

# Uncertain Supply Chain Management

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## The effect of lean on the operational performance of medium-sized Thai manufacturing companies

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### ABSTRACT

Lean practices appear to have aided organisations in improving their operations, especially manufacturing companies. This paper reports on an in-depth study comparing Thai medium-size manufacturing companies who use Lean with those which have not yet adopted Lean. In this paper the word “Lean” is used to refer to “lean practices” as well as “lean strategies”. Lean methods include just-in-time (JIT), total productive maintenance (TPM), automation, value-stream mapping (VSM), Kaizen, material requirement planning (MRP), Kanban, 5S and waste elimination. Primary data were obtained through questionnaires which were analysed using a number of statistical processes including factor analysis (CFA) and structural equation modelling (SEM). Some 230 medium-sized manufacturing companies were the focal target of this study. Three latent variables, Lean (exogenous variable), product customisation (endogenous) and operational performance (endogenous) are formed in this study. There were 24 parameters and the findings provide further evidence regarding the effects which Lean practices have on product customisation and operational performance of the companies, for example. The methods for analyzing the data favour the proposed structural equation model. The results show that Lean strategies are linked to improved operational performance in the firms which practice them. Management teams in Thai medium-size manufacturing companies which have resisted Lean are encouraged to adopt Lean in order to improve operational performance, particularly in the present economic climate.

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## 1. Introduction

The manufacturing industry is under increasing pressure to achieve operational excellence and increase efficiency in order to minimise costs and deliver higher-quality goods in a shorter period of time. Numerous manufacturing firms have used the Lean concept to accomplish this (Kumar, 2014; Boyer & Pagell, 2000; Lewis, 2000; Garza-Reyes et al., 2012). In this research report the word “Lean” refers to a set of strategies and tools for increasing the efficiency of an organisation’s objectives (Bhasin, 2012) in order to obtain a strategic edge over its competitors (Belekoukias, Garza-Reyes, Cua et al., 2001; Forrester et al., 2010; Sparrow, Hird and Cooper, 2015). The five principles of Lean established by Womack and Jones (1996, 2003) have formed the foundation of Lean philosophy. These are: i) define the customer's value, ii) describe the value stream, iii) make the value flow through the value stream, iv) extract the value from the value stream, and v) aim for perfection. According to Rocha-Lona et al. (2013), the most effective Lean approaches are just-in-time (JIT), total productive maintenance (TPM), automation, value stream mapping (VSM), and kaizen/continuous improvement (CI). JIT (just-in-time) is a strategy that helps determine the right level of inventories and services at the right time (Womack & Jones, 2003), reducing inventories, saving storage usage, and minimising wastes. The most commonly associated Lean

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tools, for example, are one-piece flow, pull system, cell manufacturing, levelled production, kanban, visual control, multifunctional staff, and JIT inventory (Ahmed, Hassan & Taha, 2004; Kumar, 2010; Liu et al., 2017).

