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Linking lean implementation and occupational health and safety through leading indicators

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Abstract

Purpose - This study aims to propose the usage of leading indicators to measure the impact of lean implementation on occupational health and safety (OHS). Hypotheses based on the relationship between lean and OHS are built and quantitatively tested.

Design/methodology/approach - Data from multiple sources was collected through international survey responses from more than 20 countries. Industries utilizing lean practices constitute the study sample. Partial least square-based structural equation modeling (PLS-SEM) was employed as the overall approach. Prior to data analysis, data referring to independent, moderating, meditating, and dependent variables was systemically encoded.

Findings - The model testing and hypotheses support the importance of using OHS leading indicators to appropriately measure the impact of lean implementation on workers' health and safety, along with the mediating effect of the antecedents of OHS performance between lean implementation and OHS performance.

Research limitations/implications - The contribution of lean maturity and proposed OHS leading indicators connected to lean practices are briefly explored in this study. Therefore, to achieve a deeper understanding of the relative influence of specific lean and OHS practices, additional research is needed.

Practical implications - Since there are synergetic and trade-off relationships between lean and OHS, the findings of this study will enable managers and organizations to enforce the positive effects of lean implementation and reduce the negative effects associated with employee health and safety at work.

Originality/value - This is the first study that proposes the use of OHS leading indicators to measure the impact of lean implementation on OHS performance.

Keywords - Lean implementation, health and safety, OHS performance, antecedents, leading indicators, structural equation modeling (SEM), survey.

Article classification - Research paper

1. Introduction

Companies are under tremendous pressure to perform at the lowest cost, highest quality, and fastest pace; therefore, lean has emerged as a popular management philosophy for companies to attain a competitive edge (Manuele, 2007; Chiarini et al., 2016). The lean philosophy originated at Toyota, where it was used to shorten the lead time through eliminating wastes from work processes (Holweg, 2007). Waste in an organization is the non-value added tasks for which customers would not pay (Cudney et al., 2013). Therefore, the lean philosophy attempts to identify and reduce/eliminate non-value added tasks through several tools and techniques. In addition, recent literature considers the lean philosophy more than just waste reduction initiatives. For instance, Garnett et al. (2011) discuss the lean implementation process in construction industry in the UK from a strategic point of view. According to the nature and utility of lean, beyond the manufacturing sector, a wide variety of industries have implemented lean tools and techniques. Commonly reported positive results of using lean thinking include improved productivity, cost reduction, shortened work cycle time, and improved quality (Rahman et al., 2010; Taj, 2008).

The change from traditional mass production to lean production often requires the redesign of production processes, employees' activities, and process layout. In accordance with these broad changes occurring within the workplace, critical arguments have arisen among researchers and practitioners (Bruno and Jordan, 2002), particularly with respect to occupational health and safety (OHS) issues. There is concern about overlooking OHS issues while lean is being implemented in the workplace (Cudney et al., 2010). Some authors have conducted studies with respect to lean implementation impacts on OHS (Longoni et al., 2013; Saurin and Ferreira, 2009); however, there is no agreement on the impact of lean implementation on OHS performance. For instance, while positive effects such as job autonomy, worker participation, empowerment, and job enlargement have been reported (Womack et al., 1990), negative effects such as occupational stress increase, rise in occupational accidents, and the growth of muscle-skeletal disorders have also been reported (Conti and Angelis, 2006; Hallowell et al., 2009).

With the disparities in synergy and trade-off impacts of lean on OHS, it can be concluded that the relationship between lean and safety is not fully understood (Cudney et al., 2010). In the literature, many authors claim that further research is needed to better understand the impact of lean implementation on OHS (Cudney et al., 2010; Longoni et al., 2013). Moreover, a more suitable approach to measure these impacts still needs to be proposed and implemented. The studies to date use traditional lagging indicators to measure the impact of lean implementation on OHS performance. However, this method of analysis has several limitations. For example, recent evidence (Sinelnikov et al., 2015) suggests that solely using lagging indicators is less useful in measuring OHS performance in organizations. Although extensive research has been carried out on the relationship between lean production and OHS, no single study exists that has used leading indicators to investigate this relationship. Additionally, a comprehensive framework embodying the full spectrum of mechanisms and drivers linking OHS and lean is lacking in the literature. That is, the studies regarding the relationship between OHS and lean have noted lean implementation as an input and safety performance as an output. Accordingly, the underlying elements influencing these variables and the mechanisms driving their relationships remain under investigated.

Therefore, the objectives of this study are twofold: (1) developing a comprehensive model disentangling the relationship between lean and OHS, and (2) highlighting the importance of using leading indicators in understanding and measuring the impact of lean on OHS performance. The paper aims at addressing these two objectives through a deductive quantitative study.

The rest of the paper is organised as follows. The next section discusses the relevant literature on lean concepts and implementation, OHS management and performance, and the state-of-the-art knowledge on the relationship between the two. The third section introduces the research framework, which leads to the research questions and hypotheses. The fourth section depicts the research methodology and data analysis. Then, sections five and six are devoted to reporting and discussing the findings. Lastly, the implications, limitations, and future research are presented.

2. Literature review

2.1 Lean concepts, tools, and techniques

Lean is a management philosophy that challenges the practices of mass production. As described by Ohno (1988) in his book, *Toyota Production System*, the primary goal of lean is to eliminate waste in production. His idea was to manufacture products in the right amounts, at the time needed, and the unit needed. To better understand lean tools and techniques, Shah and Ward (2003) classified lean tools and techniques into four sets of consistent practices: total quality management (TQM), just-in-time (JIT), human resource management (HRM), and total productive management (TPM). Furthermore, Cudney et al. (2013) introduced the major lean practices.

Although the lean philosophy originated within the automotive industry at Toyota, it is not limited to this specific manufacturing sector (Cua et al., 2001). Nowadays, a wide range of industries uses lean tools and techniques in their systems across the world. As an illustration, Taj (2008) investigated the application of lean manufacturing in a wide variety of production plants (e.g., electronics, pharmaceutical, telecommunication) in China and reported significant benefits in connection with lean implementation. Moreover, applying lean tools and techniques is not limited to large organizations. Both small and large enterprises are applying lean (Anand and Kodali, 2008; Cudney et al., 2013). In accordance with the lean diffusion across different industries around all over the world, numerous studies have investigated the barriers and facilitators of lean implementation (Aij et al., 2013; Dora et al., 2013). Additional research has been conducted on the synergies or trade-off effects of lean techniques with concepts such as safety, six sigma, green manufacturing, and resilience (Birkie 2016; Cudney et al., 2010).

