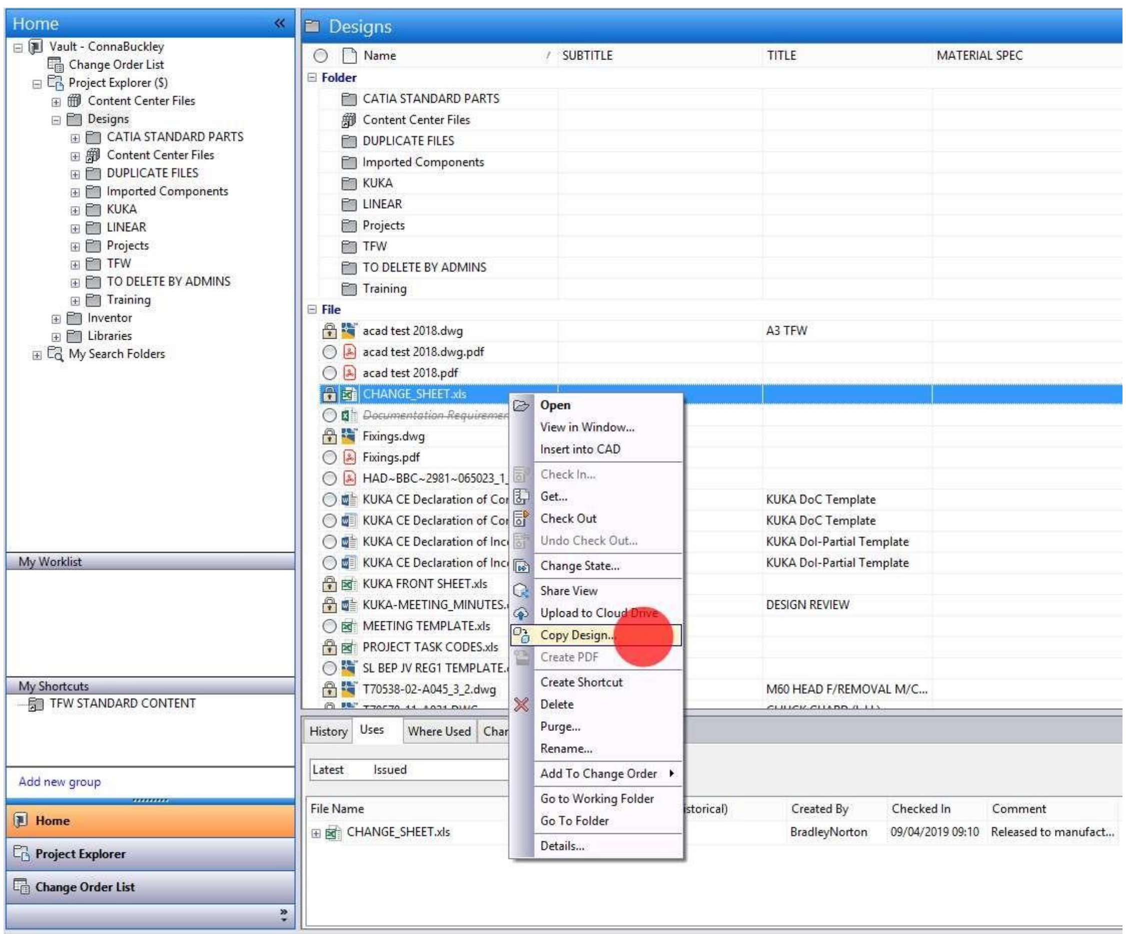
1, Description

A change request must be completed at each occurrence of a part being modified, added or removed from a bill of material (BOM). Multiple occurrences of parts being modified, added or removed can be captured on a single change request across multiple machine sections but they must all be associated with a specific contract number.

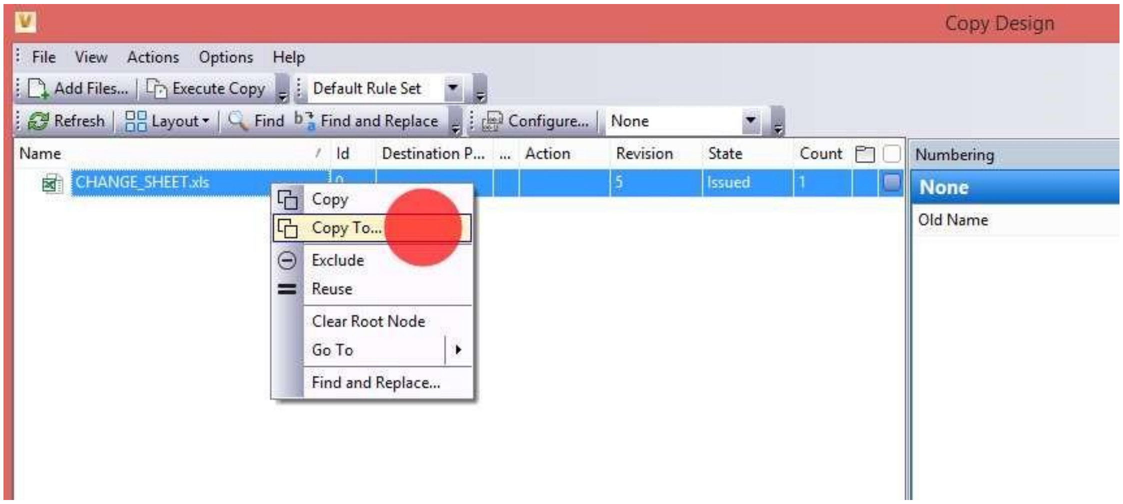
Change requests are stored under revision control inside the document management system Vault.

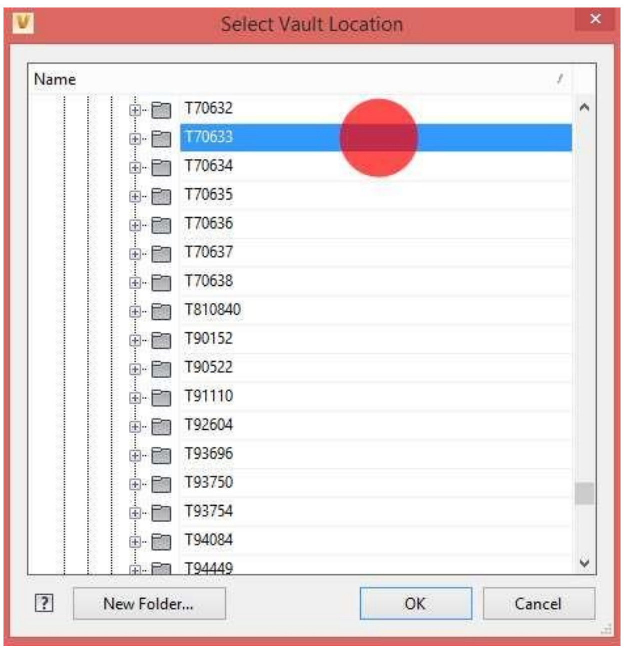
To create a change request inside Vault the following steps must be followed:

1. In the project explorer select ‘Designs’, right click ‘F246 – Change Sheet Template.xls’ before selecting ‘Copy Design’ as displayed below.

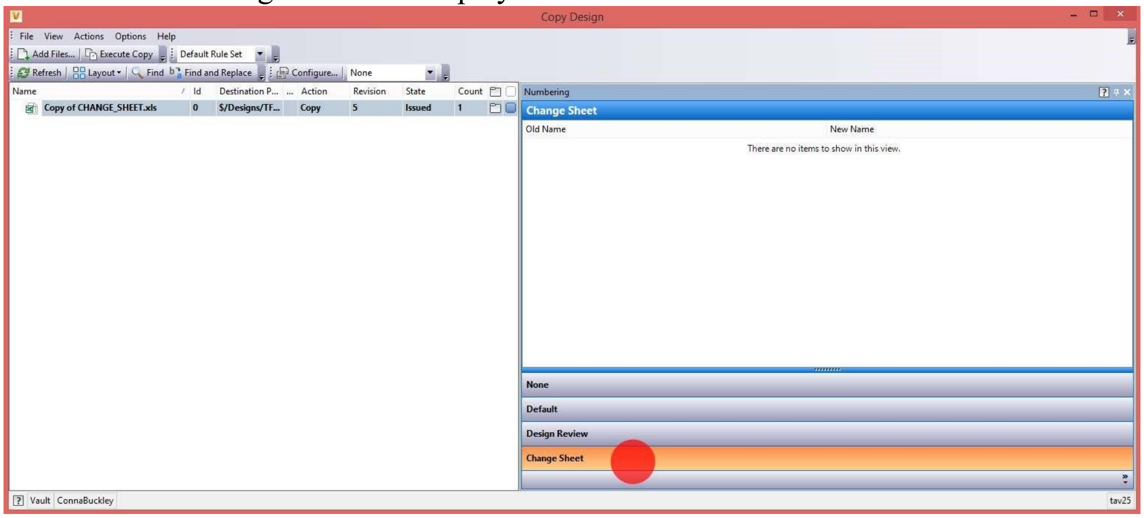


2. Right click 'CHANGE_REQUEST.xls' and select 'Copy To…' before proceeding to store it in the relevant location inside Vault as shown below.

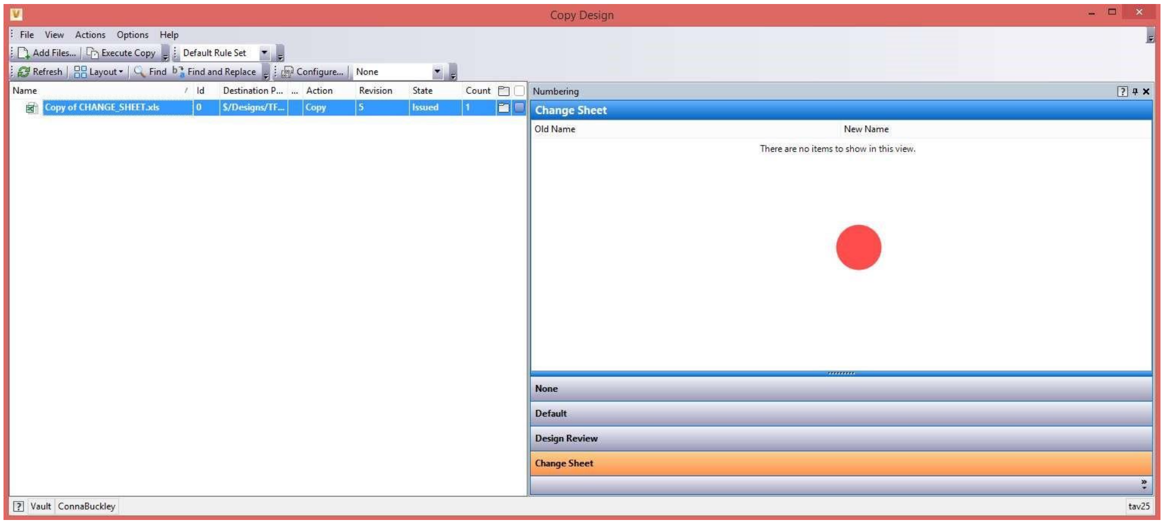




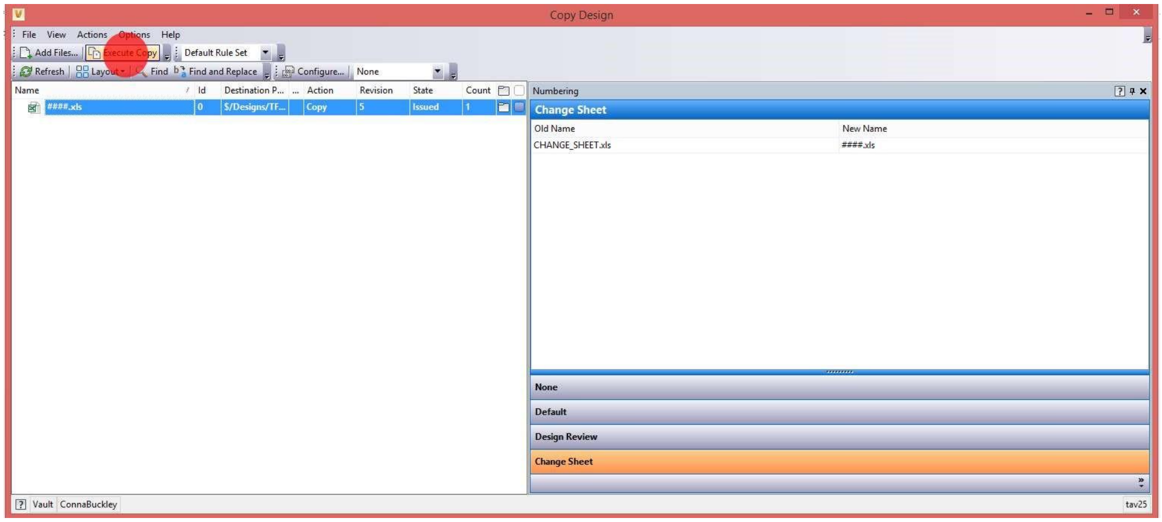
3. Select ‘Change Sheet’ as displayed below.



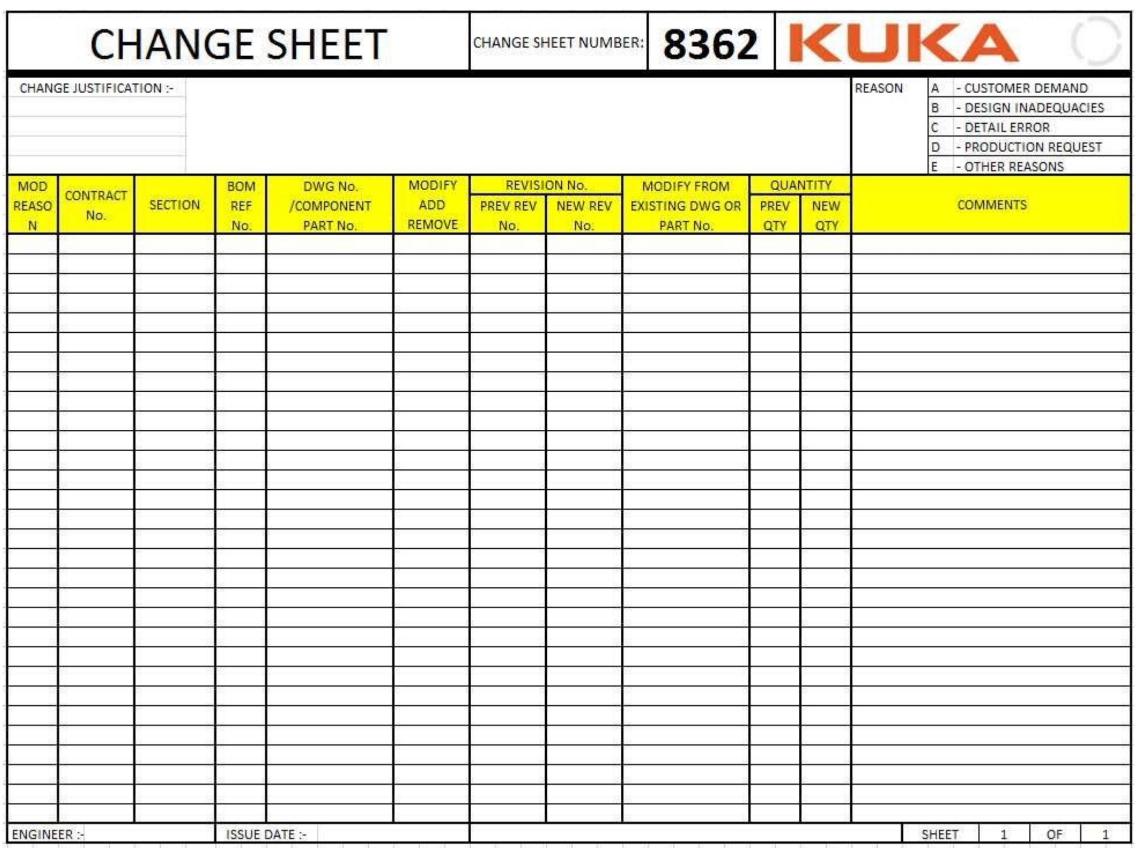
4. Select the excel sheet on the left hand side of the page and drag and drop it into the area shown below.



5. Select ‘Execute Copy’ as shown below which will automatically generate an excel sheet number along the lines of ####. This excel sheet can be found within the location previously selected inside Vault.

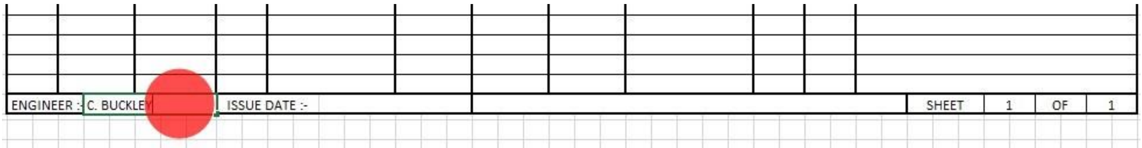


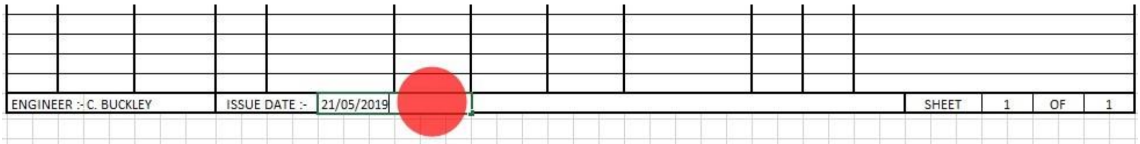
6. When opening the change request, the excel sheet shown below will appear which should be populated in accordance with the following steps.