TPM is a Lean manufacturing strategy that optimises predictive, preventive, and corrective maintenance practices to maximise efficiency and gain the most value from the employment of manufacturing equipment (Brah and Chong, 2004). TPM accomplishes this by the use of resources such as overall equipment effectiveness (OEE), single-minute die exchange (SMED), 5S, autonomous maintenance, efficiency maintenance, initial control, and a hygienic environment (Rocha-Lona et al., 2013; Randhawa & Ahuja, 2017; Upadhye, Deshmukh & Garg, 2010). Autonomy, also known as *jidoka*, is a Lean approach to quality management that employs strategies such as mistake-proofing devices (i.e. *poka-yokes*), visual control systems (i.e. *andons*), and a completely functional framework (Shingo, 1986; Romero, Gaiardelli, Power, Wuest, and Thürer, 2003). During the transformation process of a product, VSM is a Lean manufacturing method that visually defines and calculates waste caused by any form of inefficiencies of information, of time, of finance, of space, of people effort, and of machines, for example (Pavnaskar et al., 2003; Zahraee, Hashemi, Abdi & Shahpanah, 2014). A number of studies have shown that Lean production is an effective tool for improving operational performance (Cua et al., 2001; Forrester et al., 2010; Sparrow, Hird and Cooper, 2015). Just-in-time (JIT) inventory management is a well-known and widely recognised Lean approach in manufacturing. Several studies have recently shown that JIT improves operational efficiency. JIT is used in businesses to handle inventory, but it can also be used in an organisation's maintenance department to minimise waste by catering to the right services at the right time. According to studies conducted by Gupta and Jain (2013) and Phogat and Gupta (2019), implementing JIT philosophy in a maintenance department can reduce a large inventory of spare parts and reduce unnecessary maintenance time. Organisations would benefit from a planned decrease in maintenance wastes, saving them a lot of money over time (Phogat & Gupta, 2019). Hakim's research discovered that implementing the JIT method in Indonesian companies increased productivity and reduced production costs (Hakim, 2016). Meckelprang and Nair (2010) performed a meta-analysis on the effect of JIT on organisational efficiency. They discovered that JIT practices had the most significant impact on performance outcomes. Their work examined factors which had a moderating effect on the relationship between JIT practices and performance. According to their findings, JIT increased nearly every output metric, including manufacturing costs, inventory turnover, cycle time, on-time delivery, quick delivery, volume flexibility, and mix flexibility. Cost of production, inventory turnover, and cycle time of products can be viewed as important metrics which relate to a firm's productivity, according to Liu et al. (2017). They investigated the evaluation approach to a stage in the Lean transition cycle. Pull processing, regular schedule adherence, small lot size, set-up time reduction, flow-oriented layout/cellular manufacturing, and JIT supply are examples of JIT techniques. These techniques were found to improve cost efficiency by minimising manufacturing costs, cycle time, and inventory levels, including raw materials, work-in-progress (WIP), and finished goods. JIT has been widely known since the 1970s as an operations management technique designed to help manufacturing companies increase production by reducing waste. Materials and inventories must arrive when needed, thus there is little or no need for inventory. In a JIT inventory scheme, the company just buys the inventory it needs for the current manufacturing process. It is regarded as a good strategy for increasing efficiency by reducing waste by not maintaining excessive inventories (Kaneko and Nojiri, 2008). As a result, capital can be released.

According to Kyobe (2004), the JIT strategy can provide businesses with greater bargaining leverage to ensure timely deliveries, for example. JIT management philosophy is to constantly look for ways to make processes more effective and to deliver products and services without generating unnecessary waste. Approaches to reducing operational costs are critical in addressing the issue of financial constraints that many SMEs face. SMEs must look for ways not only to increase consumer satisfaction but also to lower costs. The Lean approach includes cost-cutting strategies, improved product and service quality, increased operating performance, and a greater ability to adapt to changing consumer demands. Lean practices such as JIT in conjunction with total productive maintenance (TPM), automation, value stream mapping (VSM), Kaizen, material requirement planning (MRP), Kanban, 5S, and waste elimination have been shown to have a positive impact on the operational efficiency of businesses. This has been confirmed by many researchers (Belekoukias, Garza-Reyes & Kumar, 2014; Bhasin, 2012; Boyer & Pagell, 2000; Cua et al., 2001; Forrester et al., 2010; Lewis, 2000; Garza-Reyes et al., 2012; Sparrow, Hird & Cooper, 2015). In addition, by adopting Lean practices, large companies have been able to improve their global market competitiveness (Lewis, 2000). This has been done by reducing stocks and improving quality and productivity. Many successful JIT and other Lean implementations have been shown to assist in improvements in operational, financial, and strategic operations (Chong et al., 2001; Kennedy & Hyland, 2003; Meybodi, 2003; Ahmad et al., 2004; Mistry, 2005; Salaheldin, 2005; Liao & Tu, 2008). In turn, small businesses that supply parts and components to such manufacturers have no choice but to change their business practices.

However, for a variety of reasons, SMEs seldom follow Lean practices (Ramaswamy et al., 2002). SMEs, unlike large corporations, lack the human capital and materials required for such organisational adaptations and project execution. They also appear to be reluctant to modify any part of their existing relationships with consumers, vendors, and financial institutions (Prajogo & Johnston, 1997). JIT appears to be the best known and practical among the various Lean methods for SMEs. TPM, automation, VSM, Kaizen, MRP, Kanban, and waste elimination appear to be less widely used or accepted by SMEs. JIT is perhaps more suitable for medium-sized businesses since it is more compatible with their business partners or counterparts such as large manufacturing companies. Other Lean practices do not offer such advantages. Several studies, though, have found that SMEs can themselves benefit from Lean implementations (Alkhoraif, Rashid, and McLaughlin, 2019). According to Shah and Ward (2003), contextual variables such as the company's size can affect Lean implementation.

