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The Lean Link: Exploring Industry 4.0's Influence on Sustainable Operational Performance for Services

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Abstract:	

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Abstract

Purpose: This empirical study explores the intricate relationships between Industry 4.0 (I4), Lean practices, and sustainable operational performance (SOP) within the dynamic context of the services sector. Rooted in the theoretical framework of Resource Orchestration Theory (ROT), the research investigates the nuanced interplay between these paradigms and their collective impact on firm performance.

Design/methodology/approach: The research methods included creation of a structural model, hypothesis formulation, and advanced data analysis. Primary data were gathered through an online questionnaire distributed among service sector professionals. Analysis was completed using Partial Least Squares (PLS) Structural Equation Modeling (SEM) using the smart-pls software.

Findings: The results underscore the mediating role of Lean practices between I4 and SOP, emphasizing the imperative of harmonized integration to enhance overall firm performance. In alignment with ROT principles, the study illuminates the positive influence of Lean practices on sustainable operational outcomes.

Research implications: The study contributes to the scholarly discourse on I4, Lean, and Services, emphasizing the strategic necessity of integrating I4 capabilities with Lean practices. Practical insights guide practitioners in orchestrating a balanced adoption of Industry 4.0 and Lean practices for sustainable operational performance. This research offers actionable insights for industry leaders seeking to cultivate sustainable operational performance within their organizational contexts.

Originality/value: This study contributes to the evolving understanding of the interplay between Industry 4.0, Lean practices, and sustainable operational performance within the services sector, offering novel insights for both academia and industry practitioners.

Keywords – Lean, Industry4.0, Service Operations, Sustainability, Resource Orchestration Theory

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1.0 Introduction

Industry 4.0 (I4), first conceived by a German think tank (Lasi et al., 2014) is the collective term used for IT driven changes bringing out far reaching consequences for the industry. It comprises of new age technologies such as artificial intelligence, cloud, IoT (Internet of things), robotics, machine learning, smart factory, cyber physical system etc.(Shahin et al., 2020; Sony & Naik, 2020).

Also called as the 4th Industrial revolution, Industry 4.0 has ushered in a sea change spanning across engineering, business administration and information management systems (Lasi et al., 2014). The deep technological prowess has enabled firms to be super fast, efficient as well as seamlessly connected within the end to end supply chain. I4 has multiple advantages including enhanced quality, decreased cost and delivery time, and higher flexibility and efficiency (Iarovyi et al., 2015; Moeuf et al., 2018). According to a McKinsey report, I4 has the potential to improve labor productivity by 15-30%, throughput by 30%, reduce downtime by 30-50% and costs of quality by 20% (Ewelina Gregolinska et al., 2022)

The influence of the I4 generated developments is not just restricted to technological changes but furthermore have organization wide implications including areas such as strategy and human resource development (Fettig et al., 2018; Lasi et al., 2014). The entire economic environments, including customers and society are getting altered with this wave of digitization (Bilan et al., 2019; Brettel et al., 2014; J. Lee et al., 2014). I4 is also influencing social sustainability, policy deployment as well as governance across the world (Bai et al., 2022; Grybauskas et al., 2022; Hussainey et al., 2022; Kaur et al., 2022; Nikonenko et al., 2022).

Benefits from of I4, thus are realised beyond the manufacturing sector. The services sector is also equally getting transformed as a result of the widespread availability of Industry 4.0 technological advancements. Many traditional services companies are getting morphed into "technology companies" as a result of these changes. Banks, Healthcare, Insurance and other financial services, Transportation, Hospitality are some of the sectors where this change has started becoming visible. Many large established banks such as Citibank[1], JP Morgan[2], Deutsche Bank[3], ING[4] and other have started to call themselves as a "technology company with a banking license". Given that Services now account for 67% of global GDP and account for more than 51% of employment (The World Bank, 2022), it is imperative to study the transformation that the services sector is going through as result of I4.

There is limited literature published on application of I4 tool and technologies in the services environment. The existing studies are about I4 deployment in either Industrial Services sector as a spill over from manufacturing (Bonamigo & Frech, 2020; Lim et al., 2016) or about supporting services of a manufacturing firm such as supply chain and logistics (Cichosz, 2018). Scholars have also looked at Servitization within the manufacturing domain along with I4 (Chiarini et al., 2020; Frank et al., 2019; Grandinetti et al., 2020; Paiola et al., 2021)

[1] https://www.citigroup.com/citi/news/executive/140225Ea.htm
[2] https://www.businessinsider.in/finance/jpmorgan-we-are-a-technology-company/articleshow/51111115.cms
[3] https://www.db.com/newsroom_news/2016/ghp/september-message-to-employees-from-john-cryan-en-11679.htm
[4] https://www.ing.com/Newsroom/News/We-want-to-be-a-tech-company-with-a-banking-license-Ralph-Hamers.htm

A comprehensive bibliometric analysis by (Mariani & Borghi, 2019) studied more than 700 academic articles and concluded that there are not many studies conducted to explore the impact of I4 technologies in pure services sector and the research on I4 for services can be said to be at "very embryonic stage"(Mariani & Borghi, 2019).

As a part of this paper, we plan to address this by formulating the first research question –

RQ 1 – How does the Industry4.0 technologies impact the services sector firm performance?

Inspired by the "Toyota Production System" Lean as a concept was first introduced in the famous book "The machine that changed the world" (Womack et al., 1990). Lean on one hand can be defined as a methodology focused on the customer while on the other as systematic method to eliminate waste and enhance value (S. Gupta et al., 2016). Lean practices have provided significant benefits to industries over the last two to three decades. (Li et al., 2005; Shahin et al., 2020; Staats et al., 2011). While Lean as a concept was developed for and gained mass popularity for manufacturing, with the advent of service dominant economy, Lean has also been adopted feverously by service industry (S. Gupta et al., 2016). Several researchers have studied the application of Lean for services across multiple services domains such as insurance (Sandner et al., 2020), banking (Sunder M et al., 2019) , healthcare (Antony et al., 2019) , hospitality (Rauch et al., 2020), education (Cudney et al., 2020), telecom (Shamsuzzaman et al., 2018), airlines(Syltevik et al., 2018), retail, software (Griffin, 2021) and other IT enabled services (E.V. et al., 2019). Lean practices are also analysed for their impact on sustainable operational performance by researchers (Klein et al., 2022; Mohaghegh et al., 2021).