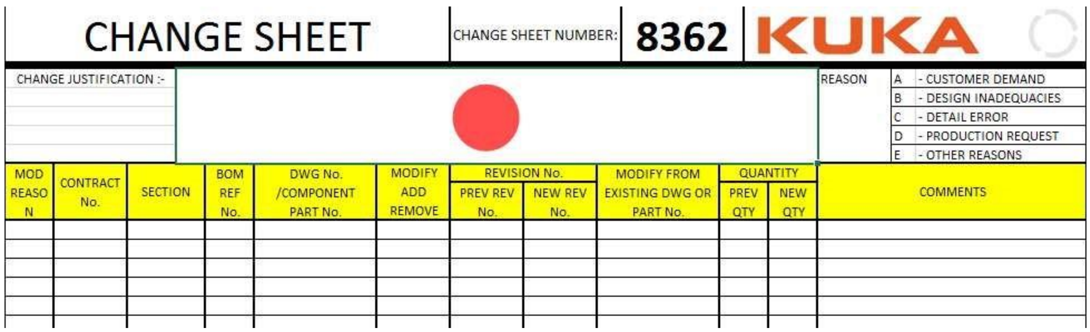
CHANGE SHEET						CHANGE SHEET NUMBER:		8362	KUKA		
CHANGE JUSTIFICATION :-									REASON	A - CUSTOMER DEMAND B - DESIGN INADEQUACIES C - DETAIL ERROR D - PRODUCTION REQUEST E - OTHER REASONS	
MOD REASON	CONTRACT No.	SECTION	BOM REF No.	DWG No. /COMPONENT PART No.	MODIFY ADD REMOVE	REVISION No. PREV REV No.	REVISION No. NEW REV No.	MODIFY FROM EXISTING DWG OR PART No.	QUANTITY PREV QTY	QUANTITY NEW QTY	COMMENTS
ENGINEER :-			ISSUE DATE :-						SHEET 1	OF 1	

7. Enter your name and the intended issue date of the change request in the bottom left corner of the excel sheet.

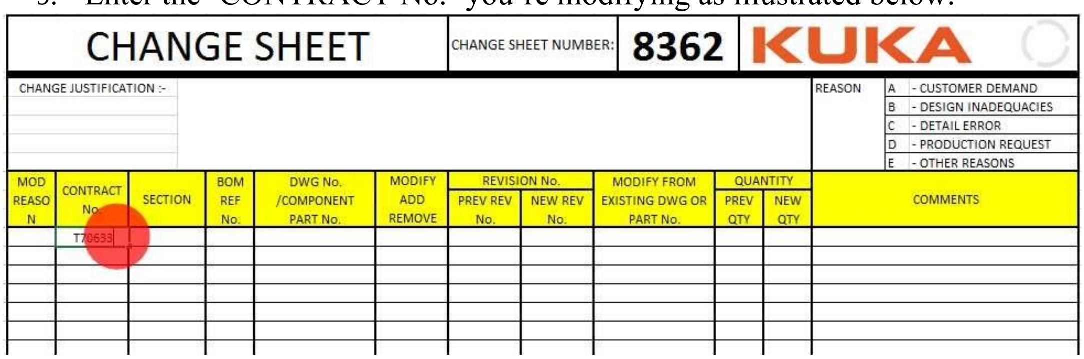




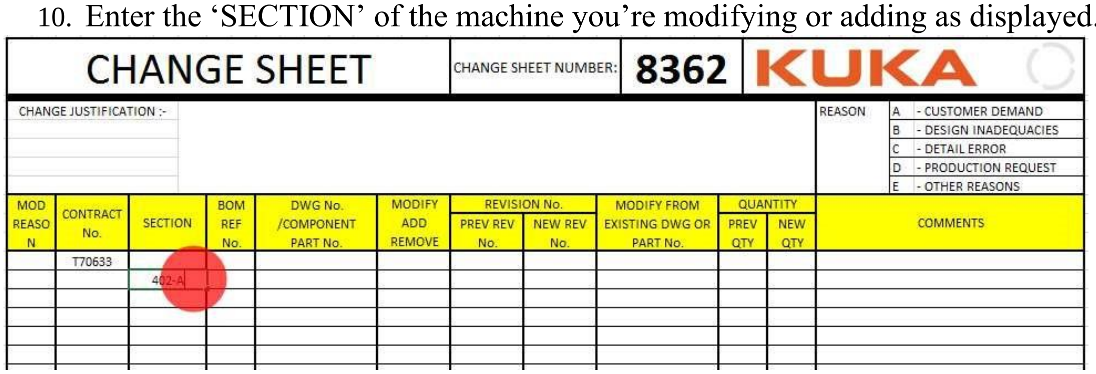
8. Write a brief overview which justifies your reason for change in the box located at the top of the excel sheet as shown below.



9. Enter the 'CONTRACT No.' you're modifying as illustrated below.

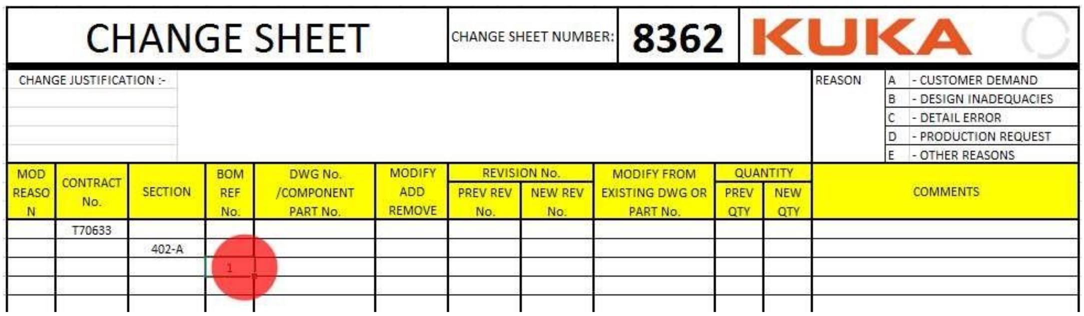


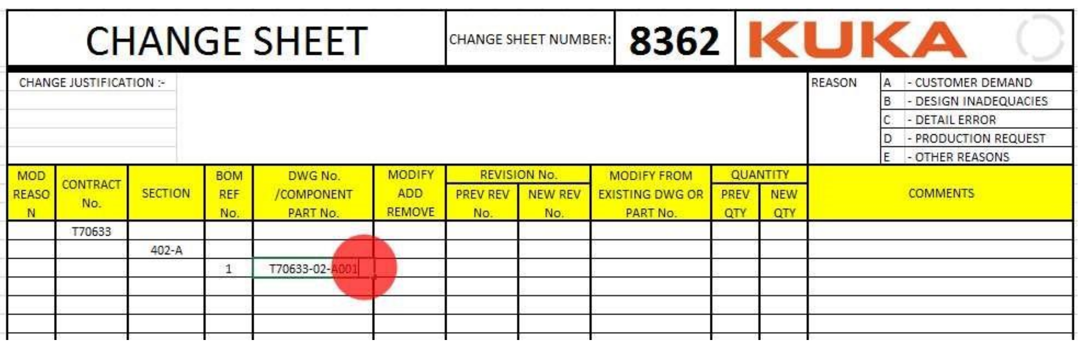
10. Enter the 'SECTION' of the machine you're modifying or adding as displayed.



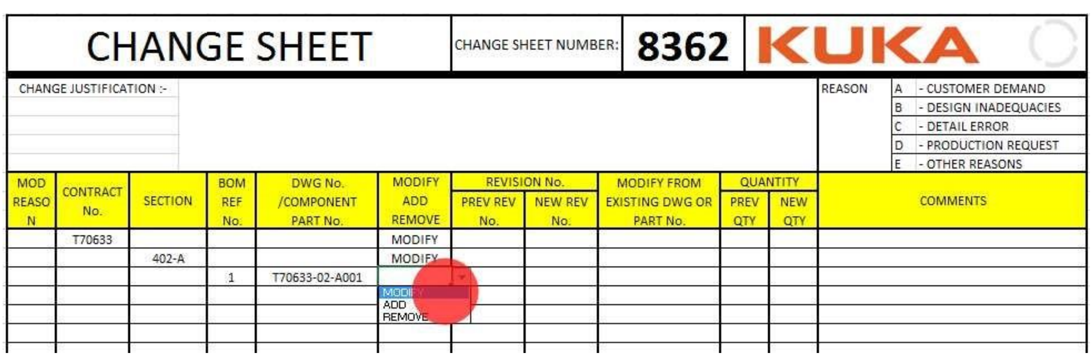
11. Entre the ‘BOM REF No.’ and associated ‘DWG No./COMPONENT PART No.’ you wish to modify, add or remove.

Note: If it’s the first issue of a project ‘SECTION’ then you DO NOT need to specify each individual ‘BOM REF No.’ & ‘DWG No./COMPONENT PART No.’ comprised on that BOM.





12. Select from the drop down menu whether the items you have recorded are being modified i.e.
a change in revision, added i.e. first issue or removed from the BOM.



13. Enter the ‘PREV REV No.’ & ‘NEW REV No.’ of each item you have recorded within the excel sheet. Note: If you’re adding a part the ‘PREV REV No.’ should read ‘N/A’ as there isn’t a previous revision of newly issued parts. If you’re removing a part the same principles apply but the ‘NEW REV No.’ will read ‘N/A’.

CHANGE SHEET CHANGE SHEET NUMBER: **8362**

CHANGE JUSTIFICATION :-

REASON: A - CUSTOMER DEMAND; B - DESIGN INADEQUACIES; C - DETAIL ERROR; D - PRODUCTION REQUEST; E - OTHER REASONS

MOD REASON	CONTRACT No.	SECTION	BOM REF No.	DWG No. /COMPONENT PART No.	MODIFY ADD REMOVE	REVISION No. PREV REV No.	REVISION No. NEW REV No.	MODIFY FROM EXISTING DWG OR PART No.	QUANTITY PREV QTY	QUANTITY NEW QTY	COMMENTS
	T70633				MODIFY	10	11				
		402-A			MODIFY	2	3				
			1	T70633-02-A001	MODIFY	1	2				

14. The ‘MODIFY FROM EXISTING DWG OR PART No.’ column is rarely used but relates to modifying an existing ‘DWG No./COMPONENT PART No.’ which was manufactured but not used on a previous contract to create a new part number for the desired contract.

CHANGE SHEET CHANGE SHEET NUMBER: **8362**

CHANGE JUSTIFICATION :-

REASON: A - CUSTOMER DEMAND; B - DESIGN INADEQUACIES; C - DETAIL ERROR; D - PRODUCTION REQUEST; E - OTHER REASONS

MOD REASON	CONTRACT No.	SECTION	BOM REF No.	DWG No. /COMPONENT PART No.	MODIFY ADD REMOVE	REVISION No. PREV REV No.	REVISION No. NEW REV No.	MODIFY FROM EXISTING DWG OR PART No.	QUANTITY PREV QTY	QUANTITY NEW QTY	COMMENTS
	T70633				MODIFY	10	11				
		402-A			MODIFY	2	3				
			1	T70633-02-A001	MODIFY	1	2				

15. Enter the ‘PREV QTY.’ & ‘NEW QTY’ of each item you have recorded within the excel sheet. Note if you’re adding a ‘DWG No./COMPONENT PART No.’ that wasn’t previously on the BOM the ‘PREV REV No.’ should read ‘N/A’ as there isn’t an existing quantity of that ‘DWG No./COMPONENT PART No.’. If you’re removing a ‘DWG No./COMPONENT PART No.’ from the BOM completely the same principles apply but the ‘NEW REV No.’ will read ‘N/A’. If you’re modifying an item comprised within the excel sheet it’s likely that the quantity will remain the same, if this is the case the figure entered into ‘NEW QTY’ box should match that within the ‘PREV QTY’ box.

CHANGE SHEET CHANGE SHEET NUMBER: **8362**

CHANGE JUSTIFICATION :-

REASON: A - CUSTOMER DEMAND; B - DESIGN INADEQUACIES; C - DETAIL ERROR; D - PRODUCTION REQUEST; E - OTHER REASONS

MOD REASON	CONTRACT No.	SECTION	BOM REF No.	DWG No. /COMPONENT PART No.	MODIFY ADD REMOVE	REVISION No. PREV REV No.	REVISION No. NEW REV No.	MODIFY FROM EXISTING DWG OR PART No.	QUANTITY PREV QTY	QUANTITY NEW QTY	COMMENTS
	T70633				MODIFY	10	11				
		402-A			MODIFY	2	3				
			1	T70633-02-A001	MODIFY	1	2		1	1	

16. The ‘COMMENTS’ column isn’t compulsory to complete but can be a useful tool to highlight important information regarding that particular part. An example of effectively using the ‘COMMENTS’ column could be “No action required, modification undertaken on shop floor”. This would prevent a duplication of work as the purchasing/production department wouldn’t proceed to organise work that’s already been undertaken.

CHANGE SHEET	CHANGE SHEET NUMBER:	8362	KUKA

CHANGE JUSTIFICATION :-	REASON		
		A	- CUSTOMER DEMAND
		B	- DESIGN INADEQUACIES
		C	- DETAIL ERROR
		D	- PRODUCTION REQUEST
		E	- OTHER REASONS

MOD REASON	CONTRACT No.	SECTION	BOM REF No.	DWG No. /COMPONENT PART No.	MODIFY ADD REMOVE	REVISION No. PREV REV No.	REVISION No. NEW REV No.	MODIFY FROM EXISTING DWG OR PART No.	QUANTITY PREV QTY	QUANTITY NEW QTY	COMMENTS
	T70633				MODIFY	10	11				
		402-A			MODIFY	2	3				
			1	T70633-02-A001	MODIFY	1	2		1	1	NO ACTION REQ'D, MOD UNDETAKEN ON S/FLOOR.

17. To complete the change request the final step requires a ‘MOD REASON’ letter to be entered for all ‘DWG No./COMPONENT PART No.’. There are 5 letters to choose from in a drop down menu as displayed below. The only time this box should be left empty is when you’re issuing parts for the first time, otherwise the letter deemed the most appropriate should be entered. It’s important when selecting a letter to fill in the ‘MOD REASON’ column that you’re honest as they act as a Key Performance Indicator (KPI) for the business.

CHANGE SHEET	CHANGE SHEET NUMBER:	8362	KUKA

CHANGE JUSTIFICATION :-	REASON		
		A	- CUSTOMER DEMAND
		B	- DESIGN INADEQUACIES
		C	- DETAIL ERROR
		D	- PRODUCTION REQUEST
		E	- OTHER REASONS

MOD REASON	CONTRACT No.	SECTION	BOM REF No.	DWG No. /COMPONENT PART No.	MODIFY ADD REMOVE	REVISION No. PREV REV No.	REVISION No. NEW REV No.	MODIFY FROM EXISTING DWG OR PART No.	QUANTITY PREV QTY	QUANTITY NEW QTY	COMMENTS
	T70633				MODIFY	10	11				
		402-A			MODIFY	2	3				
			1	T70633-02-A001	MODIFY	1	2		1	1	NO ACTION REQ'D, MOD UNDETAKEN ON S/FLOOR.
A											
B											
C											
D											
E											

REASON		
	A	- CUSTOMER DEMAND
	B	- DESIGN INADEQUACIES
	C	- DETAIL ERROR
	D	- PRODUCTION REQUEST
	E	- OTHER REASONS

18. Once you have completed filling in your change request it's important to set the revision of the file to an issued state inside Vault. This will prevent anyone from being able to edit the file without releasing it to an initial state. In addition, you should create a PDF of the change request and save it under a file path similar to Y:\Contracts\T##### - Friction Welding Machine Test\14.0 DRAWING_SYSTEM\14.4 CHANGE_REQUESTS replacing the highlighted text with the associated contract folder. The filename of the PDF should match that of the change request i.e. ####.

Name	Date modified	Type	Size
8215.pdf	20/02/2019 08:41	Adobe Acrobat D...	218 KB
8219.pdf	21/02/2019 11:45	Adobe Acrobat D...	66 KB
8237.pdf	01/03/2019 15:58	Adobe Acrobat D...	235 KB
8257.pdf	08/03/2019 12:16	Adobe Acrobat D...	42 KB
8261.pdf	11/03/2019 10:40	Adobe Acrobat D...	221 KB
8264.pdf	13/03/2019 11:22	Adobe Acrobat D...	216 KB
8272.pdf	02/04/2019 10:16	Adobe Acrobat D...	329 KB

19. All part drawings enlisted within the change request which have been modified should have their title block populated with the change request number in the 'MOD No' column prior to any drawings being issued.

3	CB	JP	26/04/2019	8349	(2x) HOLES REMOVED. BACK C/BORE HOLE DIM DATUM FACES CHANGED.
2	CB	JP	01/03/2019	8237	CHUCK CYLINDER MOUNTING PLATE FIXING HOLES QTY INCREASED AND HOLE PATTERN CHANGED. LIFTING HOLE PATTERN CHANGED TO CLEAR POS'N OF NEW CHUCK CYLINDER MOUNTING PLATE HOLES.
1	CB	JP	12/02/2019		MODIFIED FROM T70634-02-A087 @ REV 001.
ISSUE	ENG	APPD	DATE	MOD No	DESCRIPTION

The changes recorded in the change request should then be replicated inside Visibility in order to generate the associated BOM's.

25 WI168 – Introduction to Purchase Requisitions

WI168 - Introduction to Purchase Requisitions

Document Number:	WI168
Process Owner	
Description:	Introduction to Purchase Requisitions

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

A purchase requisition is one of three formal methods of getting a part ordered by the purchasing department.

Purchase requisitions should be used in an instance when modifying the 'Company – Indented Bill of Material' would make it incorrect for future reference. A prime example of using a purchase requisition is when a brought-out item has been accidently damaged during the machine build or lost. In this situation increasing the quantity of the required item on the 'Company – Indented Bill of Material' would make it incorrect for future reference i.e. if the sub-assembly was manufactured again there would be a spare item that isn't required.

Purchase requisitions SHOULDN'T be used in an exercise to avoid undertaking a change request. To get a purchase requisition raised an email will need to be sent to an authorised individual.

The information that should be included is as follows:

1) Visibility part number (If there is one).
2) Part description.
3) Cost if known - This can be given in the form of a quote or email from the supplier.
4) Quantity.
5) The project code to book it against i.e. K05778-4100.
6) Specified delivery date if required.

Once the email has been sent, the authorised individual will then take ownership of processing the request. After which they will then inform the purchasing department in order to get the desired item on order.

26 WI203 – Introduction to Lifting Plans

WI203 - Introduction to Lifting Plans

Document Number:	WI203
Process Owner	
Description:	Introduction to Lifting Plans

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

A Lifting Plan document outlines the process and equipment required to lift a specific piece of equipment or assembly.

Regulation 8(2) of LOLER defines a lifting operation as 'an operation concerned with the lifting or lowering of a load'. A ‘load’ is the items being lifted, which includes a person or people.