2.2 Lean maturity

Although many companies have been implementing lean programs, each company is different in size, location, process, culture, policy, and other circumstances. Moreover, the competitive situations and the underlying expectations are different from one company to another. These topics become important when managers decide to implement the lean approach. It is worth noting that misplaced expectations of how quickly lean programs enhance operational activities can compromise lean efforts. Thus, managing the lean implementation process is more important than the program itself. In this regard, the lean maturity concept is another area of recent research. Netland and Ferdows (2014) launched a study in 2007 at Volvo Corporation where they investigated how the Volvo Production System (VPS), which was based on lean principles, was implemented in 19 countries across the world. In this study, two variables, including how widely and how thoroughly lean is implemented, were proposed as the lean maturity's forming variables. This study shows that resistance to change in initial stages of lean implementation is subsided by thorough and wide diffusion of lean techniques in later stages. According to Ansari et al. (2010), how thoroughly and widely lean techniques are implemented in an organization is in accordance with fidelity and extensiveness dimensions of a program. Additionally, previous studies show that experience with lean implementation in an organization could increase the effectiveness of lean implementation (Aij et al. 2013; Ansari et al., 2010). As much as a company is experienced with lean implementation, challenges are overcome regarding knowledge, employees' skills, expertise, information flow, communication with suppliers, and customer improvement. Furthermore, cultural, technical, and political fits seem plausible to become more and more common in late stages compared to early stages of lean implementation (Ansari et al., 2010). In conclusion, fidelity, extensiveness, and experience are identified as the formative constructs of lean maturity.

2.3 Occupational health and safety management

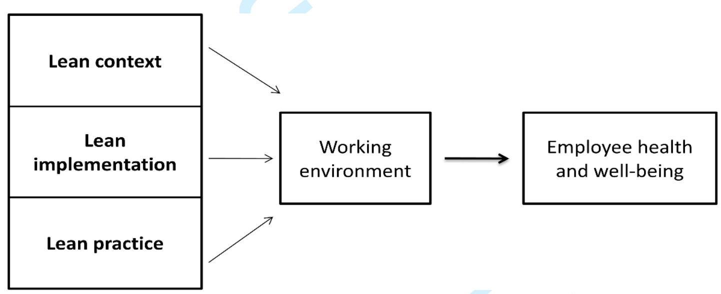
Occupational health and safety management is described as the science and art of anticipation, recognition, evaluation, and control of occupational hazards in the workplace (Nahrgang et al., 2011). Any changes that happen in the workplace will influence the health and safety of the workers. Therefore, safety professionals should be aware of hazard creation in connection with the implementation of a new program in the workplace. Evidence shows that determining the antecedents of OHS performance has a major role in effectively reducing the number of accidents in the workplace (Neal and Griffin, 2002). Scholars have mentioned various types of antecedents in the safety literature; however, no clear definition has been proposed in this context. For example, Neal and Griffin (2006) claim that traditionally individual factors have been noted as antecedents of OHS performance, but recently other factors, such as the working environment and management practices, have been taken into account as forming elements of antecedents of safety performance. Mousavi et al. (2017) contributed to this research stream by proposing a new definition of an OHS antecedent as "any direct and indirect items which influence safety performance". Moreover, they classified antecedents into four distinct categories including working environment, task characteristics, workforce characteristics, and organizational factors. The main elements forming these four categories were also reported as they appear in extant literature.

Another open issue affecting OHS management science and practice is the measurement of performance. Different approaches have been proposed in the literature for measuring OHS performance. Reiman and Pietikäinen (2012) state that "safety indicators can play a key role in providing information on organizational performance, motivating people to work on safety and increasing organizational potential for safety" (p. 1993). Agumba and Haupt (2011) argued that health and safety performance indicators can be broadly classified into two groups including lagging and leading indicators. While lagging measurements can provide data about incidents after the fact, the question remains regarding the value of these metrics as future predictors for safety in the workplace (Hinze et al., 2013). In recent years, there has been increasing literature on using a combination of leading and lagging indicators to measure OHS performance. For example, Hinze et al. (2013) conclude that any firm that truly embraces the zero-injury philosophy will readily consider using other measures than traditional lagging indicators of safety performance. They also noted that "while the use of lagging indicators will continue, as required by safety regulatory agencies and insurance companies, companies that track leading indicators will be able to maintain a more accurate assessment of the effectiveness of the safety program or the safety process" (p. 28). A general agreement can be inferred in the literature on the value of taking into account the role of OHS leading indicators to anticipate and prevent OHS hazards at the source. However, less attention has been given to the use of OHS leading indicators as a more robust way to measure OHS performance. This issue is assumed to be even more important when a new management philosophy, such as lean, is implemented in an organization to radically transform operations models and practices.

2.4 Relationship between lean implementation and OHS management

The issue of OHS performance has been a controversial and much disputed subject when it comes to investigating the benefits and impacts of lean implementation at the shop floor level. Several studies have investigated the association between lean and OHS management, but a systematic understanding of how lean contributes to or impairs OHS performance is still lacking (Cudney et al., 2010). In recent years, only a few studies have provided some exploratory models on the relationship between lean and OHS management. For example, an important study addressing the integration of lean and safety was released by ANSI (2007). The aim of the report was to provide guidelines to industries to concurrently address lean and safety concerns when using machinery. The report proposes a risk assessment framework to address lean and safety concerns. Similarly, Hasle et al. (2012) studied the relationship between lean and OHS based on the model provided in Figure 1, which illustrates how the lean approach directly affects the working environment and indirectly affects employee health and well-being.

Figure 1: Relationship between lean and occupational health and safety (Hasle et al., 2012)



Extant literature highlights the complexity of the impact of lean on OHS, and many studies indicate the need for a better understanding of the mechanisms that drive the relationship between the two (Cudney et al., 2010; Longoni et al., 2013).

2.5 The lack of a generalized model of the relationship between lean and OHS

Despite its benefits in improving productivity and profitability, lean may jeopardize employees' health and safety. Although many studies have been conducted on the positive side of lean, as reported in the previous section, less attention has been devoted to the possible drawbacks of lean implementation on OHS performance.