There are many studies available in literature where an implementation of Lean methodology along with I4 tools have been studied. These studies have covered various dimensions of the phenomenon such as sequence of adoption of the two methodologies (Satoglu et al., 2018) and the impact on performance (S. Kamble et al., 2020; Khanchanapong et al., 2014; G. Tortorella et al., 2021; G. L. Tortorella et al., 2019). Multiple studies have also evaluated relationships and interdependencies between Lean and I4 (Dombrowski et al., 2017; G. Tortorella et al., 2018; Varela et al., 2019).

Both I4 and Lean are methodologies comprising of various tools and methods aimed to improve performance or solve a business problem. These tools have been studied to understand the application of each Lean tool with I4 technology and how the two can be combined (Mayr et al., 2018; Mrugalska & Wyrwicka, 2017; Satoglu et al., 2018; Shahin et al., 2020).

There are also a few meta studies/ literature reviews that have studied the existing literature about the relationship, interaction and impact of Lean and I4 together in organizations (Buer et al., 2018; Ejsmont et al., 2020; Ejsmont & Gładysz, 2020; Mariani & Borghi, 2019; Shahin et al., 2020; Varela et al., 2019).

All of these studies have only looked at the phenomenon using a manufacturing lens. For example, a detailed literature review of academic publications on Lean and Industry 4.0 has been conducted by Ejsmont et al. (Ejsmont et al., 2020), while the search terms used by the authors did not specify production or manufacturing, all the articles included in the study pertained only to manufacturing setup. Similarly, another review study conducted by Danese et al (Danese et al., 2018), studied literature on Lean from 2003 to 2015 and identified only 11% studies were covering services. Even from the 24 studies on Lean in services, there were no empirical study and all the covered research was based on case studies.

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Thus, there is this gap in academic literature on interaction of Lean and Industry 4.0 for services. As per our current understanding, there is a lack of empirical research examining the relation between Lean and I4 in the services sector. Using the existing literature on I4 and Lean for services, we intend to develop and validate a research model to investigate this relationship. We intend to address this with our next research question.

RQ 2 – What is the complex interrelationship among the industry 4.0, Lean, and organization performance? How do I4 and Lean together impact the organizational performance with respect to services firms?

Subsequently in this paper, section 2 covers theoretical background and proposed hypothesis. Section 3 has the details on research methodology. The results from data analysis are included in section 4 and finally, the last section has academic and managerial implications along with the limitations before presenting the conclusion.

2.0 Theoretical Background & Hypothesis development

2.1 Industry 4.0 for Services

"Industry 4.0" initiative was envisaged with an objective to enhance the long-term competitiveness of manufacturing sector in Germany. With focus on cyber physical system and smart manufacturing, it is only natural that most of the early adoption and discussion about this phrase was centred around manufacturing.

The development of new and innovative technologies, emergence of associated computing power and supporting infrastructure was however sector agnostic. These developments have equally influenced other sectors as well. The developments in telecommunication - 3G, 4G and now 5G network availability assisted many organizations to offer innovative solutions, specially in B2C segments. Cheaper access to mobile phone and availability of fast internet connectivity has enabled customer reach with elimination of middle man for many B2C organizations.

Powered with cloud computing, artificial intelligence and machine learning services companies are now able to scale up faster, become efficient and delight their customers. Use of tools like Virtual Reality (VR), Artificial Reality (AR) and the upcoming Metaverse, the line between real and virtual is blurring. Beside being deployed in gaming and shopping, these tools also find relevance in improving medicine (assisting in surgery), improving training and reduce risk of accidents. Big data and analytics are enabling all firms, including services organizations to do better customer segmentation, execute targeted marketing and realize faster and efficient growth. In addition, the insights are helping services operations improve their decision making across areas such as credit/insurance underwriting, differentiated customer service and prevention of errors/defects.

Another set of revolutionary technologies that is challenging the status quo and has the ability to take down established institutions is Blockchain (BC). The distributed ledger concept of blockchain facilitates faster, low cost and efficient transaction processing besides improved trust and transparency in the system.

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Table 1: Industry 4.0 Technologies in Service Industry

Technology	Impact	Sources
AI, ML, NLP	Faster processing, error reduction, optimize effort, quality improvement	(Blöcher & Alt, 2021; Bock et al., 2020; Flavián & Casaló, 2021; Huang & Rust, 2018; Nuruzzaman & Hussain, 2018; Puntoni et al., 2021)
Cloud, Digital	Efficiency, Interconnected systems, seamless flow of information and data, sustainable operations, 24x7 availability for customers	(Bogataj Habjan & Pucihar, 2017; D. Chen, 2022; X. Chen et al., 2022; Lee Ya Ching, 2019; Y. Liu et al., 2020)
AR/VR, Metaverse	Assist in complex manual work (eg medial surgery), Reduced training costs, time and effort, reduced risks	(Buhalis et al., 2022; Ivanova, 2018; C. W. Lee, 2022; Moriuchi et al., 2021; Ronaghi & Ronaghi, 2022)
Big Data / Analytics	Enhanced customer experience (personalization, segmentation) Improved forecasting and decision making (underwriting), defect prevention	(Attaran & Attaran, 2018; Cohen, 2018; Dezi et al., 2018; Mariani & Baggio, 2022; Santoro et al., 2019)
Block Chain	Improved transparency, trust & controls, lower transaction costs, faster & efficient process (eliminating middle man)	(Fiergbor, 2018; Kar & Navin, 2021; Karamchandani et al., 2020, 2021; Mettler, 2016; Pal et al., 2021; Wang, 2022)

2.2 Role of Technology in Lean for Services

Typically, the approach towards Lean deployment at a local level covers a detailed process study (also called as "value stream mapping") and identification of "waste" or opportunities for improvement. Solutions to address these identified opportunities are then designed and implemented by the project team.(Zepeda-Lugo et al., 2020) .Traditionally, these solutions had very little technology play, however, increasingly the solutions deployed are technology based. For example, to reduce errors in data entry, using mistake proofing (Poka-Yoke a Lean tool), the Lean project teams are utilizing an IT automation which prevents incorrect data instead of a traditional, less effective approach of using a checklist for the operator.