In planning any lifting operation, the identification and assessment of risk is key to identifying the most appropriate equipment and method for the job.

Lifting operations range from:

- Routine Lifts - where minimal on-the-job planning by trained, competent people may be all that is needed to manage risk.
- Complex Lifts - which require detailed planning / records, with expert input, monitoring and supervision - undertaken by specially trained personnel. The complexity of the plan and the extent of the resources used to manage risk must reflect the complexity and difficulty of the lifting operation.

The planning of individual routine lifting operations may be the responsibility of those who carry them out (eg a slinger or crane operator). But for much more complex lifting operations (eg a tandem lift using multiple cranes), a written plan should be developed by a person with significant and specific competencies - adequate training, knowledge, skills and expertise - suitable for the level of the task.

The plan should set out clearly the actions involved at each step of the operation and identify the responsibilities of those involved. The degree of planning and complexity of the plan will vary and should be proportionate to the foreseeable risks involved in the work.

2, Process

Complete each of the sections within the template providing the relevant information.

Introduction:

Provide a brief introduction specifying the project name and description of equipment as prompted.

Example:

1 Introduction

This document outlines the process and equipment required to lift Model 150 Double Ender Friction Welding Machine (M150 FWM)

Summary Details - Size of
Major Components:
Specify the overall dimensions of each major component which will be lifted with associated part number. Example:

2.1 Size of Major Components

Machine Assembly - TFW5-A11A-202: 13417mm Long x 2045mm Wide x 2808mm High

Weight of Major Components:

State the weight of the load

Example:

2.2 Weight of Major Components

Mass of Assembly: 40000 kg

Access Opening Size:

Specify the access route and any apertures that the load must pass through.

Example:

2.3 Access Opening Size

Roller Shutter Door: 4.2m Wide x 4.6m High

Equipment Required:

Specify all equipment required, such as Versa-lifts, Building Overhead Travelling Cranes, Slings, Shackles, etc.

3, Method

Method -
Pre-Requisites:
Specify any prerequisites that must be undertaken/completed before any lifting operations can be undertaken. Example:

3.1, Prerequisites:

- An industrial risk assessment has been carried out and has been read, understood, and signed on to by the operatives.
- All operatives involved in the work will be briefed by the task supervisor on this lifting plan and associated risk assessment prior to commencement and will sign the attached register to indicate their understanding of the contents.
- Ensure that all personnel are SQEP to carry out their designated duties.
- Work shall not start until the method statement and risk assessment have been approved and relevant permits to work have been issued.
- Confirm test certificates are valid for all lifting equipment.

- Ensure the work area is free of hazards and that all obstacles are clearly identified in task risk assessment.
- Confirm all anchor bolts have been removed.
- Confirm all services have been disconnected.
- Confirm all components on the assembly have been secured for transport.

Risk Mitigation:

Identify any risk mitigation methods which must be adhered to.

Example:

3.2 Risk Mittigation:

- Personnel access to be restricted during lifting operations. Barriers to be erected around the work area during lifting operations.
- All Versa-Lift operations to be controlled and gradual to minimise any swinging movements of suspended loads.
- Where deemed neccessaary a banksman will be utilised to assist with lifting operations.

Method:

List the steps required to be undertake the lifting operation. Identify any hold point or key points required. Example:

3.3 Method – Versa Lift:

Step:	Action:	Key Points:
1.	**Hold Point:** Confirm all pre-requisites have been carried out.	
2.	Install 4x M36 Transport Bolts to secure to the Inner Bed within the Outer Bed.	
3.	Position the Machine Moving Skates underneath the M150 FWM	
4.	Lower the M150 FWM onto the skates by lowering the 12x Jacking Bolts in the Base.	
5.	Move the M150 FWM to the designated laydown area	
6.	Using the Versa-lift with the forks attached gradually lift the M150 FWM from the ground through the fork lift slots in the Base.	**Note:** Ensure correct balance before any movement is undertaken.
7.	Position the Versa-lift above the transport vehicle bed.	**Note:** Ensure Versa-Lift movements are gradual to minimise any movement during lifting operations.
8.	Gradually lower the M150 FWM onto the transport vehicle bed.	
9.	Ensure area is cleaned down and all equipment and tools are stored correctly.	**Note:** Inform Building manager of completion of work.

References:
List any references such as GA Drawings, Part Drawings, Regulations or Manufacturer's Instructions etc. Example:

4 References

REF	Document Reference	Issue	Title
R1	GA Drawings	xxxxx	xxxxxxxx
R2	xxxxxxxx	xxxxx	xxxxxxxx
R2	xxxxxxxx	xxxxx	xxxxxxxx

Lifting Drawing:

If it is required a suitable lifting drawing shall be produced demonstrating the method required for lifting the component / assembly being lifted.

27 WI205 – Document Naming and Numbering Convention Work Instruction

WI205– Document Naming and Numbering Convention Work Instruction

Document Number:	WI197
Process Owner	
Description:	Document Naming and Numbering Convention Work Instruction

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

All Technical and Engineering Documents shall be suitably named with a relevant title which reflects the content of the document or drawing, and unique document number assigned.

The Technical and Engineering Documents shall be recorded on their relevant sections of the project specific F231 - Front Sheet Template and saved within the project location within Vault or the preagreed location where deemed necessary.

The following numbering convention for Technical and Engineering Documents shall be adhered to:

PROJECT-SECTION-100 to 199 – Documentation (Example: Calculations, Lifting Plans & Leak Test Procedures).

PROJECT SECTION-200 to 299 General Assembly Drawings.

PROJECT SECTION-300 to 499 – Detail / Manufacturing Drawings.

Note:

- Section specific Technical and Engineering Documents such as drawings and calculations these shall be produced and stored under their relevant section number.
- Overarching Project Technical and Engineering Documents such as specification shall be produced and stored under 450A – Project Support.

For Project related documentation utilising the company Form Templates such as F239 - Meeting Minutes, F234 - Engineering Discussion, F223 - New Sales Enquiry Hours, etc the following numbering convention shall be adhered to:

PROJECT – FORM NUMBER – TITLE (OR REVIEW TOPIC) - DATE

28 WI242 – Introduction to Shop Floor Document Package

WI242 - Introduction to Shop Floor Document Package

Document Number:	WI242
Process Owner	
Description:	Introduction to Shop Floor Document Package

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

The shop floor document package is a company requirement which should be produced upon the project being issued to the shop floor. The shop floor document package consists of all general assembly drawings (GA's). An A2 hard copy of each drawing should be printed, folded, put in an A3 plastic wallet, and compiled in an A3 folder. This folder should then be given to the Production Manager. It is the responsibility of the Production Manager to then issue this folder to the shop floor.

29 WI266 – Initial Standard Modules Development Work Instruction

WI266 - Initial Standard Modules Development Work Instruction

Document Number:	WI266
Process Owner	
Description:	Introduction to how to develop new standard modules

	Print Name	Sign	Date
Originator:			
Reviewed By:			
Process Owner:			
Process Owner:			
Quality Manager:			

Amendment History

Issue	Amendment	Author	Date
01	Initial Issue		

Contents

1, Description

The following work instruction aims to instruct personnel on how to develop a standard modular design for an existing product type. When considering a legacy product type, several steps should be taken to ensure that the achieved specification covers an appropriate range without being excessive. The steps detailed below have also been proven by developing a modular product for previous products, so the process is established.

2, Develop a design specification

The first step in developing the new modular standard machine type is to create a specification for the product. A specification contains a product description and serves as a guideline for the design engineers to ensure the final product meets the desired objectives. For this document to be generated, the engineer must plan what machine sections or modules are intended to be the basis of the new machine type.

3, Selection of modules

Table 1 below shows the selection process that should be undertaken. Firstly, a list of all the machines sold was compiled. This data is sourced from the company's machine list, a Microsoft Excel list showing all machines sold, the size of the machine, the component types and the data of sale. This Excel document has filters applied that enable a 10-year period to be filtered out, as well as the machine type. This ten-year period was used in this example, but it may be different depending on the product selected and the duration that it has been manufactured.

Table 1, Machine Module Selection Process

STEP	ACTION
1	List all Piston Rod (PR) and Drill Pipe (DP) machines sold in the last 10 years.
2	List all modules used for each machine.
3	List all General arrangements used for each module.
4	List the specifications for each module.
5	Identify duplicate GA's and remove them.
6	Identify special 1-off modules and remove them.
7	Identify the GA as the master design for each module.
8	Model the selected Modules to the new drawing office standard.
9	Detail the module to BS 8888.
10	Check that the modules fit together and update the model and drawings as required.

Once the machine list had been generated, the modules or Bills of Materials (BOMs) that make up each machine specific to the customer's order are listed. This data can be sourced from the company's ERP System. Once the modules used for each machine have been listed, the General Arrangement (GA) drawings are listed for each module.

The next step is to list the specifications for each GA. This stage is necessary as adding this data will ensure that the machine can achieve the broadest specifications whilst still serving as a guideline for the design engineers to ensure the final product meets the desired objectives. Selecting the modules that have the best performance will ensure this is the case. An example is the Clamp assembly for the Piston Rod machine; the largest component this can hold could be ø140mm or a diameter of ø160mm. Going for the larger diameter will ensure that the largest range of components possible can be welded on the machine. However, consideration needed to be given to ensure that the other modules on the machine can also achieve this larger diameter. Not checking that all the relevant modules can achieve this larger diameter can result in additional unnecessary costs being incorporated into the machine. This assumption, being based on a larger part that can't function at this larger size, contains more material and, therefore, costs more to manufacture.

Table 2, TFW3 - Machine Database Comparison example

				T70592	T70619
				Mar-13	Mar-18
				Drill Rods & Drill Pipe	Drill Rods
1	402A	HEAD ASSEMBLY	Front Bearing Bore (mm)	Ø190.5	Ø190.5
			Pulley Ratio	43 : 60	43 : 60
			Belt	Eagle Pd	Eagle Pd
			Brake	Yes	Yes
			Forge Cylinder Stroke (mm)	[illegible]	600
			Motor Type	AC	AC
			Motor Ref	E1088-00035	E1088-00143
			Motor kW	150 kW	125 kW
			GA Sheet 1	T70592-02-A SHT1	T70619-02-A
			GA Sheet 2	T70592-02-A SHT2	
2	402-B	PNEUMATICS		T70592-02-B	T70619-02-B
3	402-E	HEAD LINEAR TRANSDUCER		T70592-02-E	T70556-02-E
4	403-A	BASE ASSEMBLY	Reference	T70592-03-A001	T70580-03-A001
			Length (mm)	4095	3795
5	404-A	BACKSTOP ASSY FIXED BASE MOUNTED			T70619-04-E
6	404-C	TIE BAR ASSEMBLY			T70619-04-A
	404-D	ROLLER STEADY POSITIONER			
7	404-G	BACKSTOP ASSEMBLY MANUAL			
8	404-H	AUTOMATIC BACKSTOP, TIE-BAR MOUNTED		T70592-04-D SHT1	
				T70592-04-D SHT2	
9	405-A	HYDRAULICS		T70592-05-A	T70619-05-A
10	405-C	HYDRAULICS INSTALLATION			T70619-05-C
11	406-A	HEAD LUBRICATION		T70592-06-A	T70556-06-A
12	406-B	SLIDE LUBRICATION (SELF CENTRE CLAMP)		T70592-06-B	
13	406-C	ROLLER STEADY LUBRICATION		T70592-06-C	
14	406-D	MANUAL LUBRICATION		T70592-06-D	T70619-06-D
15	406-E	SLIDE LUBRICATION (FORGE CLAMP)			T70574-06-B
16	407-A	3 JAW SFRONT OPERATED SPRING CHUCK			T70619-06-D
	407-B	2 JAW DRAWBAR CHUCK			
			FULLY OPEN PER JAW		
			@ GRIP PER JAW		
	407-D	COLLET CHUCK			
17	407-E	3 JAW FRONT OPERATED HYDRAULIC CHUCK			
16	407-G	3 JAW DRAWBAR OPERATED CHUCK		T70592-07-C	T70619-07-C
18	407-S	CHUCK SWITCHING			T70619-07-S
19	408-A	SELF CENTRING CLAMP		T70592-08-A	
20	408-B	CLAMP POSITIONER		T70592-08-B	
21	408-C	MACHINE MOUNTED ROLLER STEADY			T70619-08-C
			MAX DIAMETER (mm)		150
			MIN DIAMETER (mm)		20
22	408-E	FORGE CLAMP			041-08-E
23	408-S	ROLLER STEADY - FIXED TO TIEBAR			T70619-08-G
			MAX DIAMETER (mm)		140
			MIN DIAMETER (mm)		
24	408-K	ROLLER STEADY - STATIC FREE STANDING		T70592-08-F	
25	408-L	MANUAL ROLLER STEADY TIEBAR MOUNTED		T70592-08-C	T70619-08-F
			MAX DIAMETER (mm)		140
			MIN DIAMETER (mm)		

The next step is to identify which modules are considered specials and are therefore, not to be included in the standard machine options. The defining feature of these modules that identified them as special is that they had been used only once or twice in the 10-year period selected. Therefore, they are not considered standard options that will be regularly sold to customers. Although from the perspective of a percentage of machines sold, discarding modules that have been used twice may seem excessive. The driving factor for this is the requirement for standardisation of commonly used sections and cost reductions. All modules that can be incorporated into the base machine add cost to this machine, so the number of modules has to be reduced to the minimum while still achieving the customer's desired objectives. Once these have been removed, the GAs are selected, which will be the master design for each module.

30 F226 – Learning From Experience (LFE)

The LFE template document should be read in conjunction with WI154 – Introduction to Learning From Experience (LFE).

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31 F228 – DRAs Template

The design risk assessment template should be read in conjunction with WI158 – Design Risk Assessment Work Instruction.

F228 - DRA Template

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Author		Date	
Department			

	Print Name / Position	Signature	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By			

Verify you are using the latest issue of this document.
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AMENDMENT HISTORY

Issue	Amendment	Date
1	First Issue	

1 Introduction

Taken from BS EN ISO 12100:2010. Table B.1 - Mechanical Hazards. Electrical Hazards. Thermal Hazards. Noise Hazards. Vibration Hazards. Radiation Hazards. Material / Substance Hazards. Ergonomic Hazards. Hazards Associated With The Environment in Which the Machine is Used. Phases of Machine Life Cycle (Table B.3): Transport. Assembly & Installation. Commissioning. Setting. Operation. Cleaning and Maintenance. Fault Finding and Troubleshooting. Dismantling and Disabling.

2 Description of Equipment

1 Introduction

INTRODUCTION

Adding protective measures to a design can increase costs and restrict the facility of use of the machine if added after a design has been finalized or the machinery itself has already been built. Changes to machinery are generally less expensive and more effective at the design stage, so it is advantageous to perform hazard risk assessment during machinery design.

The hazard risk assessment (sometimes referred to as Design risk assessment) is performed once again when the design is finalized, when a prototype exists and after the machinery has been in use for a while. Apart from at the design stage, during construction and during commissioning, hazard risk assessment can also be performed during revision or modification of machinery or at any other time for the purpose of assessing existing machinery, e.g., in the case of mishaps or malfunctions. The effectiveness of implemented protective measures will need to be verified before the carrying out of further iterations (BSI, 2024).

PREPARATION

Hazard risk assessment is generally more thorough and effective when performed by a team. The size of a team varies according to the following: a) the risk assessment approach selected; b) the complexity of the machine; c) the process within which the machine is utilized; The team should bring together knowledge on different disciplines and a variety of experience and expertise. However, a team that is too large can lead to difficulty in remaining focused or reaching consensus. The composition of the team can vary during the risk assessment process according to the expertise required for a specific problem. A team leader, dedicated to the project, should be clearly identified, as the success of the risk assessment depends on his or her skills. However, it is not always practical to set up a team for risk assessment and it can be unnecessary for machinery where the hazards are well understood, and the risk is not high (BSI, 2024).

METHOD (TOP DOWN)

A top-down approach is one that takes as its starting point a checklist of potential consequences (e.g. cutting, crushing, hearing loss — see potential consequences in ISO 14121-1:2007, Tables A.1 and A.2) and establishes what could cause harm (working back from the hazardous event, to the hazardous situation and thence the hazard itself). Every item in the checklist is applied to every phase of use of the machinery and every part/function and/or task in turn. One of the drawbacks of a top-down approach is the over reliance of the team on the checklist, which cannot be complete. An inexperienced team will not necessarily appreciate this. Therefore, checklists should not be interpreted as exhaustive, but should encourage creative thinking beyond the list (BSI, 2024).

This form uses this top-down approach where the column marked Type or Group of Hazard lists the source of the hazard. Next the column marked Origin list the mode or behaviour of the machine that could result in a hazard. Next is the column marked Potential Consequences which lists kind of harm that could result from the hazard. Next is the column marked Machine Phase where the various machine uses are listed so as to differentiate those hazards that might arise from the machine being in operation, maintenance, setting or transport. Finally, the column marked Specific Hazard Description is how the particular hazard applies to the machine under assessment.

DEGREE OF POSSIBLE HARM (DPH)

Choosing just one DPH to be considered is not always easy. The most severe can be very improbable and the most probable inconsequential, so that using either will lead to an inappropriate estimation of risk. For example, it is almost always credible that death will be the worst severity of harm: a simple cut can kill if it becomes septic or severs an artery; nevertheless, despite the probability of a cut being high, death is usually a remote probability. It can therefore be helpful to estimate the risk of a range of representative severities and use the one that gives the highest risk (BSI, 2024).

FREQUENCY OF EXPOSURE

The estimation of the exposure to the hazard under consideration (including long-term damage to health) requires analysis of, and shall account for, all modes of operation of the machinery and methods of working. In particular, the analysis shall account for the needs for access during loading/unloading, setting, teaching, process changeover or correction, cleaning, fault-finding, and maintenance. The risk estimation shall also take into account tasks, for which it is necessary to suspend protective measures.

1 Introduction

POSSIBILITY OF AVOIDANCE

Possibility of Avoidance is the possibility of avoiding or limiting harm. Consider, for example, whether the machine is to be operated by skilled or unskilled persons, how quickly a hazardous situation can lead to harm, and the awareness of risk by means of general information, direct observation or through warning signs, so as to determine the level of avoidance (BSI, 2024).