Previous studies measuring the impact of lean on OHS performance have suffered from a lack of well-grounded theoretical considerations, and most of these studies relied on lagging indicators; whereas a theoretical association between lean implementation and leading indicators of OHS has received less attention. Existing studies have addressed lean implementation as an input and OHS performance as the output (e.g. Longoni et al., 2013). In this respect, lean is considered as one single concept without any consideration of the associated factors, such as those constituting lean maturity. The lack of agreement on the formative variables for both lean implementation and OHS performance turns into disparate and contradictory results (e.g. Longoni et al., 2013). Therefore, developing a comprehensive model covering all formative elements of both lean implementation and OHS performance is needed.

3. Research framework

Based on the current gaps in the literature and the need for a comprehensive model to link lean implementation and OHS performance, the following research questions are put forth:

RQ1: *How does lean implementation affect the antecedents of OHS performance?*
RQ2: *What are the leading indicators that capture the influence of lean implementation on OHS performance?*

In order to investigate and assess the influence of lean implementation on OHS performance, the approach suggested by Gertler et al. (2011) is employed in this study. According to Gertler et al. (2011), three aspects should be taken into account when measuring the impact of a newly implemented program on a system, namely: how, where, and when. Some scholars addressed these aspects in the lean literature as well. For instance, the two items proposed by Netland and Ferdows (2014) include how thoroughly and how widely, which address the how and where to quantify the impact of lean implementation. Similarly, Ansari et al. (2010) address the fidelity and extensiveness dimensions. The former relates to the degree of completeness of each practice as it is currently implemented by the organisation, whereas the latter points at the degree or extent of implementation of lean practices in an organization. The when item is associated with the length of time that lean practices have been implemented in an organization. Prior studies (e.g. Aij et al., 2013) show that experience with lean in an organization could increase the effectiveness of its implementation. Concerning the Plan-Do-Check-Act (PDCA) cycle, the more a company is experienced with lean practices, the more obstacles that impede lean maturity can be overcome. Thus, the organization's experience with lean practices could indicate the effectiveness and maturity of the lean approach. Given these considerations, this study uses fidelity, extensiveness, and experience constructs as the forming variables of lean maturity.

In order to frame the antecedents of OHS performance, the taxonomy proposed by Mousavi et al. (2017) is adopted in this study. The antecedents of OHS performance are categorized into four groups, as reported in Table 1, including working environment, task characteristics, workforce characteristics, and organizational factors.

Table 1. Antecedents of OHS performance (Mousavi et al., 2017)

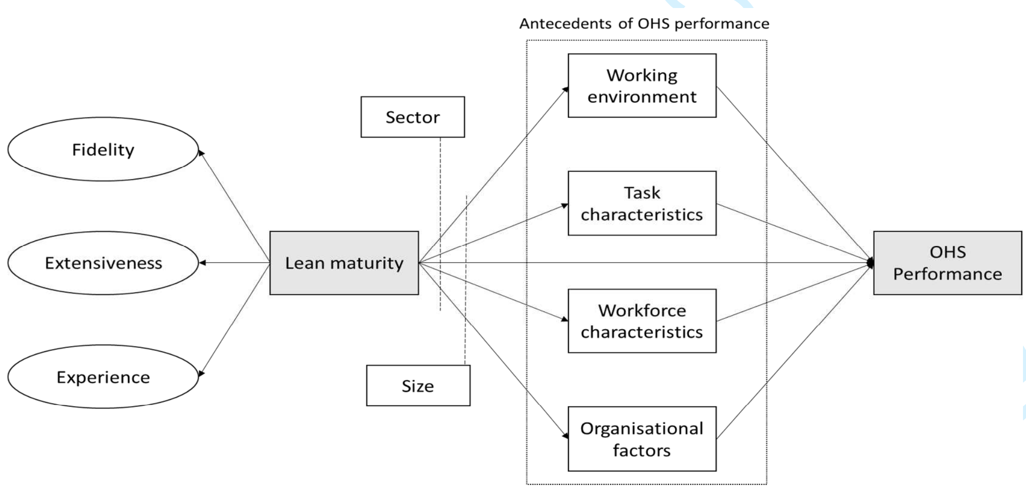
Category	**Antecedents**
Working environment	Physical aspects Chemical aspects Biological aspects Ergonomic aspects
Task characteristics	Type of task Time Job demands Equipment related characteristics
Workforce characteristics	Risk taking

	Safety knowledge Safety motivation Locus of control
Organisational factors	Policy Communication Management Culture

Additionally, four traditional lagging indicators, demonstrating the status of safety performance in an organization, are employed in this study, which include recordable injuries, worker's compensation cost, accident records, and total lost working days.

Extant literature has shown that the way of implementing lean is not the same in large and small firms (Matt and Rauch, 2013). While several scholars declare the difficulties of implementing new operational practices in large firms due to complicated processes and administrative tasks, others show a positive relationship between the size of the organisation and the success of new work system's implementation. Shah and Ward (2003; p. 133) state that "large firms are more likely to implement lean practices than their smaller counterparts"; the difficulties of implementing lean practices in small enterprises in northern Italy have been reported by Matt and Rauch (2013). The type of business and sector also bring various views on the success or failure of lean implementation. The barriers, challenges, and outcomes of implementing lean practices were analyzed in different industrial and service contexts (Poksinska, 2010; Portioli-Staudacher, 2009; Piercy and Rich, 2009; Hallowell et al., 2009) showing the relevant role of business sector as a contingent factor. Therefore, the influence of company size and sector cannot be overlooked when studying the success or failure of lean implementation. Coherently, and in line with prior similar studies (e.g. Baron and Kenny, 1986), the present study takes into account the role of company's size and sector as moderators of the relationship between lean implementation and OHS performance. The complete research framework is reported in Figure 2.

Figure 2: Research framework



To answer the two research questions, eleven hypotheses were formulated. Four hypotheses relate to the relationships between lean implementation and the four antecedents of OHS performance, one hypothesis is linked to the direct relationship between lean implementation and OHS performance. Four additional hypotheses are formulated to test the mediation effect of the antecedents on the relationship between lean implementation and OHS performance. Finally, two hypotheses address the moderating role of company size and sector on the relationship between lean implementation and OHS performance.

Since prior studies have shown both positive and negative effects (e.g. Conti and Angelis, 2006; Saurin and Ferreira, 2009), the formulation of hypotheses accounts for both possible types of influence of lean implementation on OHS performance. The full list of hypotheses is as follows:

H1: Lean implementation significantly influences OHS performance.