Similarly, at the macro level, Lean with its focus on reducing complexity and enhancing customer value add, can leverage digital and technology through the systematic methods and tools in its arsenal. (Santhiapillai & Ratnayake, 2020)

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Technology and specifically the latest breed of tech solutions from I4 can enable deployment of Lean in services organization as well. There is evidence of such impact available sporadically in the recent literature on Lean in services. A recent review of literature by Tlapa et al (Tlapa et al., 2022) covered studies about application of Lean along with digital interventions in healthcare industry. Automation, simulation, digital workflow and virtual modelling were the prime technologies that came up in the 28 studies that came up in the review. The benefits realised included improvement in TAT (Turn around time) across various processes, improvement in patient's length of stay and waiting time. A summary of such studies is included in Table 2.

Table 2 – Applying Lean and Technology Across Services

Domain / Industry	**Impact**	**Tech Tool**	**Source**
Healthcare	Improved cycle time (TAT), patient's length of stay and waiting time	Cloud based communication, Digital workflow, Automation, simulation	(Garza-Reyes et al., 2019; Ortiz-Barrios & Alfaro-Saiz, 2020; Recht et al., 2019; G. L. Tortorella & Fettermann, 2017; Tsai et al., 2021; Wannemuehler et al., 2015)
IT Services	Productivity Improvement,	Process Digitization	(Freitag et al., 2018)
Sales & Service	Lead time, productivity	Process Digitization	(Santhiapillai & Ratnayake, 2020)
Financial Services	Effective decision making,	Artificial Intelligence, Machine Learning, Process Digitization and Automation	(Boute et al., 2022)
Hospitality	Efficiency Improvement	Digitization	(Rauch et al., 2020)

Many other researchers have examined the presence of Lean along with digital technologies and observed that organizations on a path towards continuous improvement using Lean can achieve greater success when embracing digitization and other similar technologies (Boute et al., 2022; G. L. Tortorella et al., 2022). In fact, despite all the excitement around technology, researchers have also come across failure of generating significant benefits through technology deployment in absence of structured processes, which can be delivered through an initiative such as Lean. (Bortolotti & Romano, 2012; Chiarini & Kumar, 2020; Nicoletti, 2013; G. L. Tortorella & Fettermann, 2017).

2.3 Theoretical lens: Resource Orchestration Theory

Resource Orchestration Theory (ROT) builds upon the foundation of the Resource-Based View (RBV) and introduces a dynamic perspective to the interactions between resources, emphasizing the critical role of resource

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combinations in establishing and sustaining competitive advantage. In contrast to the RBV's focus on the mere presence of valuable resources, ROT asserts that the manner in which resources are orchestrated and coordinated holds equal importance in creating value. Pioneered by Sirmon et al. in 2011, ROT underscores the significance of managerial capabilities in effectively orchestrating resources within a firm, positing that the firm must possess the requisite competencies to coordinate and manage its resources optimally (Sirmon et al., 2011).

The essence of ROT lies in understanding "how" resources are utilized or orchestrated to gain a competitive edge. The alignment and synergy among multiple resources are posited as the bedrock for a firm's competitive advantage (H. Liu et al., 2016). Extending this theoretical framework, scholars have found ROT particularly pertinent in deciphering the deployment of Information Technology (IT) capabilities (Gligor et al., 2022; Zhou et al., 2017) . In alignment with this conceptualization, we contend that Lean practices, functioning as a crucial aspect of resource orchestration, facilitate organizations in realizing the full potential of resources, particularly in the context of Industry 4.0.

Lean practices, recognized for their culture and people-centric orientation, assume a pivotal role in resource orchestration. They empower managers to adeptly structure and bundle diverse resources, thereby attaining a competitive advantage(Reynders et al., 2020). By fostering a culture of continuous improvement and employee involvement, Lean practices not only optimize operational processes but also align organizational resources synergistically. This alignment is instrumental in enabling firms to harness the benefits of resources such as those embedded in Industry 4.0 technologies. Thus, Lean practices act as a facilitator, ensuring that the orchestrated deployment of resources aligns with the principles and objectives espoused by ROT, ultimately contributing to sustained competitive advantage in the ever-evolving business landscape.