RISK REDUCTION (MITIGATION)

The objective of risk reduction can be achieved by the elimination of hazards, or by separately or simultaneously reducing each of the three elements that determine the associated risk:
– severity of harm from the hazard under consideration; –
frequency of exposure to that hazard; – possibility of
avoidance of the hazard.
All protective measures intended for reaching this objective shall be applied in the following sequence, referred to as the three-step method:

Step 1: Inherently safe design measures

Inherently safe design measures eliminate hazards or reduce the associated risks by a suitable choice of design features of the machine itself and/or interaction between the exposed persons and the machine.

Step 2: Safeguarding and/or complementary protective measures

Taking into account the intended use and the reasonably foreseeable misuse, appropriately selected safeguarding and complementary protective measures can be used to reduce risk when it is not practicable to eliminate a hazard, or reduce its associated risk sufficiently, using inherently safe design measures.

Step 3: Information for use

Where risks remain despite inherently safe design measures, safeguarding and the adoption of complementary protective measures, the residual risks shall be identified in the information for use. The information for use shall include, but not be limited to, the following:
– operating procedures for the use of the machinery consistent with the expected ability of personnel who use the machinery or other persons who can be exposed to the hazards associated with the machinery;
– the recommended safe working practices for the use of the machinery and the related training requirements adequately described;
– sufficient information, including warning of residual risks for the different phases of the life of the machinery;
– the description of any recommended personal protective equipment, including detail as to its need as well as to training needed for its use. Information for use shall not be a substitute for the correct application of inherently safe design measures, safeguarding or complementary protective measures.

HAZARD RISK NUMBER

The Hazard Risk Number (HRN) is calculated automatically (SoI x FoE x PoA) and colour-coded (see Look-Up Table). In addition, the Calculator shows the corresponding Risk Level so that the user can decide if action is required. A risk is 'Negligible' if there is very little risk to health and safety; a risk is 'Low, significant' if hazards exist that require control measures; a risk is 'High' if there are potentially dangerous hazards that require control measures to be implemented urgently; and a risk is 'Unacceptable' if continued operation in this state is unacceptable.

MITIGATION ACTION REQUIRED

If action is required, it should be outlined in the first Action column. A further assessment must then be carried out to see the effect on the HRN and Risk Level of taking the action. If the Risk Level is still too high, additional action can be specified in the second Further Action Required column on the far righthand side, after which a confirmatory assessment should be carried out.

SAFETY RELATED PARTS OF THE CONTROL SYSTEM

If the Action column employs a mitigation solution involving Safety-Related Parts of the Control system (SRP/CS), a further assessment of its Performance Level requirement (PLr) must be done. To denote this additional requirement, enter a Y (yes) in the Requires SRP/C column. The PLr value will feed directly into the safety system validation effort performed via an additional document and instruction.

LO (Likelihood of Occurrence)		
0.033	Almost impossible	Only in extreme circumstances
1	Highly unlikely	Though conceivable
1.5	Unlikely	But could occur
2	Possible	But unusual
5	Even chance	Could happen
8	Probable	Not surprising
10	Likely	To be expected
15	Certain	No doubt

FE (Frequency of Exposure)	
0.5	Annually
1	Monthly
1.5	Weekly
2.5	Daily
4	Hourly
5	Constantly

HRN	Risk
0-5	Negligible
5-50	Low, significant
50-500	High
Over 500	Unacceptable

HRN = LO x FE x DPH x NP

DPH (Degree of Possible Harm)	
0.1	Scratch or bruise
0.5	Laceration or mild ill-effect
2	Break of minor bone or minor illness (temporary)
4	Break of major bone or major illness (temporary)
6	Loss of one limb, eye, hearing (permanent)
10	Loss of two limbs or eyes (permanent)
15	Fatality

NP (Number of Persons at risk)	
1	1-2 persons
2	3-7 persons
4	8-15 persons
8	16-50 persons
12	50+ persons

Source: Pilz Guide to Machinery Safety, 6th Edition

Design Risk Assessment

ANSI B11.TR3.2000 & BS EN ISO 12100:2010 | ANSI B11.TR6.2010 & BS EN ISO 13849-1:2008

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REF No.	STATION #	Phases of machine life cycle	Task	Type or Group of Hazard	Hazard Description / Origin	Potential Consequences	Initial Assessment: (LO) Likelihood of Occurrence	(FE) Frequency of Exposure	DPH (Degree of Possible Harm)	NP (Number of Persons at risk)	Hazard Risk Number	Risk level	Action Required	After Reassessment: (LO) Likelihood of Occurrence	(FE) Frequency of Exposure	DPH (Degree of Possible Harm)	NP (Number of Persons at risk)	Hazard Risk Number	Risk level	Further Action Required	Action Requires SRP/CS	Assessment: Severity of Injury	Frequency of Exposure	Probability of Avoidance	Performance Level Required	Description Of SRP/CS (Safety Related Parts Of Control System)	Safety function (description to be populated here and tested at safety buy-off)
1		Transport	Lifting				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
2		Transport	Loading				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
3		Transport	Packing				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
4		Transport	Transportation				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
5		Transport	Unloading				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
6		Transport	Unpacking				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
7		Assembly and Installation	Adjustments of the machine and its components				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
8		Assembly and Installation	Assembly of the machine				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
9		Commissioning	Connecting to power supply (electric power supply)				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
10		Commissioning	Connecting to power supply (Hydraulic / Pneumatic Power)				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
11		Commissioning	Feeding, filling, loading of ancillary fluids (for example, lubricant, grease, glue)				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
12		Commissioning	Functional / Safety Testing (Electrical & Mechanical tests - NO WELDING)				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
13		Commissioning	Running the machine without load				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
14		Commissioning	Trials with components at load or maximum load				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
15		Commissioning	Client Demonstration				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
16		Setting to work at client facility	Adjustment and setting of protective devices and other components				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
17		Setting to work at client facility	Adjustment and setting or verification of functional parameters of the machine (for example, speed, pressure, force, travelling limits)				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
18		Setting to work at client facility	Clamping/fastening the workpiece				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
19		Setting to work at client facility	Feeding, filling, loading of raw material				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
20		Setting to work at client facility	Functional test, trials				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
21		Setting to work at client facility	Mounting or changing tools, tool-setting				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
22		Setting to work at client facility	Programming verification				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
23		Setting to work at client facility	Verification of the final product				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
24		Operation	Clamping/fastening the workpiece				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
25		Operation	Control/inspection				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
26		Operation	Driving the machine				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
27		Operation	Feeding, filling, loading of raw material				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
28		Operation	Manual loading/unloading				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
29		Operation	Minor adjustments and setting of functional parameters of the machine (for example, speed, pressure, force, travel limits)				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
30		Operation	Minor interventions during operation (for example, removing waste material, eliminating jams, local cleaning)				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
31		Operation	Operating manual controls				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
32		Operation	Restarting the machine after stopping/interruption				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
33		Operation	Supervision				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
34		Operation	Verification of the final product				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
35		Cleaning & Maintenance	Adjustments				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
36		Cleaning & Maintenance	Cleaning, disinfection				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
37		Cleaning & Maintenance	Dismantling/removal of parts, components, devices of the machine				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
38		Cleaning & Maintenance	Housekeeping				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
39		Cleaning & Maintenance	Isolation and energy dissipation				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
40		Cleaning & Maintenance	Lubrication				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
41		Cleaning & Maintenance	Replacement of tooling				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
42		Cleaning & Maintenance	Replacement of tooling				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
43		Cleaning & Maintenance	Replacement of worn parts				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
44		Cleaning & Maintenance	Resetting				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
45		Cleaning & Maintenance	Restoring fluid levels				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
46		Cleaning & Maintenance	Verification of parts, components, devices of the machine				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
47		Fault Finding /	Adjustments				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
48		Fault Finding /	Dismantling/removal of parts, components, devices of the machine				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
49		Fault Finding /	Fault-finding				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
50		Fault Finding /	Isolation and energy dissipation				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
51		Fault Finding /	Recovering from control and protective devices failure				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
52		Fault Finding /	Recovering from jam				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
53		Fault Finding /	Repairing				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
54		Fault Finding /	Replacement of parts, components, devices of the machine				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
55		Fault Finding /	Rescue of trapped persons from within the cell				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
56		Fault Finding /	Resetting				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
57		Fault Finding /	Verification of parts, components, devices of the machine				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
58		Dismantling / Disabling	Disconnection and energy dissipation				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
59		Dismantling / Disabling	Dismantling				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
60		Dismantling / Disabling	Lifting				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
61		Dismantling / Disabling	Loading				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
62		Dismantling / Disabling	Packing				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
63		Dismantling / Disabling	Transportation				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
64		Dismantling / Disabling	Unloading				0.0	0.0	0.0	0.0	0.0	Negligible		0.0	0.0	0.0	0.0	0.0	Negligible						n/a		
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Section 1.	1.1.2: Principles of safety integration	Comply	Not Comply	Not Applicable	Verification
Question 1	Is machinery designed and constructed so that it is fitted for its function and can it be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the conditions foreseen but also taking into account any reasonably foreseeable misuse thereof? The aim of measures taken must be to eliminate any risk throughout the foreseeable lifetime of the machinery including the phases of transport, assembly, dismantling, disabling and scrapping.				
Question 2.1	In selecting the most appropriate methods, has the manufacturer or his authorised representative applied the following principles in the order given: - eliminated or reduced risks as far as possible (inherently safe machinery design and construction)?.				
Question 2.2	In selecting the most appropriate methods, has the manufacturer or his authorised representative taken the necessary protective measures in relation to risks that cannot be eliminated?				
Question 2.3	In selecting the most appropriate methods, has the manufacturer or his authorised representative informed users of the residual risks due to any shortcomings of the protective measures adopted?.				
Question 3	When designing and constructing the machinery and when drafting the instructions, has the manufacturer or his authorised representative envisaged not only the intended use of the machinery but also any reasonably foreseeable misuse thereof? The machinery must be designed and constructed in such a way as to prevent abnormal use if such use would engender a risk. Where appropriate, the instructions must draw the user's attention to ways (which experience has shown might occur) in which the machinery should not be used.				
Question 4	Has machinery been designed and constructed to take account of the constraints to which the operator is subject as a result of the necessary or foreseeable use of personal protective equipment?				
Question 5	Has machinery been supplied with all the special equipment and accessories essential to enable it to be adjusted, maintained and used safely?				
Section 2.	1.1.3: Materials and products				
Question 1	Are materials used to construct machinery or products used or created during its use as so not endanger persons' safety or health? In particular, where fluids are used, is machinery designed and constructed to prevent risks due to filling, use, recovery or draining?				
Section 3.	1.1.4: Lighting				
Question 1	Is machinery supplied with integral lighting suitable for the operations concerned where the absence thereof is likely to cause a risk despite ambient lighting of normal intensity?				
Question 2	Is machinery designed and constructed so that there is no shadow likely to cause nuisance, that there is no irritating dazzle and that there are no dangerous stroboscopic effects on moving parts due to lighting?				
Question 3	Are internal parts requiring frequent inspection and adjustment, and maintenance areas provided with appropriate lighting?				
Section 4.	1.1.5: Design of machine to facilitate its handling				
Question 1	Is machinery, or each component part thereof: - capable of being handled and transported safely, been packaged or designed so that it can be stored safely and without damage?				
Question 2	During the transportation of the machinery and/or its component parts, is there any possibility of sudden movements or hazards due to instability as long as the machinery and/or its component parts are handled in accordance with the instructions?				
Question 3	Where the weight, size or shape of machinery or its various component parts prevents them from being moved by hand, the machinery or each component part must: - either be fitted with attachments for lift gear, or - be designed so that it can be fitted with such attachments, or - be shaped in such a way that standard lifting gear can easily be attached. Does the machinery comply?				
Question 4	Where machinery or one of its component parts is to be moved by hand, it must: - either be easily moveable, or - be equipped for picking up and moving safely. Does the machinery comply?				
Question 5	Have special arrangements been made for the handling of tools and/or machinery parts which, even if lightweight, could be hazardous?				
Section 5.	1.1.6: Ergonomics				
Question 1.1	Has the manufacture taken into consideration under the intended conditions of use, the discomfort, fatigue and physical and psychological stress faced by the operator? This must be reduced to the minimum possible, taking into account ergonomic principles such as: - allowing for the variability of the operator's physical dimensions, strength and stamina.				
Question 1.2	Providing enough space for movements of the parts of the operator's body.				
Question 1.3	Does the machine avoid a machine-determined work rate?				
Question 1.4	Does the machine avoiding monitoring that requires lengthy concentration?				
Question 1.5	Is the man / machinery interface to the foreseeable characteristics of the operators?				
Section 6.	1.1.7: Operating positions				
Question 1	Is the operating position designed and constructed in such a way as to avoid any risk due to exhaust gases and/or lack of oxygen?				
Question 2	If the machinery is intended to be used in a hazardous environment presenting risks to the health and safety of the operator or if the machinery itself gives rise to a hazardous environment, have adequate means been provided to ensure that the operator has good working conditions and is protected against any foreseeable hazards?				
Question 3	Where appropriate, is the operating position fitted with an adequate cabin designed, constructed and/or equipped to fulfil the requirements of questions 1 and 2 in this section?				
Question 4	Is there an exit which allows rapid evacuation? Moreover, when applicable, is there an emergency exit provided in a direction which is different to the usual exit?				

Section 7.	1.1.8: Seating				
Question 1	Where appropriate and where the working conditions so permit, are work stations constituting an integral part of the machinery designed for the installation of seats?				
Question 2	If the operator is intended to sit during operation and the operating position is an integral part of the machinery, is the seat provided with the machinery?				
Question 3	Does the operator's seat enable him to maintain a stable position? Furthermore, is the seat and its distance from the control devices capable of being adapted to the operator?				
Question 4	If the machinery is subject to vibrations, is the seat designed and constructed in such a way as to reduce the vibrations transmitted to the operator to the lowest level that is reasonably possible? The seat mountings must withstand all stresses to which they can be subjected. Where there is no floor beneath the feet of the operator, footrests covered with a slip-resistant material must be provided.				
Section 8.	1.2.1: Safety and reliability of control systems				
Question 1.1	Are control systems designed and constructed in such a way as to prevent hazardous situations from arising? Above all, are they designed and constructed in such a way that: - they can withstand the intended operating stresses and external influences?				
Question 1.2	Are control systems designed and constructed in such a way as to prevent a fault in the hardware or the software of the control system leading to hazardous situations?				
Question 1.3	Are control systems designed and constructed in such as errors in the control system logic do not lead to hazardous situations?				
Question 1.4	Can any reasonably foreseeable human error during operation lead to hazardous situations?				
Question 2	Has particular attention been given to the following points: - the machinery must not start unexpectedly?, - the parameters of the machinery must not change in an uncontrolled way, where such change may lead to hazardous situations?, - the machinery must not be prevented from stopping if the stop command has already been given?, - no moving part of the machinery or piece held by the machinery must fall or be ejected?, - automatic or manual stopping of the moving parts, whatever they may be, must be unimpeded?, - the protective devices must remain fully effective or give a stop command?, - the safety-related parts of the control system must apply in a coherent way to the whole of an assembly of machinery and/or partly completed machinery?				
Question 3	For cable-less control, is an automatic stop activated when correct control signals are not received?				
Section 9.	1.2.2: Control devices				
Question 1.1	Are control devices clearly visible and identifiable?				
Question 1.2	Are control devices positioned in such a way as to be safely operated without hesitation or loss of time and without ambiguity?				
Question 1.3	Are control devices designed in such a way the movement of the control device is consistent with its effect?				
Question 1.4	Are control devices located outside the danger zones, except where necessary for certain control devices such as an emergency stop or a teach pendant?				
Question 1.5	Are control devices positioned in such a way that their operation cannot cause additional risk?				
Question 1.6	Are control devices designed or protected in such a way that the desired effect, where a hazard is involved, can only be achieved by a deliberate action?				
Question 2	Where a control device is designed and constructed to perform several different actions, namely where there is no one-to-one correspondence, has the action to be performed been clearly displayed and subjected to confirmation, where necessary?				
Question 3	Are control devices so arranged that their layout, travel and resistance to operation are compatible with the action to be performed, taking account of ergonomic principles?				
Question 4	Is machinery fitted with indicators as required for safe operation and can the operator read them from the control position?				
Question 5	From each control position, can the operator ensure that no-one is in the danger zone? Or is the control system designed and constructed in such a way that starting is prevented while someone is in the danger zone?				
Question 6	If neither of the possibilities is applicable for question 5 in this section, before the machinery starts, are acoustic and/or visual warning signal given? The exposed persons must have time to leave the danger zone or prevent the machinery starting up.				
Question 7	If necessary, has a means been provided to ensure that the machinery can be controlled only from control positions located in one or more predetermined zones or locations?				
Question 8	Where there is more than one control position, has the control system been designed in such a way that the use of one of them precludes the use of the others, except for stop controls and emergency stops?				
Question 9	When machinery has two or more operating positions, has each position been provided with all the required control devices necessary so the operators do not hinder or put each other into a hazardous situation?				
Section 10.	1.2.3: Starting				
Question 1	Is it possible to start machinery only by voluntary actuation of a control device provided for the purpose?				
Question 2.1	Is it possible only by voluntary actuation of a control device provided for the purpose, when restarting the machinery after a stoppage, whatever the cause?				