H2: Lean implementation significantly influences working environment.

H3: Lean implementation significantly influences task characteristics.

H4: Lean implementation significantly influences workforce characteristics.

H5: Lean implementation significantly influences organizational factors.

H6: Working environment significantly mediates the relationship between lean implementation and OHS performance.

H7: Task characteristics significantly mediate the relationship between lean implementation and OHS performance.

H8: Workforce characteristics significantly mediate the relationship between lean implementation and OHS performance.

H9: Organizational factors significantly mediate the relationship between lean implementation and OHS performance.

H10: There is a significant categorical moderating effect of sector on the relationships among model constructs.

H11: There is a significant categorical moderating effect of company's size on the relationships among model constructs.

4. Methodology

In this study, an approach that combines survey-based data collection and structural equation modelling (SEM) has been employed for theory testing.

4.1 Survey design and administration

This study is consistent with the concepts of explanatory research that attempts to explain the relationship between variables. Contextual theory within the explanatory survey not only quantifies the cause and effect situation between variables, but also determines the positive or negative effects of one variable over the other variables. As a result, questions in a survey instrument (questionnaire) are constructed in a manner not only to quantify the casual relationships between variables, but also to explain the rational of the relationships. Several theoretical models and several empirical research studies have already focused on explaining and measuring the impact of lean implementation on OHS (Conti and Angelis, 2006; Saurin and Ferreira, 2009). Consequently, this study, attempts to test the developed theory on the relationship between lean implementation and OHS performance in greater detail, compared to previous studies through the gathering of information from organizations implementing lean techniques and practices.

4.1.2 Data collection

A specific questionnaire was developed for the needs of the present study. The first part of the questionnaire includes demographic questions, such as age, gender, education level, location, and job function of the informant, and basic company information, such as industry type and size. Next, three questions are asked to recognize the status of lean maturity in organizations. They are as follows.

- *In your opinion, how thorough have lean practices been implemented in your organization?*
  To a Great Extent   Somewhat   Very Little   Not at All   Do not know

- *In your opinion, how wide have lean practices been implemented in your organization?*
  No Departments   Some Departments   All Departments   Do not Know

- *How long have the following lean practices been implemented in your organization?*
  Never   Less than 2 years   Between 2 to 5 years   More than 5 years   Do not know

The main part of the questionnaire gathers information on the impact of lean implementation on the antecedents of OHS performance. To find common lean practices the studies of Shah and Ward (2003) and Birkie (2016) were taken in to consideration. Finally, 16 major lean practices at shop floor level were selected for investigation. The questions inquire about the effects the respondents have experienced by implementing one or some of the listed lean practices. In particular, we asked how the antecedents of OHS performance have been affected directly because of lean implementation. As an illustration,

-By implementing lean practices, what effects has your organization experienced regarding the following issues?
Worse   Same   Better   Do not know

Lastly, the status of OHS performance with respect to lean implementation was questioned. A preliminary version of the questionnaire was sent to two academicians and two industry experts to review and provide feedback on possible improvements. Changes were then implemented based on experts' suggestions, which mainly focusing on wording, the order of the questions, and the introductory part where the objectives of the study are presented. The final version of the questionnaire included 18 main questions. Qualtrics© online software was used to administer the questionnaire and collect data. Data was gathered from multiple sources at various time points from April to July 2017.

We employed the data source that Shah and Ward (2007) used in their study, which consists of a contact list from Productivity Inc, a firm involved with the consulting, training, and implementing of lean systems. In addition, we used various social media, such as LinkedIn and Twitter, and internet sites, such as American Society for Quality (ASQ) and Institute of Industrial and Systems Engineers (IISE), for promoting the survey and the link to the online questionnaire. To obtain more responses, personal contacts with relevant scholars across the world were asked to distribute the questionnaire to various industries. By sharing the questionnaire link and using the data sources, 146 responses were received. It has been shown that the response rate of the surveys in the operations management field is typically low, with similar studies having response rates at 7.47% (Nahm et al., 2003) and 6.3% (Li et al., 2005).

4.1.3 Data sorting

After receiving the responses a csv file was extracted from the Qualtrics© platform. Guidelines from Hair et al. (2016) were used for sorting data; therefore, the observations containing more than 15% of missing data were excluded. Finally, 112 cases were included in the final dataset.

4.2 Specification of constructs

According to the study objectives, latent constructs include three distinct categories. First, the construct in connection with lean implementation is lean maturity. Second, the antecedent constructs that are working environment, task characteristics, workforce characteristics, and organizational factors. Third, the latent construct linked to OHS is OHS performance.

Since the three forming indicators of lean maturity (fidelity, extensiveness, and experience) are highly correlated with each other, the causality direction goes from lean maturity to these indicators; therefore, they are reflective indicators. In a similar fashion, the indicators associated with the OHS performance are assumed as reflective measurements.

On the other hand, the underlying indicators for other variables in the model (working environment, workforce characteristics, task characteristics, and organizational factors) are modeled as formative measurement. In summary, Table 2 depicts the latent constructs and their indicators.

Table 2: Latent constructs and corresponding reflective and formative indicators

Latent constructs	**Indicators**
Lean maturity	***Reflective indicators*** (Fid) Fidelity (Ext) Extensiveness (Exp) Experience
Working environment (WE)	***Formative indicators*** (WE_1) Awkward/strained positions (WE_2) Exposure to biological hazards (WE_3) Exposure to dust and/or smoke (WE_4) Exposure to flammable explosive chemicals (WE_5) Exposure to poisonous chemicals (WE_6) Exposure to vibration (WE_7) Exposure to workplace noise (WE_8) Extensive and frequent force (WE_9) Frequent lifting (WE_10) Repetitive motion (WE_11) Status of workplace illumination/lighting
Task characteristics (TC)	***Formative indicators*** (TC_1) Breaks (TC_2) Job autonomy (TC_3) Job safety (TC_4) Job satisfaction (TC_5) Job stress (TC_6) Machinery and tool safety (TC_7) Time pressure (e.g. deadlines) (TC_8) Work intensity (e.g. cognitive demands) (TC_9) Workload and pressure (TC_10) Work pace