2.4 Hypothesis Development

Industry 4.0 technologies are transforming the service industry by enabling companies to streamline operations and improve efficiency using automation, faster customer service and effective decision making. By adopting these I4 technologies, service companies can optimize their processes and reduce waste, which are key principles of Lean service delivery. This can lead to increased efficiency, improved service quality, and enhanced customer satisfaction. Lean deployment in services is also closely aligned with achieving these objectives by eliminating non value add and wastes and enhancing customer experience. Hence we argue,

H1 : Adoption of I4 in service sector positively influences the Lean practices deployment

Lean practices have been shown to positively impact financial, social, and environmental outcomes, thus contributing to sustainable operational performance (SOP), also known as triple bottom line (TPL). Going beyond mere financial outcomes, TPL is a widely accepted measure of performance. Environmentally, Lean practices have been shown to reduce waste, energy consumption, and greenhouse gas emissions within services (Dieste & Panizzolo, 2018; V et al., 2016). Socially, Lean practices can improve employee well-being, job satisfaction, and empowerment by involving employees in improvement activities, providing training, and promoting a culture of continuous improvement (Beraldin et al., 2019; Kilroy & Flood, 2021). Lean practices can improve financial performance is by reducing waste and increasing efficiency in service delivery. This can lead to cost savings for service organizations and improve their financial performance (Alsmadi et al., 2012). Additionally, Lean practices

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such as standardization, process improvement, and employee involvement have been found to positively impact customer satisfaction, loyalty, and retention, which in turn can improve financial performance (Saurin & Ferreira, 2009) Thus we propose,

H2 : Lean Practices positively influences sustainable operational performance

The implementation of I4 technologies in services has been linked to increased productivity, efficiency, and cost savings, which can positively impact the financial performance of the organization (H. L. Chen, 2021). In addition to financial outcomes, the implementation of I4 technologies can also have a positive impact on social and environmental outcomes. I4 technologies, such as automation and artificial intelligence, can lead to a reduction in tedious and repetitive tasks, which can improve employee well-being and job satisfaction (Makridis & Han, 2020). Moreover, I4 technologies can enhance communication and collaboration among employees, further enhancing job satisfaction (M. Liu, 2021). This improved job satisfaction and employee empowerment can lead to positive social outcomes for the organization, such as improved employee retention rates and a better organizational culture. Further, I4 technologies can help to reduce energy consumption and waste, leading to a reduction in the carbon footprint of the organization (Bhamu & Sangwan, 2014). Digital processing enabled through I4 technologies can lead to a reduction in paper usage and other materials, leading to a positive impact on the environment (Roussilhe et al., 2023). Thus, the integration of I4 technologies in service operations has the potential to improve the triple bottom line of financial, social, and environmental outcomes or in other words, an improved sustainable operational performance. Hence, we proposition -

H3 : Adoption of I4 technologies positively influences Sustainable Operational Performance (SOP)

As we examine the effect of Lean and I4 together on SOP, it would be relevant to study the interaction effect of Lean and I4 on SOP. Using Research Orchestration Theory (RoT), we proposition that implementation of Lean can help organizations in better orchestration of their resources (such as I4), enabling better performance outcomes. Which brings us to our last hypothesis -

H4: Lean practices mediate the relationship of the I4 and sustainable operational performance. Alternatively, there is an indirect effect of the I4 on sustainable operational performance via Lean practices

3.0 Research Methods

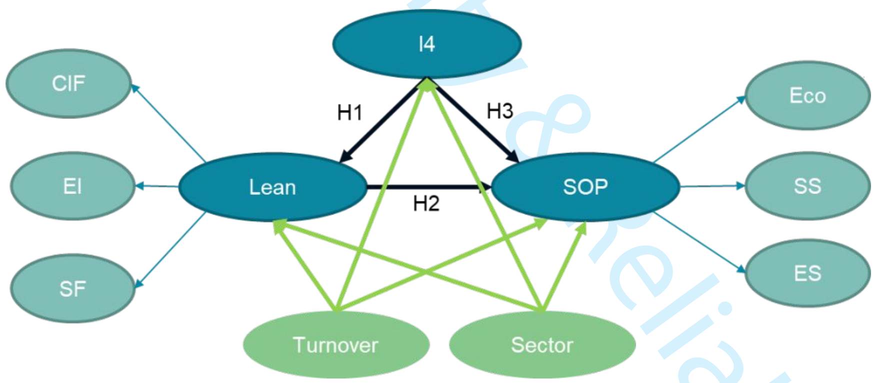
In this study, the research team employed a quantitative research approach and used a questionnaire-based survey methodology to collect empirical data and test the hypothesis propositioned. This approach has been adopted by multiple researchers to investigate similar research problems (A. K. Gupta & Gupta, 2020; Sardana et al., 2020).This section described the overall approach including design of survey instrument, data collection and analysis methodology.

3.1 Measures

To design the survey instrument, the research team drew upon established measurement scales that had demonstrated strong psychometric properties in previous studies. Responses to the survey's measurement items were collected using a five-point Likert scale. Measurement items for Lean were adapted from Shah and Ward's (Shah & Ward, 2007) and Sanders et al's work (Sanders et al., 2016). Similarly, the measurement items for SOP aimed to assess the impact of implementing Lean and I4 on services firms' SOP. These items were derived from Zhu, Geng, and Lai's (Zhu et al., 2011), Sajan et al.'s (Sajan et al., 2017), and Kamble et al's(S. S. Kamble et al., 2018) research. These scales have been originally designed and used primarily in the manufacturing set up and hence were adopted by dropping manufacturing specific context to make the survey relevant for service industry professionals. I4 implementation is at an early stage in Services organization (Bodrow, 2017), hence the survey's measurement items on I4 measure the extent of its implementation rather than its successful implementation. These measurement items were adopted from studies conducted by Kamble,et al (S. S. Kamble et al., 2018) and Tortorella & Fettermann (G. L. Tortorella & Fettermann, 2018). A group of experts with backgrounds in academics and industry reviewed the instrument for clarity and suitability of the measures, based on DeVellis's (DeVellis & Thorpe, 2021) . The experts' review confirmed that the measures adopted were appropriate for this investigation (Dillman, 1978).

Two of the constructs used in the study, namely Lean and SOP were further measured through lower order constructs as defined in the respective source scales. Lean was operationalised using employee involvement (EI), customer involvement & feedback (CIF) and supplier feedback (SF). SOP was operationalize using triple bottom line (TBL) concept with constructs around economic (eco), social (SS) and environmental performance (ES). The theorized model is shown in figure 1.