Question 2.2	Is it possible only by voluntary actuation of a control device provided for the purpose, when effecting a significant change in the operating conditions? However, the restarting of the machinery or a change in operating conditions may be effected by voluntary actuation of a device other than the control device provided for the purpose, on condition that this does not lead to a hazardous situation.				
Question 3	For machinery functioning in automatic mode, is the starting of the machinery, restarting after stoppage, or change in operating conditions possible without intervention, provided this does not lead to a hazardous situation?				
Question 4	Where machinery has several starting control devices and the operators can therefore put each other in danger, are additional devices fitted to rule out such risks? If safety requires that starting and/or stopping must be performed in a specific sequence, are there devices which ensure that these operations are performed in the correct order?				
Section 11.	**1.2.4.1: Normal stop**				
Question 1	Is machinery fitted with a control device whereby the machinery can be brought safely to a complete stop?				
Question 2	Is each workstation fitted with a control device to stop some or all of the functions of the machinery, depending on the existing hazards, so that the machinery is rendered safe?				
Question 3	Does the machinery's stop control have priority over the start controls?				
Question 4	Once the machinery or its hazardous functions have stopped, has the energy supply to the actuators concerned been cut off?				
Section 12.	**1.2.4.2: Operational stop**				
Question 1	Where, for operational reasons, a stop control that does not cut off the energy supply to the actuators is required, is the stop condition monitored and maintained?				
Section 13.	**1.2.4.3: Emergency stop**				
Question 1	Is machinery fitted with one or more emergency stop devices to enable actual or impending danger to be averted? The following exceptions apply: - machinery in which an emergency stop device would not lessen the risk, either because it would not reduce the stopping time or because it would not enable the special measures required to deal with the risk to be taken, portable hand held and/or hand-guided machinery. The device must: - have clearly identifiable, clearly visible and quickly accessible control devices, - stop the hazardous process as quickly as possible, without creating additional risks, - where necessary, trigger or permit the triggering of certain safeguard movements.				
Question 2	Once active operation of the emergency stop device has ceased following a stop command, is that command sustained by engagement of the emergency stop device until that engagement is specifically overridden?; it must not be possible to engage the device without triggering a stop command; it must be possible to disengage the device only by an appropriate operation, and disengaging the device must not restart the machinery but only permit restarting.				
Question 3	Is the emergency stop function available and operational at all times, regardless of the operating mode?				
Question 4	Are emergency stop devices a back-up to other safeguarding measures and not a substitute for them?				
Section 14.	**1.2.4.4: Assembly of machinery**				
Question 1	In the case of machinery or parts of machinery designed to work together, has the machinery been designed and constructed in such a way that the stop controls, including the emergency stop devices, can stop not only the machinery itself but also all related equipment, if its continued operation may be dangerous?				
Section 15.	**1.1.2: Principles of safety integration**				
Question 1	Does the control or operating mode selected override all other control or operating modes, with the exception of the emergency stop?				
Question 2	If machinery has been designed and constructed to allow its use in several control or operating modes requiring different protective measures and/or work procedures, has it been fitted with a mode selector which can be locked in each position? Each position of the selector must be clearly identifiable and must correspond to a single operating or control mode. The selector may be replaced by another selection method which restricts the use of certain functions of the machinery to certain categories of operator.				
Question 3	If, for certain operations, the machinery must be able to operate with a guard displaced or removed and/or a protective device disabled, does the control or operating mode selector simultaneously: - disable all other control or operating modes?, - permit the operation of hazardous functions only by control devices requiring sustained action?, - permit the operation of hazardous functions only in reduced risk conditions while preventing hazards from linked sequences?, - prevent any operation of hazardous functions by voluntary or involuntary action on the machine's sensors?				
Question 4	If the four conditions of question 3 in this section cannot be fulfilled simultaneously, does the control or operating mode selector activate other protective measures designed and constructed to ensure a safe intervention zone?				
Question 5	If the four conditions of question 3 in this section cannot be fulfilled simultaneously, is the operator able to control operation of the parts he is working on from the adjustment point?				
Section 16.	**1.2.6: Failure of the power supply**				
Question 1	Does the interruption, the re-establishment after an interruption or the fluctuation in whatever manner of the power supply to the machinery lead to dangerous situations?				
Question 2.1	Has particular attention been given to the following point: - the machinery must not start unexpectedly?				
Question 2.2	Has particular attention been given to the following point: - the parameters of the machinery must not change in an uncontrolled way when such a change can lead to hazardous situations?				
Question 2.3	Has particular attention been given to the following point: - the machinery must not be prevented from stopping if the stop command has already been given?				
Question 2.4	Has particular attention been given to the following point: - no moving part of the machinery or piece held by the machinery must fall of be ejected?				
Question 2.5	Has particular attention been given to the following point: - automatic or manual stopping of the moving parts, whatever they may be, must be unimpeded?				

Question 2.6	Has particular attention been given to the following point: - the protective devices must remain fully effective or give a stop command?				
Section 17.	1.3.1: Risk of loss of stability				
Question 1	Is machinery and its components and fittings stable enough to avoid overturning, falling or uncontrolled movements during transportation, assembly, dismantling, and any other action involving the machinery?				
Question 2	If the shape of the machinery itself or its intended installation does not offer sufficient stability, has an appropriate means of anchorage been incorporated and indicated in the instructions?				
Section 18.	1.3.2: Risk of break-up during operation				
Question 1	Are the various parts of machinery and their linkages able to withstand the stresses to which they are subject when used?				
Question 2	Is the durability of the materials used adequate for the nature of the working environment foreseen by the manufacturer or his authorised representative, in particular as regards the phenomena of fatigue, ageing, corrosion and abrasion?				
Question 3	Do the instructions indicate the type and frequency of inspections and maintenance required for safety reasons? They must. Where appropriate, indicate the parts subject to wear and the criteria for replacement.				
Question 4	Where a risk of rupture or disintegration remains despite the measures taken, are the parts concerned mounted, positioned and/or guarded in such a way that any fragments will be contained, preventing hazardous situations?				
Question 5	Are both rigid and flexible pipes carrying fluids, particularly those under high pressure, able to withstand the foreseen internal and external stresses and firmly attached and/or protected to ensure that no risk is posed by a rupture?				
Question 6	Where the material to be processed is fed to the tool automatically, are the following conditions fulfilled to avoid risks to persons: - when the work piece comes into contact with the tool, the latter must have attained its normal working condition?, - when the tool starts and/or stops (intentionally or accidentally), the feed movement and the tool movement must be coordinated?				
Section 19.	1.3.3: Risks due to falling or ejected objects				
Question 1	Are precautions taken to prevent risks from falling or ejected objects?				
Section 20.	1.3.4: Risks due to surfaces, edges or angles				
Question 1	Insofar as their purpose allows, do accessible parts of the machinery have no sharp edges, no sharp angles and no rough surfaces likely to cause injury?				
Section 21.	1.3.5: Risks related to combined machinery				
Question 1	Where the machinery is intended to carry out several different operations with manual removal of the piece between each operation (combined machinery), has it been designed and constructed in such a way as to enable each element to be used separately without the other elements constituting a risk for exposed persons?				
Question 2	For the purpose of question 1 in this section, is it possible to start and stop separately any elements that are not protected?				
Section 22.	1.3.6: Risks relating to variations in operating conditions				
Question 1	Where the machinery performs operations under different conditions of use, has it been designed and constructed in such a way that selection and adjustment of these conditions can be carried out safely and reliably?				
Section 23.	1.3.7: Risks relating to moving parts				
Question 1	Have the moving parts of machinery been designed and constructed in such a way as to prevent risks of contact which could lead to accidents or , where risks persist, been fitted with guards or protective devices?				
Question 2	Have all necessary steps been taken to prevent accidental blockage of moving parts involved in the work? In cases where, despite the precautions taken, and a blockage is likely to occur, the necessary specific protective devices and tools must, when appropriate, be provided.				
Question 3	Do the instructions and, where possible, a sign on the machinery identify these specific protective devices and how they are to be used?				
Section 24.	1.3.8: Choice of protection against risks arising from moving parts				
Question 1	Have guards or protective devices designed to protect against risks arising from moving parts been selected on the basis of the type of risk?				
Section 25.	1.3.8.1: Moving transmission parts				
Question 1	Are guards designed to protect persons against the hazards generated by moving transmission parts: fixed guards as referred to in section 1.4.2.1, or interlocking moveable guards as referred to in section 1.4.2.2?				
Question 2	Are interlocking movable guards used where frequent access is envisaged?				
Section 26.	1.3.8.2: Moving parts involved in the process				

Question 1	Are guards or protective devices designed to protect persons against the hazards generated by moving parts involved in the process: - either fixed guards as referred to in section 1.4.2.1, or - interlocking movable guards as referred to in section 1.4.2.2, or - protective devices as referred to in section 1.4.3, or - a combination of the above?				
Question 2	When certain moving parts directly involved in the process cannot be made completely inaccessible during operation owing to operations requiring operator intervention, are such parts fitted with: - fixed guards or interlocking movable guards preventing access to those sections of the parts that are not used in the work, and - adjustable guards as referred to in section 1.4.2.3 restricting access to those sections of the moving parts where access is necessary?				
Section 27.	1.3.9: Risk of uncontrolled movements				
Question 1	When a part of the machinery has been stopped, is any drift away from the stopping position, for whatever reason other than action on the control devices, prevented or be such that it does not present a hazard?				
Section 28.	1.4.1: Required characteristics of guards and protective devices				
Question 1.1	Are guards and protection devices of robust construction?				
Question 1.2	Do guards and protection devices not give rise to any additional hazard?				
Question 1.3	Are guards and protection devices not easy to by-pass or render non-operational?				
Question 1.4	Are guards and protection devices located at an adequate distance from the danger zone, - cause minimum obstruction to the view of the production process?				
Question 1.5	Do guards and protection devices enable essential work to be carried out on the installation and/or replacement of tools and for maintenance purposes by restricting access exclusively to the area where the work has to be done, if possible without the guard having to be removed or the protective device having to be disabled?				
Question 2	Do guards, where possible, protect against the ejection or falling of materials or objects and against emissions generated by the machinery?				
Section 29.	1.4.2.1: Fixed guards				
Question 1	Are fixed guards fixed by systems that can be opened or removed only with tools?				
Question 2	Do their fixing systems remain attached to the guards or to the machinery when the guards are removed?				
Question 3	Where possible, are guards incapable of remaining in place without their fixings?				
Section 30.	1.4.2.2: Interlocking movable guards				
Question 1.1	Do interlocking movable guards as far as possible remain attached to the machinery when open?				
Question 1.2	Have interlocking movable guards been designed and constructed in such a way that they can be adjusted only by means of an intentional action?				
Question 2.1	Are interlocking movable guards associated with an interlocking device that prevents the start of hazardous machinery functions until they are closed?				
Question 2.2	Are interlocking movable guards associated with an interlocking device that gives a stop command whenever they are no longer closed?				
Question 3.1	Where it is possible for an operator to reach the danger zone before the risk due to the hazardous machinery functions has ceased, have movable guards been associated with a guard locking device in addition to an interlocking device that prevents the start of hazardous machinery functions until the guard is closed and locked?				
Question 3.2	Where it is possible for an operator to reach the danger zone before the risk due to the hazardous machinery functions has ceased, have movable guards been associated with a guard locking device in addition to an interlocking device that keeps the guard closed and locked until the risk of injury from the hazardous machinery functions has ceased?				
Question 4	Are interlocking movable guards designed in such a way that the absence or failure of one of their components prevents starting or stops the hazardous machinery functions?				
Section 31.	1.4.2.3: Adjustable guards restricting access				
Question 1.1	Are adjustable guards restricting access to those areas of the moving parts strictly necessary for the work adjustable manually or automatically, depending on the type of work involved?				
Question 1.2	Are adjustable guards restricting access to those areas of the moving parts strictly necessary for the work readily adjustable without the use of tools?				
Section 32.	1.4.3: Special requirements for protective devices				
Question 1.1	Are protection devices designed and incorporated into the control system in a way such that moving parts cannot start up while they are within the operator's reach?				
Question 1.2	Are protection devices designed and incorporated into the control system in a way such that persons cannot reach the moving parts while parts are moving?				
Question 1.3	Are protection devices designed and incorporated into the control system in a way such that the absence or failure of one of their components prevents starting or stops the moving parts?				

Question 2	Are protection devices adjustable only by means of an intentional action?				
Section 33.	1.5.1: Electricity supply				
Question 1	Is machinery which has an electricity supply, designed, constructed and equipped in such a way that all hazards of an electrical nature are or can be prevented? The safety objectives set out in the Low Voltage Directive 2014/35/EU shall apply to machinery. However, the obligations concerning conformity assessment and the placing on the market and/or putting into service of machinery with regard to electrical hazards are governed solely by this Directive.				
Section 34.	1.5.2: Static electricity				
Question 1	Is machinery designed and constructed to prevent or limit the build-up of potentially dangerous electrostatic charges and/or fitted with a discharging system?				
Section 35.	1.5.3: Energy supply other than electricity				
Question 1	Is machinery which is powered by source of energy other than electricity so designed, constructed and equipped as to avoid all potential risks associated with such sources of energy?				
Section 36.	1.5.4: Errors of fitting				
Question 1	Where errors likely to be made when fitting or refitting certain parts which could be a source of risk made impossible by the design and construction of such parts or, failing this, by information given on the parts themselves and/or their housings? The same information must be given on moving parts and/or their housings where the direction of movement needs to be known in order to avoid risk. Where necessary, the instructions must give further information on these risks.				
Section 36.	1.5.4: Errors of fitting				
Question 2	Where a faulty connection can be the source of risk, are incorrect connections made impossible by design or, failing this, by information given on the elements to be connected and, where appropriate, on the means of connection?				
Section 37.	1.5.5: Extreme temperatures				
Question 1	Are steps taken to eliminate any risk of injury arising from contact with or proximity to machinery parts or materials at high or very low temperatures?				
Question 2	Are the necessary steps taken to avoid or protect against the risk of hot or very cold material being ejected?				
Section 38.	1.5.6: Fire				
Question 1	Has machinery been designed and constructed in such a way as to avoid any risk of fire or overheating posed by the machinery itself or by gases, liquids, dust, vapours or other substances produced or used by the machinery?				
Section 39.	1.5.7: Explosion				
Question 1	Has machinery been designed and constructed in such a way as to avoid any risk of explosion posed by the machinery itself or by gases, liquids, dust, vapours or other substances produced or used by the machinery?				
Question 2	Does machinery comply , as far as the risk of explosion due to its use in a potentially explosive atmosphere is concerned, with the provisions of the specific Community Directives?				
Section 40.	1.5.8: Noise				
Question 1	Is machinery designed and constructed in such a way that risks resulting from the emission of airborne noise are reduced to the lowest level, taking into account the technical progress and the availability of means of reducing noise, in particular at source?				
Question 2	Has the level of noise emission been assessed with reference to comparative emission data for similar machinery?				
Section 41.	1.5.9: Vibrations				
Question 1	Is machinery designed and constructed in such a way that risks resulting from vibrations produced by the machinery are reduced to the lowest level, taking account of technical progress and the availability of means of reducing vibration, in particular at source?				
Question 2	Has the level of vibration emission may be assessed with reference to comparative emissions data for similar machinery?				
Section 42.	1.5.10: Radiation				
Question 1	Is undesirable radiation emissions from the machinery eliminated or is it reduced to levels that do not have adverse effects on persons?				
Question 2	Is any functional ionising radiation emissions limited to the lowest level which is sufficient for the proper functioning of the machinery during setting, operation and cleaning? Where a risk exists, have the necessary protective measures been taken?				
Question 3	Is any functional non-ionising radiation emissions during setting, operation and cleaning limited to the levels that do not have adverse effects on persons?				
Section 43.	1.5.11: External radiation				

Question 1	Is machinery designed and constructed in such a way that external radiation does not interfere with its operation?				
Section 44.	1.5.12: Laser radiation				
Question 1.1	Where laser equipment is used, has the following been taken into account: - laser equipment on machinery must be designed and constructed in such a way as to prevent any accidental radiation?				
Question 1.2	Where laser equipment is used, has the following been taken into account: - laser equipment on machinery must be protected in such a way that effective radiation, radiation produced by reflection or diffusion and secondary radiation do not damage health?				
Question 1.3	Where laser equipment is used, has the following been taken into account: - optical equipment for the observation or adjustment of laser equipment on machinery must be such that no health risk is created by laser radiation?				
Section 45.	1.5.13: Emissions of hazardous materials and substances				
Question 1	Is machinery designed and constructed in such a way that risks of inhalation, ingestion, contact with the skin, eyes and mucous membranes and penetration through the skin of hazardous materials and substances which it produces can be avoided?				
Question 2	Where hazard cannot be eliminated, is the machinery equipped so that hazardous materials and substances can be contained, evacuated, precipitated by water spraying, filtered or treated by another equally effective method?				
Question 3	Where the process is not totally enclosed during normal operation of the machinery are the devices for containment and/or evacuation situated in such a way as to have the maximum effect?				
Section 46.	1.5.14: Risk of being trapped in a machine				
Question 1	Is machinery designed, constructed or fitted with means of preventing a person from being enclosed within it or, if that is impossible, with a means of summoning help?				
Section 47.	1.5.15: Risk of slipping, tripping or falling				
Question 1	Are parts of the machinery where persons are liable to move about or stand designed and constructed in such a way as to prevent persons slipping, tripping or falling on or off these points?				
Question 2	Where appropriate, are these parts fitted with handholds that are fixed relative to the user and that enable them to maintain their stability?				
Section 48.	1.5.16: Lightning				
Question 1	Is machinery in need of protection against the effects of lightning while being used fitted with a system for conducting the resultant electrical charge to earth?				
Section 49	1.6.1: Machinery maintenance				
Question 1	Are adjustment and maintenance points located outside danger zones? It must be possible to carry out adjustment, maintenance, repair, cleaning and servicing operations while machinery is at a standstill.				
Question 2	If one or more of the conditions set out in question 1 of this section cannot be satisfied for technical reasons, have measures been taken to ensure that these operations can be carried out safely (see section 1.2.5)?				
Question 3	In the case of automated machinery and, where necessary, other machinery, has a connecting device for mounting diagnostic fault-finding equipment been provided?				
Question 4.1	Have automated machinery components which have to be changed frequently capable of being removed and replaced easily and safely?				
Question 4.2	Does access to the components enable these tasks to be carried out with the necessary technical means in accordance with a specified operating method?				
Section 50.	1.6.2: Access to operating positions and servicing points				
Question 1	Is machinery designed and constructed in such a way as to allow access in safety to all areas where intervention is necessary during operation, adjustment and maintenance of the machinery?				
Section 51.	1.6.3: Isolation of energy sources				
Question 1	Is machinery fitted with a means to isolate it from all energy sources? Are such isolators clearly identified? Are they capable of being locked if reconnection could endanger persons?				
Question 2	Are isolators also capable of being locked where an operator is unable, from any of the points to which he has access, to check that energy is still cut off?				
Question 3	In the case of machinery capable of being plugged into an electrical supply, is removal of the plug sufficient, provided that the operator can check from any of the points to which he has access that the plug remains removed?				
Question 4	Where circuits are required to remain connected to the supplies, have special steps been taken to ensure operator safety?				
Question 5	After the energy is cut off, is it possible to dissipate normally any energy remaining or stored in the circuits of the machinery without risks to persons?				