Workforce characteristics (WC)	***Formative indicators*** (WC_1) Skills utilization (WC_2) Risk-taking behavior (WC_3) Motivation for safe working (WC_4) Knowledge about safety issues (WC_5) Defined/clear job functions (WC_6) Employee involvement (overall) (WC_7) Employee involvement in creating a safe environment
Organizational factors (OF)	***Formative indicators*** (OF_1) Employee involvement in improving work methods (OF_2) Labor management (OF_3) Management commitment to safety issues (OF_4) Organization's policies on safety issues (OF_5) Reward systems for safety (OF_6) Safety culture (OF_7) Safety systems (e.g. lock-out, tag-out) (OF_8) Teamwork and communication (OF_9) Training on safety and health principles (OF_10) Workplace health promotion programs
OHS performance	***Reflective indicators*** (OHS_1) Recordable injuries (OHS_2) Worker's compensation cost (OHS_3) Accident records (OHS_4) Total lost working days

4.3 Data analysis method

Structural equation modeling is a second-generation method for multivariate data analysis (Chin, 1998). While the traditional methods were only able to analyze one level of the association between independent and dependent variables, SEM methods enable researchers to analyze multiple dependent and independent variables simultaneously. Within the modern version of data analysis researchers have more flexibility to interplay the data and theory in comparison with traditional methods (Wong, 2003). In the context of the present study, the partial least square (PLS) approach was used because of its suitability in small sample sizes, no requirement of data normality, as well as convenience for moderation analysis. Specifically, SmartPLS version 3 was employed in this study (www.smartplas.de). The design and test of models were graphically performed through constructing latent variables, drawing paths, and linking observed variables to latent variables.

Table 3 presents the descriptive summary of the dataset. The classification of the company size is based on the European and American standards, which has been divided into two main categories: small and medium sized enterprises (SME), and large enterprises. Further, the business sector is classified into two main categories: manufacturing and services industries.

Table 3: Descriptive analysis

Age	Frequency
18-24	6
25-34	27
35-44	30
45-54	27
55-64	16
+65	6
Total	**112**

Sex	Frequency
Male	88
Female	24
Total	**112**

Education level	Frequency
High School	5
BS	34
MS	56
PhD	17
Total	**112**

Business size	Frequency
Small and Medium	57
Large	55
Total	**112**

Business sector	Frequency
Manufacturing	53
Services	59
Total	**112**

Country	Frequency
Europe	28
Asia	22
Australia	8
South America	12
North America	29
Africa	13
Total	**112**

Job category	Frequency
Health and Safety	39
Engineering	19
Operation / Production	18
Human resources	12
Consulting	8
Education	9
Other	7
Total	**112**

In order to deliver the model estimation, the empirical measures of the relationship between the constructs and their indicators, and among latent constructs are required. The collected data provides theoretical information to qualify the measurement models and structural models with reality. That is, whether the theory fits the data or not.

By running the PLS algorithm, the output results are provided for reflective and formative indicators. Tables 4 and 5 show the results of reflective and formative measurement, respectively.

Table 4: Results summary for reflective measurement models

Latent construct	Indicators	Loading	Indicator reliability	Composite reliability	AVE	Discriminant validity?
Lean maturity	Fid	0.891	0.793	0.851	0.657	**Yes**
	Ext	0.721	0.519			
	Exp	0.811	0.657			
OHS performance	OHS_1	0.777	0.603	0.824	0.541	**Yes**
	OHS_2	0.775	0.600			
	OHS_3	0.716	0.512			
	OHS_4	0.712	0.506			

Based on the reliability results of reflective indicators linked to lean maturity, the three reflective indicators of lean maturity (i.e., fidelity, extensiveness, and experience) are highly related to each other and significantly explain the lean maturity construct. This in support of the Ansari et al. (2010) study that introduces fidelity and extensiveness as the forming items of the lean maturity variable and the study of Satoğlu & Durmuşoğlu (2000) that introduces experience level as a parameter showing lean maturity in industries.

Further, the results of the OHS performance construct show a high reliability among its reflective indicators (i.e., number of accidents, number of injuries, number of lost working days, and compensation cost). This in support of previous studies (Hinze et al., 2013; Qien, Utne, & Herrera, 2011) that establish OHS lagging indicators to measure the performance of OHS in the workplace.

In order to establish the significance of outer weights of formative indicators, the value of 5% (α = 0.05) and its probability of error, 1.96, were chosen for this analysis. For the seven indicators that were not significant (NS), the bootstrap sign change options procedure proposed by Hair et al (2016) was utilized. The final results confirm their significance. Therefore, the validity of all formative indicators linked to antecedents is in an acceptable range. Further, the results of the *t* value show that formative indicators in the model significantly contribute to their constructs (i.e., four antecedents). Based on these results, all of the formative indicators of each antecedent were retained in the model.

Table 5: The outer weights of formative indicators

Formative constructs	Formative indicators	Outer weights (outer loadings)	*t* Value	Significance level	P Value
WE	WE_1	0.133 (0.440)	2.631	*	0.009
	WE_2	0.170 (0.269)	1.105	NS	0.269
	WE_3	0.099 (0.541)	1.70	*	0.092
	WE_4	0.068 (-0.658)	2.014	*	0.046
	WE_5	0.039 (0.797)	2.051	*	0.042
	WE_6	0.142 (0.298)	1.732	*	0.089
	WE_7	-0.097 (-0.495)	1.981	*	0.050
	WE_8	0.259 (0.088)	1.711	*	0.087
	WE_9	0.089 (0.573)	0.600	NS	0.548
	WE_10	0.327 (0.029)	2.249	*	0.025
	WE_11	0.403 (0.003)	2.965	*	0.003
WC	WC_1	0.067 (0.061)	2.292	*	0.024
	WC_2	-0.283 (-0.170)	1.991	*	0.049
	WC_3	-0.045 (-0.012)	0.158	NS	0.874
	WC_4	0.295 (0.247)	1.832	*	0.069
	WC_5	-0.288 (-0.230)	1.661	*	0.438
	WC_6	0.461 (0.363)	2.632	*	0.009
	WC_7	0.835 (0.614)	1.790	*	0.074
TC	TC_1	0.339 (0.321)	2.170	*	0.030
	TC_2	0.133 (0.123)	1.642	*	0.103
	TC_3	0.337 (0.358)	1.899	*	0.058
	TC_4	0.099 (0.124)	2.71	*	0.007
	TC_5	0.056 (0.037)	0.196	NS	0.844
	TC_6	0.298 (0.315)	2.162	*	0.031
	TC_7	0.043 (0.029)	0.148	NS	0.883
	TC_8	0.096 (0.112)	2.014	*	0.046
	TC_9	-0.027 (-0.32)	2.921	*	0.004
	TC_10	0.087 (0.066)	1.893	*	0.612