Figure 1 : Conceptual Model with Hypothesis



3.2 Sampling and Data Collection

For this study, participants were selected using a “convenience sampling me. The survey was administered to professionals within the social circle of the researchers who had knowledge and expertise in service industry. Although convenient sampling has its limitations, it was chosen due to the ease of access to the target population. The sample consisted of professionals from various service industries, including IT/ITES, Consulting, Banking and retail. The survey was administered over the internet using online form, and the participants were informed of the study's purpose and confidentiality of their responses. The study followed ethical guidelines and principles of informed consent. Participants were provided with information about the study and informed about the confidentiality and anonymity of their responses. Responses were voluntary and participants were assured the freedom to withdraw from the study at any stage without facing any negative consequences.

The researchers took steps to minimize potential bias by providing clear instructions for completing the survey and avoiding leading or biased questions. The sample size for this study was 220+ participants. As per literature guidelines, the sample should be at least 5 times the number of items in the study, hence a sample size of more than 200 can be deemed appropriate for the research (Kyriazos, 2018).

4.0 Data Analysis & Results

4.1 Reliability & Validity

Given that the study was conducted in a different context from where the scales have been adopted, it was necessary to verify that the groups obtained through exploratory factor analysis (EFA) were consistent with the scale used. Our main objective in conducting EFA was to identify latent dimensions, and we chose to use the maximum likelihood extraction (MLE) method (also known as common factor method) to avoid inflation in shared variance.

KMO test (Kaiser, 1974) and Bartlett's Test of Sphericity (Bartlett, 1951) were conducted subsequently. The results indicated KMO value of 0.77, indicating high sampling adequacy, and Bartlett's test of Sphericity p-value was 0.00, suggesting that factor analysis can be conducted. In order to identify factors or constructs, Varimax with Kaiser Normalization was used. Initial results had a couple of items with lower loading and high cross loading loadings across multiple factors. After selectively dropping those items, the overall results were within the threshold limits. Table 3 provides a summary of the final items included and results obtained from the EFA.

Table 3 : Included scale items and factor loadings and VIF

	I4	CIF	EI	SF	Eco	SS	ES	VIF
I41	0.588	0.183	0.027	0.135	0.244	0.082	0.144	1.658
I42	0.766	0.244	0.055	0.203	0.217	0.081	0.196	2.086
I43	0.739	0.196	0.080	0.216	0.097	0.064	0.181	1.902
I44	0.777	0.205	0.046	0.172	0.149	-0.019	0.198	1.998
I45	0.782	0.230	0.056	0.172	0.160	0.090	0.175	2.286
I46	0.743	0.202	0.051	0.185	0.139	0.069	0.213	2.214
I47	0.745	0.245	0.096	0.241	0.134	0.009	0.178	1.756
I48	0.791	0.379	0.200	0.256	0.158	0.129	0.182	1.961
CIF1	0.197	0.626	0.272	0.289	0.310	0.208	0.392	1.351
CIF2	0.218	0.746	0.410	0.365	0.174	0.250	0.427	1.905
CIF3	0.186	0.757	0.387	0.350	0.196	0.302	0.297	1.914
CIF4	0.297	0.788	0.265	0.295	0.201	0.226	0.332	1.944
CIF5	0.301	0.804	0.323	0.383	0.268	0.193	0.361	1.903
CIF6	0.242	0.740	0.271	0.383	0.249	0.300	0.352	1.676

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EI1	0.198	0.258	0.694	0.268	0.286	0.420	0.251	1.383
EI2	0.045	0.320	0.762	0.306	0.242	0.437	0.241	1.706
EI3	0.047	0.355	0.796	0.311	0.253	0.479	0.254	1.774
EI4	0.098	0.423	0.822	0.295	0.260	0.517	0.297	1.892
EI5	0.039	0.246	0.746	0.249	0.135	0.443	0.243	1.613
SF1	0.264	0.277	0.285	0.696	0.198	0.167	0.225	1.189
SF2	0.151	0.354	0.330	0.781	0.242	0.157	0.252	1.622
SF3	0.166	0.402	0.236	0.748	0.193	0.069	0.181	1.488
SF4	0.218	0.368	0.267	0.779	0.161	0.103	0.337	1.683
Eco1	0.149	0.228	0.213	0.230	0.743	0.279	0.307	1.314
Eco2	0.131	0.262	0.261	0.188	0.841	0.312	0.374	1.492
Eco5	0.229	0.263	0.258	0.215	0.775	0.348	0.303	1.322
SS1	0.131	0.168	0.318	0.145	0.444	0.656	0.306	1.285
SS3	0.045	0.347	0.528	0.126	0.206	0.827	0.315	1.807
SS5	0.022	0.252	0.500	0.135	0.316	0.843	0.344	1.885
SS6	0.085	0.226	0.491	0.122	0.288	0.746	0.349	1.438
ES1	0.250	0.344	0.184	0.265	0.395	0.298	0.787	1.354
ES2	0.181	0.399	0.254	0.250	0.377	0.315	0.837	1.498
ES3	0.151	0.413	0.379	0.277	0.208	0.411	0.749	1.324

We also assessed the loading of items to evaluate any cross loading onto constructs other than which the items constitute. The loading must be higher on the parent constructs than all the other constructs in the study (Wasko & Faraj, 2005). The results indicate the factor loading for all the items on all the constructs was higher than all the other constructs thus validating discriminant validity (see Table 3).

Multicollinearity was checked for all the indicators using variance inflation factor (VIF) statistic. The VIF values computed for all the indicators, as included in Table 3, are well below the threshold of 5, thus confirming absence of any multicollinearity among the variables included in this study.

Subsequently, in our data analysis we tested the reliability & validity of the scales. We started by using the Cronbach alpha coefficient as a measure for reliability and discovered that all measures had values above the recommended 0.70 (Hair et al., 2019) except for one variable Economic sustainability where it was 0.69, marginally short of 0.7. Additionally, we employed confirmatory factor analysis (CFA) to determine the composite reliability (CR). CR was computed and found to be above the threshold of 0.7 for all the constructs, as presented in Table 4. Overall, the measurement system was found to be reliable using the statistical measures.