Question 6	As an exception to the requirement laid down in the previous paragraphs, certain circuits may remain connected to their energy sources in order, for example, to hold parts, to protect information, to light interiors, etc. In this case, are special steps taken to ensure operator safety?				
Section 52.	1.6.4: Operator intervention				
Question 1.1	Is machinery so designed, constructed and equipped that the need for operator intervention is limited?				
Question 1.2	If operator intervention cannot be avoided, is it possible to carry it out easily and safely?				
Section 53.	1.6.5: Cleaning of internal parts				
Question 1	Is machinery designed and constructed so that it is fitted for its function and can it be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the conditions foreseen but also takils the machinery designed and constructed in such a way that it is possible to clean internal parts which have contained dangerous substances or preparations without entering them; any necessary unblocking must also be possible from the outside?				
Question 2	If it impossible to avoid entering the machinery, is it designed and constructed in such a way as to allow cleaning to take place safely?				
Section 54.	1.7.1: Information and warnings on the machinery				
Question 1.1	Is information and warnings on the machinery preferably provided in the form of readily understandable symbols or pictograms?				
Question 1.2	Is any written or verbal information and warnings expressed in an official Community language or languages, which may be determined in accordance with the Treaty by the Member State in which the machinery is placed on the market and/or put into service and may be accompanied, on request, by versions in any other official Community language or languages understood by the operators?				
Section 55.	1.7.1.1: Information and information devices				
Question 1	Where health and safety of persons may be endangered by a fault in the operation of unsupervised machinery, is the machinery equipped in such a way as to give an appropriate acoustic or light signal as a warning?				
Question 2	Are visual display units or any other interactive means of communication between the operator and the machine easily understood and easy to use?				
Section 56.	1.7.1.2: Warning devices				
Question 1	Where health and safety of persons may be endangered by a fault in the operation of unsupervised machinery, is the machinery equipped in such a way as to give an appropriate acoustic or light signal as a warning?				
Question 2	Where machinery is equipped with warning devices are these unambiguous and easily perceived?				
Question 3	Does the operator have facilities to check the operation of such warning devices at all times?				
Question 4	Is the requirements of the specific community directives concerning colours and safety signals complied with?				
Section 57.	1.7.2: Warning of residual risks				
Question 1	Where risks remain despite the inherent safe design measures, are safeguarding and complementary protective measures adopted, the necessary warnings, including warning devices, provided?				
Section 58.	1.7.3: Marking of machinery				
Question 1	Is all machinery marked visibly, legibly and indelibly with the following minimum particulars: - the business name and full address of the manufacturer and, where applicable, his authorised representative?, - designation of the machinery?, - the CE Marking?, - designation of series or type?, - serial number, if any?, - the year of construction, that is the year in which the manufacturing process is completed?				
Question 2	It is prohibited to pre-date or post-date the machinery when affixing the CE marking. Has this item been checked?				
Question 3	Is machinery designed and constructed for use in a potentially explosive atmosphere marked accordingly?				
Question 4	Does machinery also bear full information relevant to its type and essential for safe use? (Such information is subject to the requirements set out in section 1.7.1).				
Question 5	Where a machine part is handled during use with lifting equipment, is its mass indicated legibly, indelibly and unambiguously?				
Section 59.	1.7.4: Instructions				
Question 1	Is all machinery accompanied by instructions in the official Community language or languages of the Member State in which it is placed on the market and/or put into service?				
Question 2	Are the instructions accompanying the machinery either 'Original instructions' or a 'Translation of the original instructions', in which case the translation must be accompanied by the original instructions?				
Question 3	By way of exception, are the maintenance instructions intended for use by specialised personnel mandated by the manufacturer or his authorised representative supplied in only one Community language which the specialised personnel understand?				

Section 60.	**1.7.4.1: General principles for the drafting of instructions**				
Question 1.1	Are the instructions drafted in one or more of the official Community languages?				
Question 1.2	Do the words 'Original instructions' appear on the language version(s) verified by the manufacturer or his authorised representative?				
Question 2	Where no 'Original instructions' exist in the official language(s) of the country where the machinery is to be used, is a translation into that/those language(s) provided by the manufacturer or his authorised representative or by the person bringing the machinery into the language area in question? The translations must bear the words 'Translation of the original instructions'.				
Question 3	Do the contents of the instructions cover not only the intended use of the machinery but also take into account any reasonably foreseeable misuse thereof?				
Question 4	In the case of machinery intended for use by non-professional operators, does the wording and layout of the instructions for use take into account the level of general education and acumen that can reasonably be expected from such operators?				
Section 61.	**1.7.4.2: Contents of the instructions**				
Question 1	Please give details of the instruction manual inspected.				
Question 2	Does the instruction manual contain a repeat of the information with which the machinery is marked?				
Question 3	Does the instruction manual contain the foreseen use of the machinery (including reasonable foreseen misuse)?				
Question 4	Does the instruction manual contain warnings concerning ways in which the machinery must not be used that experience has shown might occur?				
Question 5	Does the instruction manual contain drawings, diagrams and the means of attachment and the designation of the chassis or installation on which the machinery is to be mounted?				
Question 6	Does the instruction manual contain the workstation(s) likely to be occupied by operators?				
Question 7	Does the instruction manual contain adequate instructions for putting into service?				
Question 8	Does the instruction manual contain adequate instructions for safe use?				
Question 9	Does the instruction manual contain adequate instructions for safe handling, giving the mass of the machinery and its various parts where they are regularly to be transported separately?				
Question 10	Does the instruction manual contain the frequency of safety inspections?				
Question 11	Does the instruction manual contain adequate instructions for safe installation?				
Question 12	Does the instruction manual contain instructions for safe assembly and dismantling?				
Question 13	Does the instruction manual contain instructions for the adjustment and maintenance operations that should be carried out by the end user and the preventive maintenance measures that should be observed; - instructions designed to enable adjustment and maintenance to be carried out safely, including the protective measures that should be taken during these operations?				
Question 14	Does the instruction manual contain the specifications of the spare parts to be used, when these affect the health and safety of operators?				
Question 15	Does the instruction manual contain, where necessary, training instructions?				
Question 16	Does the instruction manual contain all relevant drawings?				
Question 17	Does the instruction manual contain where applicable; - the operating method to be followed in the event of accident or breakdown; if a blockage is likely to occur, the operating method to be followed so as to enable the equipment to be safely unblocked?				
Question 18	Does the instruction manual contain; -instructions relating to installation and assembly for reducing noise or vibration; - information about the residual risks that remain despite the inherent safe design measures, safeguarding and complementary protective measures adopted; - instructions on the protective measures to be taken by the user, including, where appropriate, the personal protective equipment to be provided; - the essential characteristics of tools which may be fitted to the machinery?				
Question 19	Does the instruction manual contain the following information on airborne noise emissions?: - the A-weighted emission sound pressure level at workstations, where this exceeds 70dB(A); where this level does not exceed 70dB(A), this fact must be indicated, - the peak C-weighted instantaneous sound pressure value at workstations, where this exceeds 63Pa (130db in relation to 20microPa), the A-weighted sound power level emitted by the machinery, where the A-weighted emission sound pressure level at workstations exceeds 80dB(A). These values must be either those actually measured for the machinery in question or those established on the basis of measurements taken for technically comparable machinery which is representative of the machinery to be produced. In the case of very large machinery, instead of the A-weighted sound power level, the A-weighted emission sound pressure levels at specified positions around the machinery may be indicated. Where the harmonised standards are not applied, sound levels must be measured using the most appropriate method for the machinery. Whenever sound emission values are indicated the uncertainties surrounding these values must be specified. The operating conditions of the machinery during measurement and the measuring methods used must be described. Where the workstation(s) are undefined or cannot be defined, A-weighted sound pressure levels must be measured at a distance of 1 metre from the surface of the machinery and at a height of 1.6 metre from the floor or access platform. The position and value of the maximum sound pressure must be indicated.				
Question 20	Does the instruction manaul contain the following information?; -Where specific community directives lay down other requirements for the measurement of sound pressure levels or sound power levels, those directives must be applied and the corresponding provisions of this section shall not apply; - where machinery is likely to emit non-ionising radiation which may cause harm to persons, in particular persons with active or non-active implantable medical devices, information concerning the radiation emitted for the operator or exposed persons.				
Section 62.	**1.7.4.2: Contents of the instructions**				
Question 1	Does sales literature describing the machinery not contradict the instructions as regards health and safety aspects? Sales literature describing the performance characteristics of machinery must contain the same information on emissions as is contained in the instructions.				

32 F230 – Residual Risk Register Template

The Residual Risk Register template should be read in conjunction with WI159 - Residual Risk Register work instruction.

Residual Risk Register

Document Number:	**K0XXXX-XXX**
Tlitle:	
Revision Date:	

	Print Name	Sign	Date
Prepared By:			
Reviewed By:			
Approved By:			

Page 1 of 4

Form	25/06/2019		Form Rev	01
Form	F230 - Residual Risk Register Template			

Amendment History

Issue	Amendment	Date

Page 2 of 4

Form Date	25/06/2019	Form Rev	01
Form No	F230 - Residual Risk Register Template		

1 Introduction

The purpose of this document is to collate the residual risks identified during the design risk assessments of the [Project], such that the residual risks can be taken into account when preparing further documentation, when carrying out future risk assessments and to comply with the requirements of the Construction (Design Management) Regulations 2007.

2 Description of Equipment

Form No	F230 - Residual Risk Register Template		
Form Rev	01		
Form Date	25/06/2019	Low Residual Risk	L
Page 4 of 4		Medium Residual Risk	M
K0XXXX-XXX		High Residual Risk	H

Residual Risk Register:

Identified In Document No.	System Reference	Hazard Ref. No.	Description of Hazard	Hazard Type	Suggested Control Measures	Residual Risk

F231 – Front Sheet Template

The front sheet template should be read in conjunction with WI162 – Introduction to the Front sheet

Form No	F231 - Front Sheet Template
Form Date	0
Form Rev	4
CONTRACT No.	
CUSTOMER	
PROJECT DESCRIPTION	

Revision	Date	Comment	Author

F231 - Front Sheet Template	SHT 1 OF 3

CONTRACT No.		0		
CUSTOMER		0		
PROJECT DESCRIPTION		0		
LEAD ENGINEER NAME				
No	No	Internal Tollgate Deliverable	External Tollgate Deliverable	Completed
Tollgate A	1	New Sales Enquiry Specification Generated (No Non-standard machine elements) (F224)	New Sales Enquiry Specification Generated (Non-standard machine elements listed) (F224)	
	2		New Sales Enquiry Hours Generated (F223)	
	3		(F597 or F598) - TFW5 or TFW3 MACHINE CODEX_MASTER (Standard machine elements listed)	
	4	Process Parameters Sheet Generated (F225)		
Tollgate B	5	Revised Sales Enquiry Specification Generated (No Non-standard machine elements) (F224)	Revised Sales Enquiry Specification Generated (Non-standard machine elements listed) (F224)	
	6		Revised Sales Enquiry Hours (F223)	
	7		Concept Design (WI197)	
	8		(F597 or F598) - TFW5 or TFW3 MACHINE CODEX_MASTER (Standard machine elements listed)	
	9	Revised Process Parameters Sheet Generated (F225)		
Tollgate 3.1	10	Move the sales enquiry folder to the contract folder.		
	11	Design Risk Assessment (DRA) Generated (Draft) (F228)		
	12	Residual Risk Register (RRR) Generated (Draft) (F230)		
	13	Design Brief Generated (F413)		
	14	Switch List Issued (F411)		
Tollgate 3.2	15	Peer Design Reviews Undertaken (If Required) (F233)		
	16	Peer Design Review Quesionnaire (If Required) (F419)		
	17	Design Failure Mode Effect Analysis (DFMEA) Undertaken (If Required) (F234)		
	18	Process Failure Mode Effect Analysis (PFMEA) Undertaken (If Required) (F242)		
Tollgate 3.3	19	Production Design Reviews Undertaken (If Required) (F233)		
	20	Design Review Questionnaire (F419)		
	21	Design Risk Assessment (DRA) (Approved) (F228)		
	22	Residual Risk Register (RRR) (Approved) (F230)		
	23	Paint Specification Issued (F409 If Standard paint spec)		
Tollgate 3.4	24	Manufacturing Design Reviews Undertaken (If Required) (F233)		
	25	Finalised Switch List Issued (F411)		
Tollgate T4	26		Design Risk Assessment (F228)	
	27		Residual Risk Register Issued (F230)	
	28		All Checked and Approved Drawings Issued	
	29		Frozen Bills Of Materials (BOMs) Issued	
	30		Issue Spare Parts List	
	31		Panel Build RFQ (F489)	
	32		Panel Checklist (F490)	
	33		Functional Safety Assessment (F451)	
	34	Front Sheet Check Undertaken		
	35	Controls Calculations (F488)		
	36	Component Safety Assessment (WI231)		
Tollgate 5	37		Design Risk Assessment (F228)	
	38		Risk Assessment Template (F240)	
	39		Rotary Friction Welder Microphone Position Template (F495)	
	40		New Features Test Requirements Template (F491)	
	41		Shop floor documentation Package	
	42		Performance Acceptance Criteria Template (F436)	
	43		Lifting Plan Issued (F235)	
Tollgate 6	44		Declaration of Conformity / Incorporation Issued (F236 or F237)	
	45		Customer Documentation Package	
	46	Front Sheet Closed (F231)		

F231 - Front Sheet Template

SHT 2 OF 3

CONTRACT No.	0
CUSTOMER	0
PROJECT DESCRIPTION	0

ASSEMBLY	ASSEMBLY No.	1ST. ISSUED	LAST ISSUED	COMPLETION					ENGINEER	NOTES OR COMMENTS	STATE
				0%	25%	50%	75%	100%			

F231 - Front Sheet Template	SHT
	3
	OF
	3

33 F232 – Calculations Template Word

The purpose of the calculation template is to standardise the approach to undertaking calculations within the Mechanical Engineering Department. This should improve the quality of the calculations being undertaken and additionally assist with interpretation to aid learning.

F232 - Calculation Template Word

Project number	
Project title	
Project description	
Customer / Employer	
Client	

Doc. Number		**Issue**	
Author		**Date**	
Department		**Total pages**	x

	Print Name	Sign	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By:			

Document: F232
Form Rev: 01

Form Date: 25/06/2019

Page 1 of 8

Amendment History

Issue	Amendment	Date
01	Initial Issue	Month yyyy

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
KSUK	KUKA Systems UK Ltd
LTR	Lifetime Records
QCP	Quality Control Plan
QP	Quality Plan

Endorsement / Signature List

Name	Organisation	Position	Signature

1 Introduction

2 Equipment Overview

3 Scope / Objectives

4 Assumptions

5 Software Validation

This document is written using proprity Mathcad Prime Version 5, NX Nastran & FEMAP software therefore software calidation is not required.

All Drawing / Model reference and associated measurements have been generated

6 Analysis Methods

The stress analysis contained within this document is a static stress analysis using methods and permissibles from BS 2573 Pt 1:1983 (R1) in conjunction with classical stress analysis techniques.

7 References

REF	Document Reference	Issue	Title
R1	BS 2573-1	1983	Rules for the design of cranes – Part 1 Specification for classification, stress calculations and design criteria for structures
R2	xxxxxxxx	xxxxx	xxxxxxxx
R2	xxxxxxxx	xxxxx	xxxxxxxx

8 Drawing & Document References

REF	Document Reference	Issue	Title
D1	xxxxxxxx	xxxxx	xxxxxxxx
D2	xxxxxxxx	xxxxx	xxxxxxxx
D3	xxxxxxxx	xxxxx	xxxxxxxx

9 Calculation Data

9.1 General Data

9.2 Masses

9.3 Materials

9.4 Fasteners

9.5 Load Case 1

9.6 Load Case xx

10 Conclusion

A summary of reserve factors can be found in the following sections.

10.1 Summary of Reserve Factors

RF Number	Value	Acceptable	Description
1		>1, Acceptable	
2		>1, Acceptable	
3		>1, Acceptable	

11 Appendices

11.1 Appendix A

11.2 Appendix X

34 F233 – Design Review Template

The design review template should be read in conjunction with SOP117 – Design Review Procedure.

Design Review

Project Number:	
Project Title:	
Project Description:	
Customer / Employer	
Client	

Peer Review

Ref		Name	
Date		Purpose	
Location		Objectives	
Attendees		Circulation	Project File, Attendees,

Agenda Item	Meeting Agenda	Description	Owner	Start	End	Duration	Comments

Actions Item	Due Date	Description	Owner	Priority	Comments

DFA Review

Ref		Name					
Date		Purpose					
Location		Objectives					
Attendees						Circulation	Project File, Attendees,

Agenda Item	Meeting Agenda	Description	Owner	Start	End	Duration	Comments

Actions Item	Due Date	Description	Owner	Priority	Comments

DFM Review

Ref		Name	
Date		Purpose	
Location		Objectives	
Attendees		Circulation	Project File, Attendees,

Agenda Item	Meeting Agenda	Description	Owner	Start	End	Duration	Comments

Actions Item	Due Date	Description	Owner	Priority	Comments

36 F234 – DFMEA Template

The purpose of the Design Failure Mode Effect Analysis is to identify potential failure modes or defects during the design phase of a product. The DFMEA Template should be read in conjunction with SOP071 – Design Risk Management.

Potential Failure Model and Effects Analysis (Design FMEA)

Project number	
Project title	
Description	
Customer / Employer	
Client	

Doc. Number		Issue	
Author		Date	
Department			

	Print Name / Position	Signature	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By			

Verify you are using the latest issue of this document.
This document is considered "Uncontrolled" when printed.

AMENDMENT HISTORY

Issue	Amendment	Date
1	First Issue	

1 Introduction

2 Description of Equipment

F234 - DMEA Template	Potential Failure Model and Effects Analysis (Design FMEA)			
System				
Subsystem	Responsible Engineer		FMEA Number	
Component	Date		Revision	

Notes

						Existing Conditions								Action Results				
(7.1) Item / Function	(7.2) Requirements	(7.3) Potential Failure Mode	(7.4) Potential Effects of Failure	(7.5) CLASS	(7.6) Potential Causes / Mechanisms of Failure	(7.7) Current Design Controls Prevention	(7.8) Current Design Controls Detection	(7.9) OCC	(7.10) SEV	(7.11) DET	(7.12) RPN	(7.13) Recommended Actions	(7.14) Responsibility & Target Completion Date	(7.15) Actions Taken	(7.16) OCC	(7.17) SEV	(7.18) DET	(7.19) RPN
											0							0
											0							0
											0							0
											0							0
											0							0
											0							0
											0							0
											0							0
											0							0
											0							0
											0							0
											0							0

37 F235 – Lifting Plan Template

The Lifting Plan Template should be read in conjunction with WI203 – Introduction to Lifting Plans.