OF	OF_1	0.360 (0.339)	1.821	*	0.071
	OF_2	-0.130 (-0.143)	2.012	*	0.046
	OF_3	0.040 (0.047)	2.613	*	0.010
	OF_4	-0.002 (-0.001)	0.011	NS	0.991
	OF_5	0.055 (0.038)	1.652	*	0.101
	OF_6	0.132 (0.173)	1.729	*	0.086
	OF_7	0.258 (0.261)	1.251	*	0.213
	OF_8	0.111 (0.114)	0.696	NS	0.486
	OF_9	0.403 (0.363)	2.187	*	0.031
	OF_10	0.195 (0.150)	1.694	*	0.093

Note: NS = not significant; *p < .05

In order to fully study the relationship between lean maturity, OHS antecedents, and OHS performance and decide to confirm/reject the theory of the present study, the collinearity assessment and total effects among constructs were evaluated. Collinearity assessment provides information of how well exogenous construct predicts the endogenous constructs. The variance inflation factor (VIF) is the related measure of the collinearity assessment. By running the PLS algorithm the results of VIF are presented. Table 6 shows the VIF results of the predictors in two sets. The first set focuses on whether lean maturity is a good predictor for OHS performance and the four antecedents of OHS performance. The second set investigates if the antecedents (working environment, workforce characteristics, task characteristics, and organizational factors) are good predictors of OHS performance.

Table 6: Collinearity assessment of latent constructs

First set		**Second set**	
Constructs	**VIF**	**Constructs**	**VIF**
Lean maturity	1.57 OHS performance	Working environment	3.22 OHS performance
	1.00 Working environment	Workforce characteristics	1.66 OHS performance
	1.00 Workforce characteristics	Task characteristics	4.39 OHS performance
	1.00 Task characteristics	Organizational factors	3.41 OHS performance
	1.00 Organizational factors		

As shown in Table 6, collinearity is not an issue among predictors constructs in the structural model, as all VIF values are lower than the maximum limit of 5. To determine the total effects among constructs, the bootstrapping means was performed, Table 7 shows the results.

Table 7: Results of total effetcs among constructs

Constructs	**OHS performance**	**Organizational factors**	**Task characteristics**	**Workforce characteristics**	**Working environment**
Lean maturity	0.304	0.423	0.567	0.528	0.546
Organizational	0.460				

factors					
Task characteristics	0.188				
Workforce Characteristics	0.298				
Working environment	0.520				

As shown in Table 7, the total effect of lean maturity on OHS performance is 0.304, while the total effects of lean maturity on the antecedents are higher (i.e., 0.567, 0.546, 0.528, 0.423). Additionally, the total effects of antecedents on OHS performance are reported as well.

5. Findings

5.1 Relationships among constructs

R^2 is the most commonly used measure to evaluate the relationship among constructs in a model. The coefficient represents the exogenous latent variables' combined effects on the endogenous latent variable (Hair et al., 2016; p. 174). Accordingly, the R^2 criterion shows how much the variance of the latent variable is being explained by the other latent variables. Table 8 depicts the amount of variance of endogenous constructs (i.e., working environment, task characteristics, workforce characteristics, organizational factors, and OHS performance) that are explained by lean maturity as exogenous construct linked to them.

Table 8: R^2 evaluation of the endogenous variables

Constructs	R^2
Working environment	0.321
Task characteristics	0.279
Workforce characteristics	0.271
Organizational factors	0.298
OHS performance	0.267

Among the antecedents, working environment has the highest R^2 value (i.e., 0.321) and the organizational factors has the lowest value (i.e., 0.298). It is worth noticing that the R^2 value of the direct influence of lean maturity on OHS performance is the lowest (i.e., 0.267).

5.2 Moderation analysis

In order to evaluate the moderating effects of company size and sector, the multi-group analysis (PLS-MGA) was performed. To this end, a parametric approach involving a two independent-sample *t* test was used to compare the path coefficients between groups of data. In SmartPLS, the standard deviation of path coefficient is performed via the bootstrapping procedure. By determining the variance of parameters in PLS, the differences between categorical moderators are assessed. Table 9 shows the moderating effects of company size and sector on the relationships among variables in the model.

Table 9: The moderating effects of company size and sector

Relationships	Small and medium vs. large			Manufacturing vs. Services		
	t value	Significance levels	*p value*	*t value*	Significance levels	*p value*
Lean→Fid	1.191	NS	0.236	0.064	NS	0.949
Lean→ Ext	0.032	NS	0.975	0.853	NS	0.395
Lean→Exp	0.902	NS	0.369	1.479	NS	0.144
Lean→WE	0.815	NS	0.417	1.481	NS	0.142
Lean→WC	0.584	NS	0.560	0.241	NS	0.810
Lean→TC	0.824	NS	0.412	2.125	NS	0.037
Lean→OF	0.956	NS	0.341	1.296	NS	0.198
Lean→OHS	0.189	NS	0.851	0.495	NS	0.622

Note: NS = not significant
Lean: Lean maturity Fid: Fidelity, Ext: Extensiveness, Exp: Experience, WE: Working environment, WC: Workforce characteristics, TC: Task characteristics, OF: Organizational factors, OHS: OHS performance

5.3 Mediation analysis

Since the antecedents of OHS performance are argued to play the role of mediators in the model, it is expected that a variation in the level of lean maturity cause variations in the antecedents, which eventually reflect on the OHS performance. In order to analyze the mediating effect of the four antecedents, first, the significance of the direct effect between lean maturity and OHS performance was evaluated. The direct relationship is significant ($p<0.05$). To this end, the bootstrapping procedure was implemented excluding the antecedents. In the next step, the mediator variables (antecedents) were included to analyze whether the indirect effect of lean maturity on OHS performance is significant via the antecedents. Table 10 provides the results of mediating effects of antecedents.