Further, we measured the convergent validity of the constructs using the measure of Average Variance Extracted (AVE) for all the constructs. As indicated in Table 4, all AVE values exceeded 0.50, indicating that the items included in the scales converge to measure the latent construct and the scales used possess high convergent validity (Fornell & Larcker, 1981).

Furthermore, we estimated the discriminant validity of the constructs in our study to validate that the constructs are distinct from each other and measure different characteristics of the underlying phenomenon. According to Fornell & Larcker criteria, sq- root of each construct's AVE was compared and found to be higher than its

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correlations with all other constructs as indicated in Table 4, confirming discriminant validity (Fornell & Larcker, 1981)

Table 4 : Discriminant validity (Fornell & Larcker criteria)

	I4	CIF	EI	SF	Eco	ES	SS
I4	***0.744***						
CIF	0.329	***0.746***					
EI	0.114	0.424	***0.765***				
SF	0.271	0.462	0.375	***0.752***			
Eco	0.214	0.320	0.311	0.266	***0.787***		
ES	0.246	0.484	0.338	0.332	0.418	***0.792***	
SS	0.088	0.326	0.603	0.170	0.398	0.426	***0.771***
Cronbach's alpha	0.884	0.839	0.822	0.744	0.693	0.703	0.769
Composite reliability	0.908	0.882	0.876	0.838	0.830	0.835	0.853
AVE	0.553	0.556	0.585	0.565	0.62	0.628	0.595

The diagonal values in the correlation matrix represent square root of AVE

4.2 Reliability & Validity of second order constructs

Second (Higher) order constructs in the study – Lean and SOP were checked for reliability and validity based on their measurement by the first order latent variables in the study. The results of the analysis are included in Table 5. The Cronbach's alpha for 2 of the constructs was observed to be marginally lower than the threshold of 0.7, however CR and AVE for were observed to be sufficiently higher than the respective threshold, hence we concluded the measurement system to be reliable and valid.

The discriminant validity of these construct was measured along with I4 which was the first order construct and the control variables in the study, using Fornell & Larker criteria. The results, as shown in Table 5 indicate that the constructs are distinct from each other in the data collected as a part of this study.

Table 5 : Convergent & Discriminant Validity – Higher order constructs

	Sector	Turnover	I4	Lean	SOP
Sector	**1.000**				
Turnover	0.146	**1.000**			
I4	-0.088	0.206	**0.744**		
Lean	0.041	0.277	0.305	**0.782**	
SOP	-0.01	0.265	0.236	0.588	**0.78**
Cronbach's alpha	-	-	0.884	0.685	0.679
Composite reliability	-	-	0.908	0.825	0.823
AVE	-	-	0.553	0.612	0.608
Mean	0.000	0.000	0.000	0.000	0.000

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Std Deviation	1.002	1.002	1.002	1.002	1.002

The diagonal values in the correlation matrix represent square root of AVE

4.3 Common method variance

To ensure the validity of the survey results, the researchers assessed the potential for common method variance (CMV) or common method bias (CMB) in the data collected through the survey. CMV/CMB occurs when the variance in the data is attributed to the measurement instrument rather than the construct being measured. CMV can artificially create a correlation between measures, which can lead to spurious support for tested theories and influence the significance of the outcome. Therefore, CMV poses a significant validity threat in social sciences research, as noted by Campbell and Fiske (Campbell & Fiske, 1959) and Doty and Glick (Doty & Glick, 1998). To mitigate this risk, several steps were taken firstly, we explicitly informed respondents that their responses are anonymous and will remain confidential (Podsakoff et al., 2003).The survey questions were designed to measure distinct constructs, and each construct was measured using multiple items, we also placed the variables measuring each of the constructs in different sections of the online survey form. Additionally, scrupulous attention was dedicated to ensuring that the item statements utilized in the study were diligently crafted to embody simplicity and unambiguity, thereby facilitating ease of comprehension and minimizing any potential confusion or uncertainty among the participants.

Post data collection, Harman single factor (HSF) test was conducted to identify CMV. HSF test showed that the variance explained by the first factor was 23.1%, which was below the threshold of 50%, concluding that data collected through the survey was reliable, valid, and free from CMV/CMB.

4.4 Data analysis results

In this study, we used the structural equation modelling (SEM) method using Smart PLS software to test our research hypotheses. The SEM method allowed us to simultaneously analyse the relationships among I4, Lean and SOP which helped us to better understand the complex interplay between them in our conceptual model (Byrne, 2016). We created the path model based on the conceptual model proposed and test the hypothesis proposed in the earlier sections.

Demographic Effects

Firm size, measured by the turnover and the sector in which the firm is operational are the set of demographic variables included in the study. Effect of both the variables was analysed on all the three model variables ie Lean, I4 and SOP. The results indicate that while sector has no effect on any of the model variables, firm turnover has significant effect on Lean and I4, while the effect on SOP was not significant.

Direct Effects

The hypothesis H1 and H2 as propositioned in the study were found to be empirically supported by the data analysis, indicating evidence of a positive effect of I4 on Lean and Lean on SOP. The analysis indicated no

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evidence in support of H3, which was about the effect of I4 on sustainable organization performance (SOP). The β values, t statistic and p values are included in table 6.