F235 - Lift Plan

Project number	
Project title	
Project description	
Customer / Employer	
Client	

Doc. Number		**Issue**	
Author		**Date**	
Department		**Total pages**	x

	Print Name	Sign	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By:			

Form No: F235 - Lifting Plan Template
Form Issue: 1
Form Date: 19/08/2019

Page 1 of 8

Amendment History

Issue	Amendment	Date
01	Initial Issue	Month yyyy

Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
LTR	Lifetime Records
QCP	Quality Control Plan
QP	Quality Plan
SQEP	Suitable Qualified Experienced Personnel

Endorsement / Signature List

Name	Organisation	Position	Signature

1 Introduction

This document outlines the process and equipment required to lift [Equipment Descrition]

2 Summary Details

2.1 Size of Major Components

2.2 Weight of Major Components

2.3 Installation Route

[Detail Installation Route]

Note: This is a suggested installation route and should be confirmed by the installation contractor and detailed within their Installation Method Statement). [Delete if not applicable}

- All the major equipment should be manoeuvred into position using a trolley, pallet truck or building crane.
- All miscellaneous items which are below manual handling limits should be manually lifted into position.
- All equipment should be stored in an agreed temporary laydown area during installation.

2.4 Access Opening Size

2.5 Equipment Required

3 Method

3.1 Pre-requisites:

- An industrial risk assessment has been carried out and has been read, understood and signed onto by the operatives.
- All operatives involved in the work will be briefed by the Task Supervisor on this lifting plan and associated risk assessment prior to commencement, and will sign the attached register to indicate their understanding of its contents.
- Ensure that all personnel are SQEP to carry out their designated duties.
- Work shall not start until the method statement and risk assessment have been approved and relevant permits to work have been issued.
- Confirm test certificates are valid for all lifting equipment.
- Ensure work area is free of hazards and that all obstacles are clearly identified in task risk assessment.

3.2 Method:

Step:	Action:	Key Points:
1	Confirm all pre-requisites have been carried out.	
2		

4 References

REF	Document Reference	Issue	Title
R1	GA Drawings	xxxxx	xxxxxxxx
R2	xxxxxxxx	xxxxx	xxxxxxxx
R2	xxxxxxxx	xxxxx	xxxxxxxx

38 F238 – Self-Check Tick List Template

F238 - Document Self Checking Tick List

Checks Required:	**Y / N**
Is the document on the agreed template?	
Is the document correctly/uniquely identified? With a title in the correct format and document number.	
Is the file saved with corresponding document number in the correct project location?	
document clearly identifies the Author & date of production / modification?	
Is the document clearly identifies the Revision or Modification reference status?	
Is the document readable, understandable, and in a logical sequence?	
Is the document legible and suitable as a record?	
Does the document meets the criteria for its intended use and any associated specification?	
Detail Drawings:	
Is the correct Scale shown in the drawing border?	
Revision box has been populated stating reason for issue? For Example 'FIRST ISSUE', 'ISSUED FOR MANUFACTURE' etc.	
Does the material specified follow the relevant BS / ISO standard?	
'Treatment Spec' has been specified, in line with the FDS or customer requirements?	
Are all required drawing views are included without ambiguity, needless generalities or repetition?	
All required dimensions are included and clearly visible? **Note:** Dimensions should **NEVER** be manually entered or typed over. Dimensioning to Hidden Detail to be avoided.	
Drawing annotations are correct to BS 8888: 2017?	
Has a spelling and grammar check been carried out on all text and notation within the drawing?	
Where applicable, has the component surface finish been specified?	
Where applicable, have weld annotations been called out correctly to BS EN ISO 2553 2013 or any other standard?	

Where GD&T is Applied:	
Is GD&T required? If so are the specified tolerances achievable?	
Are all datum's clearly identified?	
Have basic Dimensions been used for features / details where GD&T is applied?	
Are the correct geometric symbols used for the feature / detail?	
Assembly Drawings	
Is the correct Scale shown in the drawing border?	
Revision box has been populated stating reason for issue? For Example 'FIRST ISSUE', 'ISSUED FOR MANUFACTURE' etc.	
All required drawing views are included relaying the desired information without ambiguity, needless generalities or repetition?	
All required dimensions are included and clearly visible? **Note:** Dimensions should **<u>NEVER</u>** be manually entered or typed over. Dimensioning to Hidden Detail to be avoided.	
Drawing annotations are correct to BS 8888: 2017?	
Has a spelling and grammar check been carried out on all text and notation within the drawing?	
Have all components been ballooned out on the drawing?	
Where applicable, have lifting points been included and identified?	
Where applicable, have required bolt torques been specified?	

39 F239 – Meetings Template

F239 - MoM 1 of 3

Minutes of Meeting (MoM)

Ref:			Revision:		
Subject:					
Location:		Date:		Time:	

Attendees:	Appologies:	Distribution:

Agenda

1. Item 1
2. Item 2
3. Item 3
4. Item 4
5. Item 5
6. Item 6
7. Item 7
8. Item 8
9. Item 9
10. Item 10

Number	Subject	Notes	Action By	Action Date	Status
1					
2					

40 F240 – Risk Assessment Template

F240 - Risk Assessment

Project number	
Project title	
Project description	
Customer / Employer	
Client	

Doc. Number		**Issue**	
Author		**Date**	
Department		**Total pages**	x

	Print Name	Sign	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By:			

Form No: F240
Form Issue: 1
Form Date: 25/06/2019

Page 1 of 8

Amendment History

Issue	Amendment	Date
01	Initial Issue	Month yyyy

Endorsement / Signature List

Name	Organisation	Position	Signature

Form No: F240
Form Issue: 1
Form Date: 25/06/2019

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Hazard and hazard effect List here:	Who might be harmed? List groups of people who are especially at risk from the significant hazards which you have identified:	Is the risk adequately controlled? List existing controls here or note where the information may be found:	What further action is necessary to control the risk? List the risks which are not adequately controlled and the action you will take where it is reasonably practicable to do more. Cost can be a consideration but only on low and medium risks.	Who is responsible for the risk controlling actions? Person responsible and by when:		
				Person:	Date of completion	Date completed

Guidance for the use of the Risk Assessment Form:

Hazard: *Look only for hazards which you could reasonably expect to result in significant harm under the conditions in your workplace. Use the following examples as a guide:*	Who might be harmed? *There is no need to list individuals by name – just think about groups of people doing similar work or who may be affected, for example:*	Is the risk adequately controlled? Have you already taken precautions against the risks from the hazards you listed? For example, have you provided:	What further actions are necessary to control the risk? What more could you reasonably do for those risks that were not adequately controlled?	Who is responsible for doing the work to control the risk?
• Slipping/tripping hazards (e.g. poorly maintained floors or stairs). • Fire (e.g. hot processes - welding/burning. • Electricity (e.g. trailing cables) • Chemicals (e.g. cutting fluids) • Gas, fume, dust. • Moving parts of machinery (e.g. blades, rotating drills). • Fume (for example welding) • Work at height (e.g. on mezzanine floors). • Manual handling • Ejection of material (e.g. cutting operations)	• Office staff. • Maintenance personnel. • Contractors. • People sharing your workplace. • Operators. • Cleaners. • Members of the public. Pay particular attention to: • Staff with special needs. • Inexperienced staff. • Visitors. • Lone workers. • Pregnant women. • The age & fitness of workers	• Adequate control measures. • Adequate information, instruction or training? • Adequate systems or procedures? • Adequate protective equipment. Do the precautions: • Meet the standards set by a legal requirement? • Represent good practice? • Comply with a recognised industry standard?	You will need to give priority to those risks which affect large numbers of people and/or could result in serious harm. Apply the principles below when taking further action, if possible in the following order: • Remove the risk completely. • Try a less risky option. • Prevent access to the hazard (for example by guarding). • Organise work to reduce exposure to the hazard. • Issue personal protective equipment.	• List person who will do the work for immediate actions (for example erect barriers or notices). • List the person responsible for long term actions (for example arrange engineering work to remove hazard). • Record the target date for completion of the risk controlling measures. *Ensure that the team is briefed on the precautions.*

Form No: F240
Form Issue: 1
Form Date: 25/06/2019

Page 5 of 8

• Noise. • Pressure systems (for example, steam/ hydraulics/compressed air). • Poor lighting. • Vehicles (e.g. fork-lift trucks). • High/low working temperatures. • Radiation/contamination/ airborne activity. • Hazards to the Environment. • Confined spaces/ Work in Protective suits/ Breathing Apparatus • Suspended loads. • Lone working. • Spills. • Explosion. • Any other hazards. *You only get a clear picture by looking at the work area.*	They may be more vulnerable.	• Reduce risk as far as reasonably practicable? If so, then the risks are adequately controlled, but you need to indicate the precautions you have in place. You may refer to procedures, manuals, company rules etc giving this information. List other risk assessments, if applicable, for example COSHH, noise etc.	• Provide local welfare facilities (e.g. washing facilities for removal of contamination and first aid). • Include immediate short-term actions, for example, erect warning notices and/or barriers.	

1. This form will help you as a Manager or Supervisor to manage your jobs safely, but only if you think jobs through from start to finish.
2. It is your job as a Manager or Supervisor to assess the risks and produce a Safe System of Work for all your jobs, but remember that you do not have to prepare a form for every job: many of your jobs are going to involve simple routine tasks, and using one of these forms will not help: so *do not* use one of these forms if you are going to emulsion office walls, re-hang doors, change light bulbs etc.
3. Use one of these forms for hazardous jobs where you need to plan ahead: e.g. demolition work, work under live cables, working in a confined space, roof work, steel erection, non-standard lifting operations, using hazardous substances, testing and commissioning plant, work near EOT cranes, work in noisy areas, non-standard manual handling etc.
4. It is not your Safety Advisor's responsibility to complete these forms. Use him to help you.
5. You must read and understand Regulation 3 of The Management of Health Safety & Welfare Regulations in addition to any local site rules relevant to the production of risk assessments
6. When you prepare the form, ask yourself these questions, and involve the people who are going to do the work:

6.1 What is the job and what does it involve?

6.2 What can go wrong?

6.3 If things go wrong can people get hurt?

6.4 How likely is it that things will go wrong?

6.5 Which Safety Instructions must I read?

6.6 Now that I have assessed the risks can I remove them completely?

6.7 If the answer to 6.6 is "NO" what precautions must I take to reduce or control the risks?

6.8 What emergency arrangements do I need to set up?

6.9 How many people do I need?

6.10 During the job how will we communicate?

6.11 How will I ensure that everyone understands?

6.12 Do we need a rehearsal?

6.13 How will I supervise the job?

7. When you have got the answers to these questions, you can begin to fill the form in:

7.1 The Job: **Be specific and think about all aspects of the job from start to finish**: for example, if you have to paint walls in a confined space, this section must contain details of the paint, the size and location of the confined space and the final cleaning of the area; if you do this, you will be able to identify all the hazards you face.

7.2 Column 1: **Be specific**: using the example of painting in a confined space, if you find yourself using the word "fumes", you are not being specific enough; you have to name the type of fumes, e.g. "toluene fumes", and state if there are a fire risk and/or a toxic risk. Again, if you are not specific in your description in Column 1 you will not be able to spell out the proper precautions.

7.3	Column 2:	**Be specific:** think about your own employees and sub-contractors, but you also need to talk to the Area/ Plant Owner and to other workers, you need to know who else is working nearby.
7.4	Column 3:	**Be specific:** using the example of painting in a confined space, e.g. if all the Operatives and Supervisors have attended an approved confined spaces course, say so; if the confined space is already provided with a lockable door, say so; if people have not attended the course deal with it in Column 4.
7.5	Column 4:	**Be specific:** using the example of painting in a confined space, just saying "ventilation needed" is not sufficient; you must specify the type and size of the fan, where it will be situated, etc.
7.6	Column 5:	**Explain everything to the people responsible:** make sure that they have copies of the form; they might forget something: "date for completion" means "when must the precautions be in place?"; "date completed" means the date on which the precautions were in place and checked as satisfactory; in many cases, you will be able to write "before work starts" across both columns.
7.7		**Operating Instructions** are special rules which have been produced and approved by an accepted authority, which is acknowledged by your management. They will normally apply to generic tasks where the conditions are unlikely to change, i.e. fixed workshop equipment, etc. They would not apply to a portable grinder whose use is adaptable to different environments.
7.8		**If hazardous substances or special waste are involved:** The risk assessment must include a COSHH assessment, and the Safety data sheets for the hazardous sub-stance(s)
7.9		**Someone has to supervise the work:** name him and make sure that he knows what to do.
7.10		**Make sure that you check the form before you sign:** if you are a Manager, you must review each form prepared by your approved employees; if the procedures are not acceptable, do not let them start.
7.11		**You must make sure that the details on the form are explained to everyone involved in the work and that a copy is made available to them.**
7.12		**Review:** If the job is long term i.e. beyond 8 weeks, the details on the form must be **reviewed and annotated accordingly and refiled**. However, details must also be **reviewed whenever there is any significant change of circumstances**; when a review indicates that the details on the form have changed, then the form must be amended and reissued and refilled.

41 F242 – PFMEA Template

The PFMEA Template should be read in conjunction with SOP071 – Design Risk Management.

Potential Failure Model and Effects Analysis
(Process FMEA)

Project number	
Project title	
Description	
Customer / Employer	
Client	

Doc. Number		Issue	
Author		Date	
Department			

	Print Name / Position	Signature	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By			

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F242 - PFMEA Template
REV2 - July 20

Page 1 of 4

AMENDMENT HISTORY

Issue	Amendment	Date
1	First Issue	

1 Introduction

2 Description of Equipment

F242 - PFMEA Template	
	System
	Subsystem
	Component

Potential Failure Model and Effects Analysis (Process FMEA)

Responsible Engineer	
Date	

FMEA Number	
Revision	

Notes

(7.1) Item / Function	(7.2) Requirements	(7.3) Potential Failure Mode	(7.4) Potential Effects of Failure	(7.5) CLASS	(7.6) Potential Causes / Mechanisms of Failure	Existing Conditions						(7.13) Recommended Actions	(7.14) Responsibility & Target Completion Date	Action Results				
						(7.7) Current Design Controls Prevention	(7.8) Current Design Controls Detection	(7.9) OCC	(7.10) SEV	(7.11) DET	(7.12) RPN			(7.15) Actions Taken	(7.16) OCC	(7.17) SEV	(7.18) DET	(7.19) RPN
											0							0
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42 F243 – Engineering Discussion Template

F243 - Engineering Discussion Template	
Document No: Customer:	Order No: ISSUE: 1
CREATED DATE:	APPROVED DATE:
CREATED BY:	APPROVED BY:
Project:	
Present:	Copies: C.C Project File

Form No: F243
Form Issue: 1
Form Date: 10/07/2020

OFFICIAL

Page 1 of 1

43 F409 – Standard Machine Colours

OFFICIAL

F409 - Standard Machine Colours

Doc. Number	F409 – Standard Machine Colours	**Issue**	01
Author		**Date**	23/02/2021
Department	Engineering	**Total pages**	4

	Print Name	Sign	Date
Prepared By:			
Reviewed By:			
Approved By:			

Document: F409 – Standard Machine Colours
Issue: 1
Date: Month 02/03/2021
OFFICIAL
Page 1 of 4

Amendment History

Issue	Amendment	Author	Date
1.0	First Issue		

OFFICIAL

1 Machine colours

Product Group	Colour Index		RAL Colour	Component Examples
Systems	Fixed Parts	A1	7016	FWM Base, Steel constructions, deposit frames, worker platforms, tool plate base stands, Tie Bars, etc.
	Moving Parts	A2	7011	Automated guided vehicles (AGV), multi-purpose vehicle (MPV), moving positioning devices, etc.
Bought Out Components	Electrical Components	C1	As Supplied	FWM Head Motor, Servo and Lubrication Motors, Hydraulic Power Pack Motors, Air Conditioner, etc.
	Hydraulic Cylinders	C2	Matt Black	FWM Forge Cylinders, FWM Clamp Cylinders, etc.
Mechanical Components	Fixed Parts	D1	7035	Clamp Base,
	Moving Parts	D2	7035	Flash Removal Unit
Electrics	Fixed Parts	E1	7035	Control cabinet, Junction Boxes, etc.
	Moving Parts	E2	7035	Operator console, Control Pendant, Control Panel etc.
	Fixed Parts	E3	7042	Cable Ducting.
Hydraulic Components	Hydraulic Parts	G1	7035	Hydraulic Power Pack, Supports, etc.
	Hydraulic Pipework	G2	Natural	Pipework, Valves, etc.
Guarding	Machine Guards	H1	1021	FWM Clamp Guard, Chuck and Pulley Guards,
	Moving Perimeter Guards	H2	1021	Solid & Mesh Perimeter Guarding Doors, Etc
	Fixed Perimeter Guards	H3	7035	Safety fence columns & posts, cabinet column, perimeter guarding solid & mesh, etc.
Tools, fixed	Fixed Parts	W1	7035	FWM Head, Tool plates, pedestals, building blocks, transformer mounting, etc.
	Moving Parts	W2	7011	Swiveling pedestals or superstructures, toggle levers, slide superstructures, etc.

Tools, moving	Fixed Parts	**W3**	7011	Tool plates, brackets, building blocks, trans-former mounting, etc.
	Moving Parts	**W4**	7011	Swiveling pedestals, toggle levers, slide super-structures, etc.