Table 10: The mediating role of antecedents in the relationship between lean and OHS performance

Relationship	Path coefficient	Relationship	Path coefficient	Lean→OHS Indirect effect	Lean→OHS Direct effect	Total effect	VAF
Lean →WE	0.56	WE→OHS	0.34	0.19	0.30	0.49	38 %
Lean →WC	0.42	WC→OHS	0.24	0.10	0.30	0.37	27 %
Lean →TC	0.52	TC→OHS	0.26	0.13	0.30	0.40	32 %
Lean →OF	0.54	OF→OHS	0.27	0.14	0.30	0.36	38 %

WE: Working environment, WC: Workforce characteristics, TC: Task characteristics, OF: Organizational factors, Lean: Lean maturity, VAF: Variance account for = indirect effect/total effect

The variance account for indicator (VAF) was adopted to measure the relative strength of the direct and mediating effects. The direct effect of lean maturity on OHS performance has a path coefficient of 0.30, whereas the indirect effects via antecedents are 0.19, 0.10, 0.13, and 0.14 for working environment, workforce characteristics, task characteristics, and organizational factors, respectively. Thus, the total effects are captured (direct effects + indirect effects) as shown in Table 10. Finally, the VAF equals the indirect effects divided by the total effects. The values of VAF are in the range 27%-38%, which highlights a partial mediating effect for all the antecedents. Workforce characteristics is the category of antecedents with the lowest VAF, while working environment and organisational factors categories show the highest VAF.

6. Discussion

Three reflective indicators (i.e., fidelity, extensiveness, and experience) were adopted in this study to explain lean maturity. Based on the obtained loading factors, the analysis demonstrates their significance. This is consistent with the studies of Ansari et al. (2010), that used the fidelity and extensiveness as the forming items of lean maturity variable, and Satoğlu and Durmuşoğlu (2003) that introduced the experience level as a parameter showing the lean maturity in industries.

Similarly, the analysis of the OHS performance construct shows a high reliability (all above the threshold level of 0.078) of all its reflective indicators (i.e., number of accidents, number of injuries, number of lost working days, and compensation cost). This confirms the results of a previous study from Hinze et al. (2013) that proposed similar OHS lagging indicators to measure the performance of OHS in the workplace. Moreover, the results of validity analysis for both lean maturity and OHS performance are both above the threshold level (i.e., 0.05) indicating high level of validity.

In a similar fashion, the quality of formative indicators was studied. Based on the research framework, the four antecedents contain formative indicators. The validity of all formative indicators linked to antecedents was in an acceptable range. Further, to check the significance and relevance of formative indicators, a *t* test was used. The results of the *t* value and the bootstrap sign change options procedure proposed by Hair et al. (2016) show that formative indicators in the model significantly contribute to their constructs (i.e., four antecedents). These findings support the results of Mousavi et al. (2017) that identify the formative indicators of each antecedent.

After determining the reliability and validity of formative and reflective constructs, it was then possible to study the relationships among the latent variables in the model. The relationship between lean maturity and OHS performance was studied first (H1). Previous studies have revealed a significant association between lean implementation and OHS performance (Conti and Angelis, 2006; Hallowell et al., 2009). Our research confirms the previous studies that report both positive and negative effects of lean implementation on OHS performance. To evaluate the prediction level of lean maturity on OHS performance, the VIF criterion was employed. The results show that lean maturity significantly predicts the OHS performance and there is not a collinearity issue in this context (i.e., VIF=1.57). The value of the path coefficient between lean maturity and OHS performance reveals a significant direct relationship between these two variables that support hypothesis H1. The results show that lean maturity has a predictive relevance for the OHS performance.

The second part of the study related to the direct effects of lean implementation on OHS antecedents, i.e. the indirect effect of lean maturity on OHS performance via OHS antecedents. A bundle of hypotheses was formulated in this context (H2 through H5). Based on a recent study from Mousavi et al. (2017), these hypotheses were formulated to assess the impact of lean implementation on four OHS antecedents (Table 8). To study the significance of path coefficients between lean maturity and the antecedents, the VIF absence of multicollinearity among variables was firstly tested, and all VIF resulted in values lower than the maximum limit of 5. The path coefficients between lean maturity and working environment, workforce characteristics, task characteristics, and organizational factors are 0.567, 0.423, 0.528, and 0.546, respectively. The strongest influence is on the working environment (0.567), whereas the workforce characteristics received the weakest influence from lean maturity (0.423). When compared to the path coefficient of the direct influence of lean maturity on OHS performance (0.304), the importance of studying OHS antecedents as possible mediators becomes apparent.

The R^2 values confirm that all the combined effects of lean maturity on OHS antecedents are significant (i.e., R^2 >0.25). Overall, the results of path coefficients, R^2 level, and total effects between lean maturity and OHS antecedents confirm the theory formulated in the present study; accordingly, the proposal of using OHS leading indicators for measuring the impact of lean implementation on OHS performance provides direction for future research.

The next part of the study intended to examine the mediation effect of antecedents between lean maturity and OHS performance (H6 through H9). The results indicate that all of the mediating effects of the four antecedents are statistically significant. Moreover, the results indicate that the working environment has the highest mediating effect on OHS performance, since the 38% of the effect of lean maturity on OHS performance is mediated by working environment. Further, since the VAF is larger than 20%, yet smaller than 80% it is concluded that working environment has a partial mediating effect between lean maturity and OHS performance. The VAF for task characteristics, workforce characteristics, and organizational factors are 32%, 27%, and 38%, respectively, which highlights the partial mediating effects of all the four OHS antecedents. These findings verify all of the proposed hypotheses, implying that to measure appropriately the impact of lean implementation on OHS performance the role of antecedents should be taken into account.