Table 6: Analysis Results

Hypothesis		β value	T statistics	P values	Outcome
C1	Sector → I4	-0.120	1.735	0.083	Not Supported
C2	Sector → Lean	0.031	0.476	0.634	Not Supported
C3	Sector → SOP	-0.044	0.798	0.425	Not Supported
C4	Turnover → I4	0.223	3.550	0.000	Supported
C5	Turnover → Lean	0.220	3.575	0.000	Supported
C6	Turnover → SOP	0.111	1.764	0.078	Not Supported
H1:	I4→Lean	0.252	3.349	0.001	Supported
H2:	Lean →SOP	0.547	9.53	0.000	Supported
H3:	I4 → SOP	0.046	0.639	0.523	Not Supported
H4:	I4 →Lean →SOP	0.173	3.141	0.002	Supported

Indirect Effects

The mediation effect of Lean between I4 and SOP was also estimated as part of the path model analysis. Table 7 shows the summary of indirect effect results. The results show a significant mediating role of Lean (β = 0.173, t = 3.141, p = 0.002). With the inclusion of Lean as mediator, the direct effect was not significant (β = 0.062, t = 0.85, p = 0.395). Hence Lean exhibits a full mediation on this relationship. The overall structural model with β coefficients and p values is included in the figure 2.

Figure 2 : Structural Path Model

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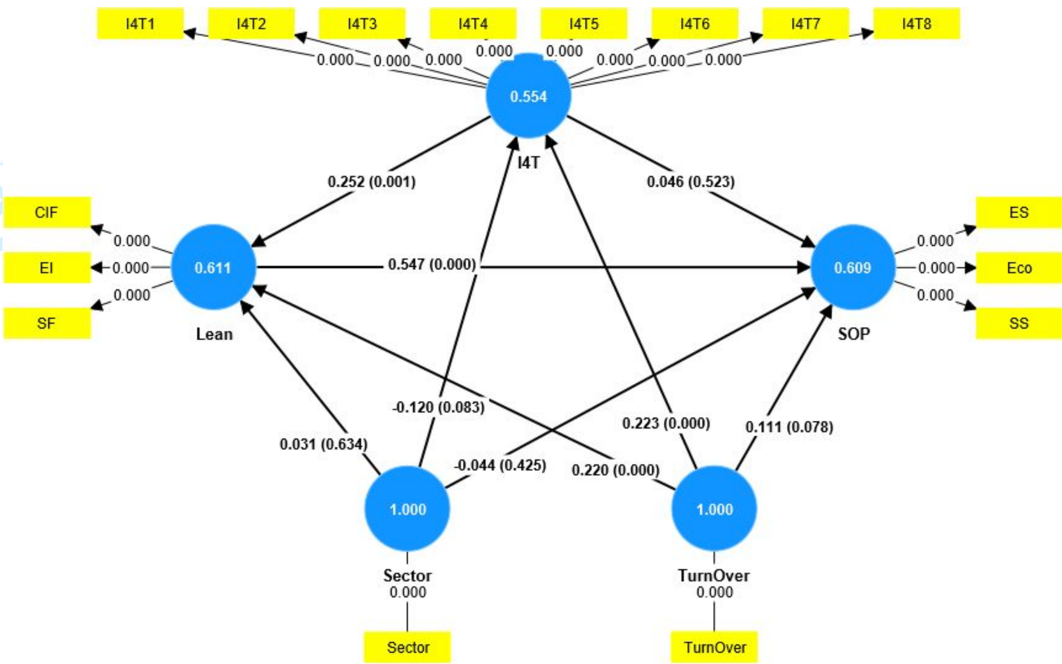

Numbers in the construct indicate AVE

5.0 Discussion & Future Research

5.1 Result Discussion

The study was conducted in India, with all respondents coming from services sector organization. Within this context, the positive influence of Industry 4.0 technologies on overall firm performance has been evidenced as prominent. The study results indicated the relationship between Lean and SOP and the relationship between I4 and SOP were both found to be significant, however the direct relationship between I4 and firm performance was evidenced as non-significant, thus the results showed full mediation of Lean on the relationship between I4 and firm performance. The finding that Lean fully mediates the relationship between I4 and firm performance supports the argument that I4 capabilities need to be complemented with operational excellence practices such as Lean ROT which postulates that the key to achieving sustained competitive advantage lies in effectively coordinating and leveraging a firm's resources and capabilities.

The significant relationship between Lean and SOP suggests that the adoption of Lean practices can contribute to sustainable operational performance outcomes. This finding is in line with previous research that has highlighted the potential of Lean to improve performance across social, economical and environmental aspects (Henao et al., 2019; Wadood et al., 2022). The non-significant direct relationship between I4 and firm performance may indicate that I4 capabilities alone may not be sufficient to drive firm performance. Rather, the complementary use of operational excellence practices such as Lean may be needed to fully realize the potential benefits of I4 capabilities. This finding is consistent with the resource orchestration theory which emphasizes the importance of complementary use of resources in achieving superior performance outcomes (Sirmon et al., 2011).The findings

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also suggest that the direct contribution of I4 capabilities to firm performance may be limited without the use of complementary practices such as Lean.

5.2 Practical and Theoretical Implications

Important inferences from this study are felt in both theory and practise. The study provides practical insights for managers in services sector on how to leverage their firm's resources and capabilities to improve performance. In the context of this study, I4 capabilities are essential but not sufficient for improving firm performance. The findings suggest that in addition to developing I4 capabilities, services firms must also effectively orchestrate their resources and capabilities to ensure that they are working in harmony towards achieving the firm's strategic objectives. This implies that firms should adopt a more holistic approach to management and seek to leverage the complementary nature of their resources and capabilities.

Moreover, the study indicates that the implementation of Lean practices can serve as a mediator in the relationship between I4 capabilities and firm performance. Hence, firms that have developed I4 capabilities should leverage Lean practices to completely realize the potential benefits of these capabilities.