44 F411 – Switch List Template

Form No			F411 - Switch List Template
Form Date			23/03/2021
Form Rev			1
CONTRACT No.			
CUSTOMER			
PROJECT DESCRIPTION			
Rev	**Engineer**	**Date**	**Details**

Form No	F411 - Switch List Template							
Form Date	23/03/2021							
Form Rev	1							
CONTRACT No.								
CUSTOMER								
PROJECT DESCRIPTION								
Machine Mounted								
DESIGNATION	VIS NUMBER	VOLTAGE	AC/DC	DESCRIPTION	MAKE AND REFERENCE	PURPOSE	DRAWING NUMBER	QTY
WELDER								
TRANSDUCER LIST								

Form No	F411 - Switch List Template								
Form Date	23/03/2021								
Form Rev	1								
CONTRACT No.									
CUSTOMER									
PROJECT DESCRIPTION									
Machine Switches 1									
DESIGNATION	VIS NUMBER	VOLTAGE	AC/DC	DRAWING NUMBER	DESCRIPTION	MAKE AND REFERENCE	PURPOSE	DRAWING NUMBER	QTY
WELDER									
SWITCH LIST									

45 F413 – Design Brief Template

Design Brief

Project number	
Project title	
Project description	
Customer / Employer	

Doc. Number		**Issue**	01
Author		**Date**	
Department	Engineering	**Total pages**	x

	Print Name	Sign	Date
Prepared By:			
Reviewed By:			
Approved By:			
Acceptance By:			

Document: F413 - Design Brief Template
Issue: 1
Date: March 2021
Page 1 of 9

Amendment History

Issue	Amendment	Author	Date

Contents

1 Overview

This Specification defines the requirements for the detail design and supply of XXXXX and associated equipment.

This Specification describes the mechanical, control and electrical assemblies required to successfully deliver both the functional and, technical requirements set-out in this document. This document provides the appropriate level of detail to support the company with all required activities associated with their ***scope of work***. These activities can generally be categorised as:

- **Complete the Manufacturing Design.**
- **Procurement of materials, components and assemblies.**
- **Manufacture, fabrication and assembly.**
- **Inspection, Integrated Testing and Verification of the completed Systems.**
- **CE Marked**
- **Installation at XXXXX.**

The company shall review and evaluate the design to ensure that it satisfies all of the requirements stated within this Technical document. Where identified, the company shall inform **XXXXX** of potential deficiencies with the design as soon as they become aware of any issue. The company shall also highlight any potential opportunities for improvement such that they can be evaluated by **XXXXX**.

If the company observes that this specification has any anomalies, ambiguities, flaws, errors or omissions they shall forthwith bring them to the attention of **XXXXX**. This Technical Specification shall be read in conjunction with all documents referenced.

Note: This specification is to be read in conjunction with the company Quotation – **XXXXX**

2 System Description

Add description, requirements & any assumptions based from the Quote, etc, here.

2.1 System Flow Diagram

3 Customer Product Specification

3.1 Customer Component List

It is assumed that the following list of documents are final frozen issue. Therefore all designs will be based off these documents, if any changes are implemented, the customer should be aware that costs or delays to programme resulting from this will be charged to the customer.

3.2 Component Parameters

Compnent Type:	Component X	Component XX	Finished Assemblies:
Maximum Diameter:			
Minimum Diameter:			
Maximum Length:			
Minimum Length:			
Maximum Wall Thickness:			
Minimum Wall Thickness:			
Material:			

3.3 Friction Weld Area

3.4 Post Weld Accuracy

4 Customer Service Requirements

XXXXXX - Service Requirements	

5 Calculations

- Load cases to be assessed by Engineering to substantiate all designs.
- Engineering will assess the weight of all major items required for specifying lifting equipment.
- All calculations to be carried out in accordance with BS 2573 – Rules for Design of Cranes.
- All calculations to be produced in MathCAD and/or FEA.

Note: No Calculation Reports will be issued as part of this contract.

6 Materials

All equipment and materials shall be new and shall comply with this Specification, the relevant British Standard and all other standards.

7 Design and Operational Life

The equipment shall be designed such that the equipment can be maintained or replaced as appropriate in order to provide a XX-year design life.

xx°C - xx°C Ambient Temperature

All equipment shall be suitable for connection to and operation in an industrial environment as categorised above.

8 Testing

8.1

8.2

9 Machine colours

10 References

Document / Drawing Number:	Title:	Revision:
	Quote:	

11 Layout

Example Plan View Cell Layout for reference.
Note: Layout may change as detail design is undertaken.

12 Regulations, Codes and Standards

Document Reference	Title
P10	Design Procedure
SOP065	Drawing Office Standard Procedure
CDM	Construction (Design & Management) Regulations 2015
HASWA	Health and Safety at Work Act 1974
2006/42/EC	Machinery Directive 2006/42/EC
S.I. 1989 No. 635	Electricity at Work Regulations 1989
2014/30/EC	EMC Directive 2014/30/EC – Valid from 20/04/2016
BS 89	Direct Acting Indicating Electrical Measuring Instruments and their accessories
IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems
BS 8888: 2017	Technical product documentation and specification
BS EN ISO 13850:2015	Safety of Machinery: Emergency Stop function, Principles for design
BS EN ISO 13849-1:2015	Safety of Machinery: Safety related parts of control systems, Principles of design
BS EN ISO 12100:2010	Safety of Machinery: General principles of design, Risk assessment & risk reduction
BS 7671	Requirements for Electrical Installations (IEE Wiring Regulations 17th Edition)
BS 7430:2011	Code of practice for protective earthing of electrical installations
BS EN 60073:2002	Basic and Safety Principles for Man-machines interface, marking and identification
BS EN 60204:2006+A1:2009	Safety of Machinery, Electrical Equipment of machines

46 F419 – Design Review Questionnaire

F419 - Design Review Questionnaire

Project number	
Project title	
Project description	
Customer / Employer	
Client	

Doc. Number		**Issue**	
Author		**Date**	
Department		**Total pages**	X

	Print Name	Sign	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By:			

Form No:419
Form Rev: 01

Form Date: 25/06/2019

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Contents

Glossary of terms and abbreviations

Term or abbreviation	Definition
LTR	Lifetime Records
QCP	Quality Control Plan
QP	Quality Plan
FDS	Functional Design Specification
SSC	Systems, Structures, Components

Endorsement / Signature List

Name	Organisation	Position	Signature

1 Design Review Questionaire

Keyword:	Suggested Questions:	Y / N	Comments:
Fit for Purpose	Is the design fit for purpose?		
Experience	Does the design reflect the learning from other projects and have Learning From Experience (LFE) records been reviewed?		
Optioneering	Has appropriate optioneering taken place, e.g. what options have been considered / ruled out and what criteria was used?		
Requirements	Does the design meet the stated project, area or system requirements? Have all requirements been validated? Is there a verification plan that is being actively addressed?		
Base Assumptions	Are the base design assumptions clearly defined, to allow re-verification after detail design is complete?		
Design Basis	Does the current design comply with the declared design basis and with previous estimates / tenders?		
Health & Safety	Is the design in accordance with KSUK's Health & Safety Policies?		
Environment	Does the design minimise direct and indirect effects on the environment? (Include choice of materials and energy use) Is the design sustainable?		
Standardisation	Are standard components used where possible?		
Cost Estimate	Has the design been developed to an appropriate degree to support the development of a cost estimate?		
Innovation	Does the design make appropriate use of innovation?		
Internal / External Hazards	Have all relevant external and internal hazards been considered in design?		
Critical Element	Is there any single element which, if it failed, would result in a severe or disproportionate consequence?		

Engineering Hold Points	Is there a risk of delay while activities are completed, e.g., design, development or equipment delivery?		
Interfaces	Does the design consider interfaces between disciplines, organisations and operational facilities?		
Standards	Have appropriate codes and standards (for engineering and QA) been used in design and specified for construction?		
ALARP	Is it reasonably practicable to reduce risks further? Does the design go beyond what is reasonably practicable?		
Risk Reduction Heirachy	Have hazards been eliminated at source if possible, risks then been minimised, and protection provided as a last resort?		
Lifetime Costs	Does the design minimise capital cost or lifetime cost?		
Local Environment	Does the design allow for local external environment (temperature, humidity etc.)? Are internal conditions appropriate?		
Complete Systems	Are process and services systems laid out to facilitate commissioning and maintenance of complete systems?		
Toxic Materials	Does the design require use of toxic or hazardous (explosive, etc) materials? Can these be eliminated?		
Chemotoxic release	Does the design create a risk of release of chemicals which may seriously harm operators or the public (COMAH)?		
Noise & vibration	Does the design ensure that high noise and vibration levels are controlled so far as is reasonably practicable?		
Programme	Is the design programme complete and reasonable?		
Radiation	Does the design minimise both public and worker exposure to radiation in operation, maintenance & decommissioning?		
Operating Hold Points	Are there points where plant operation stops pending clearance? Can these be safely designed out? Omissions?		
Processes	Are operating and manufacturing processes suitable for the application?		
Material Movement	Has the need to transport material around the process been minimised?		

Reset	If the system needs to be reset between product runs, is the reset time minimised?		
Explosive Atmosphere	Are areas where explosive atmosphere may occur correctly designated and minimised in extent?		
Fire	Has fire prevention been considered?		
Accident conditions	To what extent will the design work as intended following an accident?		
Recovery	Does the design provide for timely recovery from faults and retrieval of equipment which has failed in service?		
Contamination	Which areas of the facility are liable to contamination? Are there provisions for decontamination?		
Safeguards	Does the design require consideration of IAEA safeguards?		
Specialist advice	Does the design require specialist knowledge not available in KSUK?		
Design Substantiation	Does the design require submission of design substantiation reports? Who is responsible for their production?		
Legislation	Does the design meet all the requirements of relevant laws in all relevant jurisdictions?		
Inspection	Does the design provide access for in service inspection?		
Maintenance	Does the design make adequate provision for safe & efficient maintenance? Are components interchangeable?		
Lifetime	Has the required system life been defined, does the design provide this life and how is deterioration monitored?		
Services	Are all services available to the quantity and reliability required? Is usage minimised?		
Comprimises	Have design compromises been made following clashes between disciplines or systems? How were decisions made?		
Research & development	Has sufficient research & development been done to substantiate the system? If not, are assumptions conservative?		

Special Requirements	Are there any special requirements as a result of the design (long delivery, novel materials or procurement routes, etc.)?		
Parts & Materials	Are materials, parts & equipment suitable for the application?		
Value for Money	Does the design represent value for money (capital and lifetime)? Has a programme of Value Improving Practices been considered and completed?		
Suppliers	Have suppliers been identified? If so are they capable of delivering and do they support KSUK's EH&S policy?		
Contract	Is the contract strategy consistent with the design – are design risks in place?		
Manufacture	Can the design be manufactured safely and efficiently?		
Construction	Does the design assist safe and economic construction?		
Installation	Does the design make adequate provision for safe and efficient installation?		
Commissioning	Does the design allow for safe and efficient commissioning?		
Operability	Has design included human factors and operational research, and are design minimum manning levels clearly stated?		
Stored energy	Could stored energy (pressure, gravity, kinetic, rotational, etc) cause injury, damage or inappropriate operation?		
Fail Safe	Do SSC (Systems, Structures, Components) important to safety fail safe? If not, are defects tolerated and is failure gradual and detectable?		
Safety Systems	Are safety systems independent of control systems and protected from the incidents which they protect against?		
Access	Is unauthorised access to safety systems and hazardous areas prevented?		
Operator Information	Is instrumentation sufficient to ensure operators are aware of plant state, changes, effect of actions & accidents		

Leak Detection	Does the design provide for detection, location, management and monitoring of leakage from primary containment?		
Models	Is the design supported by physical or computer models, if necessary? Are such models soundly based and validated?		
Site Investigation	Is the design of foundations and earthworks based on comprehensive and properly conducted site investigation?		

2 Conclusion

F436 – Performance Acceptance Criteria

F436 – Performance Acceptance Criteria

Customer:		Order No:	
DOCUMENT NO: F436		ISSUE: 01	
CREATED DATE:		APPROVED DATE:	
CREATED BY:		APPROVED BY:	
Machine Capacity			
Criteria	**Specified in Sales Quote**	**Achieved**	**Test Methodology**
Maximum Forge Force.	1013kN		Taken from HMI.
Maximum Spindle RPM.	630rpm		Taken from HMI.
Maximum Pre-welded Clamped Component Length.	2700mm		Physical Measure (from stick out from clamp to max backstop position).
Minimum Pre-welded Clamped Component Length.	1400mm		Physical Measure (from stick out from clamp to max backstop position).
Maximum Chuck Opening Achieved (L.H).	105.8mm		Physical Measure of opening of jaws to M/C centreline.
Minimum Chuck Opening Achieved (L.H).	101mm		Physical Measure of opening of jaws to M/C centreline.
Maximum Chuck Opening Achieved (R.H).	105.8mm		Physical Measure of opening of jaws to M/C centreline.
Minimum Chuck Opening Achieved (R.H).	101mm		Physical Measure of opening of jaws to M/C centreline.
Maximum Clamp Opening Achieved (L.H).	480mm		Physical Measure of opening of jaws.
Minimum Clamp Opening Achieved (L.H).	300mm		Physical Measure of opening of jaws.
Maximum Clamp Opening Achieved (L.H).	480mm		Physical Measure of opening of jaws.
Minimum Clamp Opening Achieved (L.H).	300mm		Physical Measure of opening of jaws.
Maximum Clamp Position Achieved (L.H)	1265mm		Physical Measure of clamp position to M/C centreline.
Minimum Clamp Position Achieved (L.H)	480mm		Physical Measure of clamp position to M/C centreline.
Maximum Clamp Position Achieved (R.H)	1265mm		Physical Measure of clamp position to M/C centreline.
Minimum Clamp Position Achieved (R.H)	480mm		Physical Measure of clamp position to M/C centreline.

Maximum Upper Bung Position Achieved	250mm		Physical Measure over jaws.
Minimum Upper Bung Position Achieved	232mm		Physical Measure over jaws.
Maximum Lower Bung Position Achieved	186mm		Physical Measure over jaws.
Minimum Lower Bung Position Achieved	169mm		Physical Measure over jaws.
Roller Steady Range	--mm to ----mm		Physical check.
Number of Roller Steadies	----- x Tie-Bar mounted ----- x Machine mounted		Confirm Quantity.
Flash Removal Stroke (Vertical)	---mm		Physical check & HMI.
Flash Removal cutting tool reaches centre of component			Physical check.
Flash Removal Stroke (Horizontal)	---mm		Physical check & HMI.
Shear Flash Removal Cutting Position Achieved	Yes/No		Yes/ No
Shear Flash Removal Home Position Achieved	Yes/No		Yes/ No
Backstop Stroke	--mm		Physical check.
Head Stroke (L.H)	1250mm		Physical check & HMI.
Head Stroke (R.H)	1250mm		Physical check & HMI.
Load Orientation	Yes/ No		Yes/ No
Weld Accuracy / Metallurgy Results			
Criteria	**Specified in Sales Quote**	**Achieved**	**Test Methodology**
TIR Results	0.25mm		Physical Measure.
Length Control (Tolerance)	+/- 0.5mm		Physical Measure.
Angle between axes of welded component	0.10mm/ 100mm		Physical Measure.
Weld Orientation	+/- 2°		Physical Measure and compare to HMI.

Bend Test Results			Pass / Fail (Data from Metallurgy Department).
External Flash Removal Profile			Yes/ No
Internal Flash Verification			Yes/ No
Miscellaneous			
Criteria	**Specified in Sales Quote**	**Achieved**	**Test Methodology**
Collision Checks: Chuck against Clamp etc.			Physical Check.
Component Marking			Physical Check.
HMI Language	English		Physical Check.
Cycle Time (seconds)	---s		Physical measure on available components.
Tooling change time	---min		Physical Measure on available Tooling.
Chuck Tooling fitment check	YES		Physical Check.
Clamp Tooling fitment check	YES		Physical Check.
Backstop Tooling fitment check	YES		Physical Check.
Bung Tooling Fitment Check	YES		Physical Check.
External Flash Removal functionality check	YES		Physical Check.
Internal Flash Removal functionality check	YES		Physical Check.
Swarf conveyor functioning	YES		Physical Check.
All backstop positions working	YES		Physical Check.
Check Catch-pot can do component length range	YES		Physical Check.
Check Catch-pot is functioning correctly.	YES		Physical Check.
Check fume extraction is functioning correctly.	YES		Physical Check.
Test Engineer Print Name			
Test Engineer Sign Name			

Fit and Finish (Painting etc.)			
Fit and Finish (Painting etc.)	Visual checks required on completion of FAT		Visual Inspection
Test Engineer Print Name			
Test Engineer Sign Name			
Lead Engineer Print Name			
Lead Engineer Sign Name			
Project Manager Print Name			
Project Manager Sign Name			
Any criteria that don't require testing should be greyed out to prevent confusion.			

47 F491 – New Feature Test Requirements

F491 - New Feature Test Requirements

Project number	
Project title	
Description	
Customer / Employer	
Client	

Doc. Number		Issue	
Author		Date	
Department			

	Print Name / Position	Signature	Date
Prepared By:			
Reviewed By:			
Approved By:			
Customer Acceptance By			

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AMENDMENT HISTORY

Issue	Amendment	Date
1	First Issue	

1 Introduction

The following test plan is a detailed document that outlines the test strategy, objectives, resources needed, schedule and success criteria for testing a new feature. The main objective is to dicsover any defects or errors that might cause the feature to not act as intended and provide a bad experience for the end user.

2 Description of Equipment

F491 - New Feature Test Requirements	Test Plan		
Responsible Engineer		Test Number	eg, Contract number / date / 001
Date Document generated			
Test Engineer			
Test Date			
What exactly are you testing?	**Example**	**Data for actual test**	
Objective	Introduction, what do you want to achieve?		
Scope	What do you intend to test and why?		
Schedule	How long will the total test take?		
How are the tests to be carried out?	**Example**	**Data for actual test**	
Rules	Are there any rules or procedure for the tests that should be followed?		
Metrics	What metrics should be collected?		
Environment	Should the test be undertaken in different environments?		
Special Requirements	Are there any special requirements that should be tested?		
Exit Criteria	When is it OK to stop testing a feature an assume the feature is successful?		
Suspension Criteria	When should you pause a test? Is there a threshold of errors where you should stop testing and look for solutions?		
Resumption Criteria	How do you know when to resume a paused test? What are the steps for restarting testing?		
Risks and Assumptions	What do you assume will happen and are there any risks?		
Resource	What resource is required for the test? Human and equipment.		
What are the desired outcomes?	**Example**	**Data for actual test**	
Deliverables	What are the required test deliverables and how do you want it presented? Test reporting.		