The last two hypotheses (H10 and H11) relate to the effects of company size and sector on the relationship between lean maturity and OHS performance. The multi-group analysis (PLS-MGA) was performed to compare the path coefficients between groups of data. The moderating effect of the sector was not significant; therefore, H10 must be rejected in this study. This result is not in support to the studies of Poksinska (2010) and Kim (2002), where significantly different impacts of lean implementation on OHS performance were reported in manufacturing and services sectors. In addition, the moderating effect of company size was not significant. Therefore, the H11 must be rejected as well. This result is not consistent with the study from Shah and Ward (2003), where the influence of lean implementation on OHS performance was found significantly different in small and medium sized enterprises when compared to large enterprises. Table 11 summarize the results of hypotheses testing

Table 11: Summary of hypotheses testing

Hypotheses	**Accepted? (Yes/No)**
H1: Lean implementation significantly influences OHS performance	Yes
H2: Lean implementation significantly influences working environment	Yes
H3: Lean implementation significantly influences task characteristics	Yes
H4: Lean implementation significantly influences workforce characteristics	Yes
H5: Lean implementation significantly influences organizational factors	Yes

H6: Working environment significantly mediates the relationship between lean implementation and OHS performance.	Yes
H7: Task characteristics significantly mediate the relationship between lean implementation and OHS performance.	Yes
H8: Workforce characteristics significantly mediate the relationship between lean implementation and OHS performance.	Yes
H9: Organizational factors significantly mediate the relationship between lean implementation and OHS performance.	Yes
H10: There is a significant categorical moderating effect of sector on the relationship among model constructs.	No
H11: There is a significant categorical moderating effect of business type on the relationship among model constructs	No

7. Conclusion and future research

In spite of gaining advantages from lean, incidents have been reported in implementing companies with respect to the employee safety and health conditions. Prior research attempted to investigate this complex relationship by leveraging on quantitative studies based on lagging indicators (i.e., post OHS performance measures) which resulted in ambiguous and contrasting results. Accordingly, the present study is the first attempt of using OHS leading indicators to disentangle the mechanisms of impact of lean implementation on OHS performance.

7.1 Theoretical implications

The proposed model examines the relationship between lean maturity and OHS performance and provides several theoretical implications. For instance, the novel concept of lean maturity linked to lean was utilized in the current study. Through data analysis within SmartPLS software, a strong relationship was revealed between lean maturity and its three forming items (i.e., fidelity, extensiveness, and experience). This finding is new in the lean manufacturing context and can aid the academic community in working on this issue in future research. Moreover, in order to understand the association between lean and OHS leading indicators, the relationship between the antecedents of safety performance and the OHS leading indicators was investigated. The findings showed that the antecedents of safety performance are the inputs of safety efforts; therefore, their role is significant in selecting the relevant OHS leading indicators. In other words, the antecedents are the entrance of choosing OHS leading indicators to measure the impact of lean implementation. Therefore, the mediating effects of antecedents on the relationship between lean and OHS performance is highlighted for future research.

7.2 Practical/managerial implications

Since there are some synergies and trade-offs between lean and OHS, the findings of this study can help managers and organizations to reinforce the positive effects of lean implementation and reduce its negative effects with regard to OHS conditions in the workplace. For instance, by introducing leading indicators linked to lean practices, managers can predict and monitor the effects of lean implementation programs on employee health and safety prior to an adverse event. Using OHS leading indicators facilitates the engagement of safety professionals in lean implementation processes and their relationship with lean professionals.

7.3 Study limitations and future research

The proposed hypotheses regarding the moderating effects of business size and sector (H10 and H11) have not been supported. Possibly, the relative limited size of the sample has induced this situation. Therefore, there are possible avenues for future research grounded on a larger dataset.

The contribution of lean maturity constituents has been briefly explored in this study. Therefore, to establish a deeper understanding of lean maturity and its forming items, further investigation is needed. The proposed model of the relationship between lean and safety could be additionally analyzed to verify the various variables within it and propose a validated model for illustrating the relationship between lean and OHS. The last part of this study proposes a set of dedicated OHS leading indicators for common lean practices in industry. Future work can be dedicated to deepen the analysis of such leading indicators for each lean practice. Moreover, case based studies could be conducted to investigate the relevance and usefulness of the proposed leading indicators under different mixes of lean practices and contextual factors. Additional OHS leading indicators could be proposed for specific lean practices. Overall, this study paves the way to a new stream of research where the systematic use of leading indicators is leveraged for achieving a better understanding and measurement of the multifaceted relationship between lean implementation and OHS performance.

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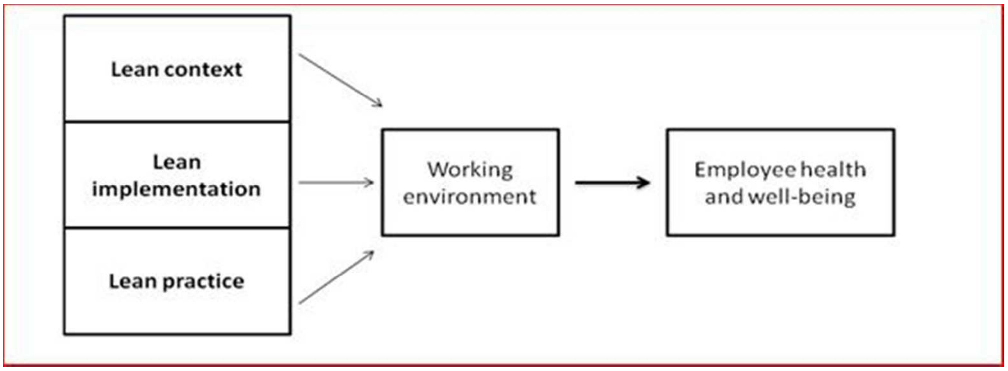

Relationship between lean and occupational health and safety (Hasle et al., 2012)

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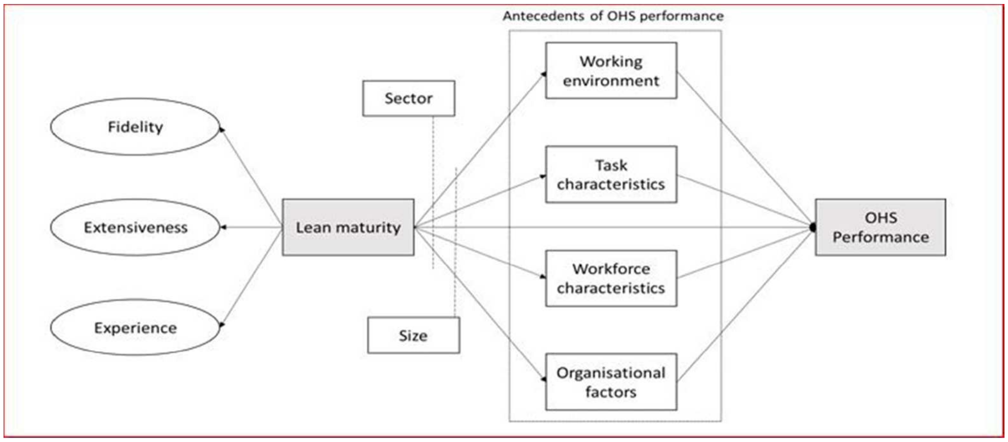

Research framework

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