Theoretically, this ***study adds to the growing body of literature on resource orchestration theory (ROT) by providing empirical evidence of how complementary resources such as I4 and Lean practices can work together to enhance firm performance outcomes in the services sector***. ROT explains how firms can combine and integrate their resources in a way that creates a unique competitive advantage and enables them to achieve superior performance outcomes. The findings support the notion that resource orchestration is a critical capability for firms to develop in order to effectively integrate and leverage their resources, and that this capability can be a key driver of competitive advantage and superior performance. This study highlights the importance of firms' ability to effectively orchestrate their resources, which includes integrating and aligning their I4 and Lean practices, to achieve superior performance outcomes. Highlighting the importance of considering the complementary nature of resources in achieving sustainable operational performance in the services sector, the application of ROT provides a useful lens to examine how services firms can effectively orchestrate their resources to achieve superior performance outcomes. Further, ***this study also adds to the broader literature on the relationship between I4 and firm performance for services sector by highlighting the mediating role of Lean practices***. This finding underscores the importance of complementarity between I4 and Lean practices in achieving improved firm performance, rather than viewing them as separate and independent sources of competitive advantage.

5.3 Limitations and Future Scope of Study

There are some limitations that should be recorded for this study. This investigation was based on cross-sectional data, imposing restrictions on the ability to establish causal inferences. Subsequent research endeavours could employ longitudinal data to scrutinize the causal connections between Industry 4.0 capabilities, operational excellence practices, and organizational performance. Moreover, the study did not consider the potential influence of external factors such as competitive environment, industry regulations, and macroeconomic factors, which could impact the relationship between I4 capabilities, Lean practices, and firm performance. The study was conducted in the context of the services sector in India, which may limit the generalizability of the findings to other sectors. Similar studies can be conducted in a different context to further validate the findings for wide applicability. Future research could explore the specific mechanisms through which Lean mediates the relationship between I4 and firm performance and investigate the potential for other operational excellence practices to complement I4 capabilities in achieving improved firm performance and sustainable operational performance outcomes.

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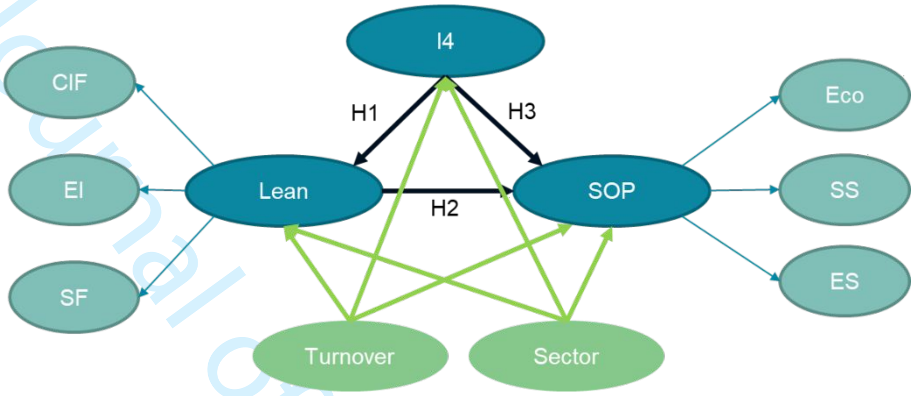
Annexure A1

Detailed Conceptual Model with Items



Item Code	Description
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Cloud Computing (CC)]
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Big Data Analytics (BDA)]
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Internet of Things (IOT)]
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Robotic Systems (RS)]
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Augmented Virtual Reality (AR)]
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Block Chain Technology]
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Machine Learning (ML)]
I4	My firm is in the process of implementing/implemented the following Industry 4.0 Technologies (I4): [Artificial Intelligence (AI)]
CIF1	In my firm CUSTOMER INVOLVEMENT and FEEDBACK helps : [To maintain close contact with them]
CIF2	In my firm CUSTOMER INVOLVEMENT and FEEDBACK helps : [To collects quality performance feedback]
CIF3	In my firm CUSTOMER INVOLVEMENT and FEEDBACK helps : [To collects delivery performance feedback]
CIF4	In my firm CUSTOMER INVOLVEMENT and FEEDBACK helps : [To involves them in existing product improvement]
CIF5	In my firm CUSTOMER INVOLVEMENT and FEEDBACK helps : [To involve them in new product/process development]
CIF6	In my firm CUSTOMER INVOLVEMENT and FEEDBACK helps : [To capture present and future demand information]
EI1	In my firm EMPLPOYEE INVOLVEMENT play a significant role in [Problem-solving teams]

EI2	In my firm EMPLPOYEE INVOLVEMENT play a significant role in [Suggestion scheme programme]
EI3	In my firm EMPLPOYEE INVOLVEMENT play a significant role in [Product improvement efforts]
EI4	In my firm EMPLPOYEE INVOLVEMENT play a significant role in [Process improvement efforts]
EI5	In my firm EMPLPOYEE INVOLVEMENT play a significant role in [Cross-functional training]
SF1	Supplier Feedback (SF): [My firm is always in close contact with our key suppliers]
SF2	Supplier Feedback (SF): [My firm provides quality performance feedback to all our key suppliers]
SF3	Supplier Feedback (SF): [My firm provides delivery performance feedback to all our key suppliers]
SF4	Supplier Feedback (SF): [My firm puts maximum efforts to develop a long-term relationship with our key suppliers]
Eco1	In my company in the last two years (Economic Sustainability): [Profits have been improving]
Eco2	In my company in the last two years (Economic Sustainability): [Product development cost has been reducing]
Eco5	In my company in the last two years (Economic Sustainability): [Rejection and rework cost has been reducing]
SS1	In my company in the last two years (Social Sustainability): [Working conditions have been improving]
SS3	In my company in the last two years (Social Sustainability): [Employee health status has been improving]
SS5	In my company in the last two years (Social Sustainability): [Employee Morale has been improving]
SS6	In my company in the last two years (Social Sustainability): [Employees work pressure has been reducing]
ES1	In my company in last two years (Environmental Sustainability): [Solid waste generation is reducing]
ES2	In my company in last two years (Environmental Sustainability): [Energy wastages have been reducing]
ES3	In my company in last two years (Environmental Sustainability): [Environmental awareness has been increasing]

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