For example, some African manufacturing SMEs have adopted JIT. Although implementing Lean practices in micro-enterprises having less than ten workers seems not to be feasible, according to Matt and Rauch (2013). However, it does seem to be possible for companies with 10 to 49 workers. Implementing Lean strategies may be a critical step toward increasing efficiency as well as increasing market competitiveness. Some Lean approaches, like multifunctional teams or total productive maintenance, are easier to adopt in SMEs than in large organisations. Just-in-Time and others would be more challenging (Åhlström, 1998; White et al., 1999).

Several writers argue that SMEs have several characteristics which make adoption of Lean practices easier than in large companies. In terms of management structure, small companies, for example, have shown greater flexibility, partly due to the fact that SMEs have less bureaucracy and shorter communication lines. Also, SME managers who are highly committed can more easily bring about the desired changes (Haksever, 1996). However, the number of SMEs who are benefiting from adopting Lean strategies is surprisingly low (Achanga et al., 2006; Elbert, 2012; Mazanai, 2012). This fact raises several questions about the obstacles and roadblocks which these businesses face. According to various analysts, SMEs face some serious challenges. When attempting to incorporate Lean practices, financial constraints seem to be the major impediment. Being small, which is both an asset and a liability, creates financial limitations as does a lack of management capability (Achanga et al., 2006; Chong, 2007; Dombrowski, Crespo and Zahn, 2010). The lack of capital and managerial experience impacts on such essentials as employee training, for example. Although the actual contribution of the human element may be minimal, if the company already lacks a customised development programme (Golhar & Stamm, 1991), or a wide product range (Cusumano, 1994), these could be additional barriers to applying Lean concepts effectively. Furthermore, a significant impediment to Lean implementation in SMEs is a lack of supplier cooperation (Alkhoraif, Rashid and McLaughlin, 2019; Finch & Cox, 1986; Satish, 2010). Some researchers are somewhat more optimistic. They say the most critical factors for effective Lean implementation in any type of enterprise are two: management engagement and motivation (Liker, 2004; Achanga et al., 2006). Employee involvement and proper application of Lean principles are two other factors (Dombrowski, Mielke and Schulze, 2012; Liker, 2004; Achanga et al., 2006; McLachlin, 1997). Lean practices, however, help SMEs boost their operational efficiency (Crute, Wickham, Johns & Graves, 2008). Knowing, understanding, and embracing Lean practices no doubt will improve the organisational efficiency of SMEs.

This present study aims to look more closely at the ramifications of Lean implementation for operational efficiency in businesses, especially in medium-sized manufacturing companies.

## 2. Research methodology

Statistical software packages were used to conduct the analyses. To determine the data's suitability for factor analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett's Test of Sphericity were used (Dziuban and Shirkey, 1974). Also, both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) are widely used in scientific studies. (Willmer, Westerberg, Lindberg, 2019). They, too, were used in this present study. EFA was performed unrotated, with eigenvalues >1 and maximum likelihood extraction. To verify the theoretical structure, EFA was used with Promax rotation with an enforced three-factor solution. Maximum likelihood extraction was used in this study. Parallel analysis (using principal axis factoring) and Velicer's Minimum Average Partial test (O'Connor, 2000) were also performed. The maximum likelihood estimation method was then used to perform the CFA. Several statistical methods were employed to evaluate the models goodness of fit: overall  $\chi^2$  (Hooper et al., 2008), root mean square error of approximation [RMSEA] (Steiger, 1990; Hooper et al., 2008), Akaike's information criterion (AIC), Bayesian information criterion (BIC), comparative fit index (CFI), Tucker-Lewis index [TLI] (Bentler, 1990), and the standardised root mean square residual [SRMSR] (Hooper et al., 2008). SEM is a mathematical technique that combines confirmatory factor analysis (CFA) and path analysis in one process. CFA calculates latent psychological characteristics like attitude, royalty, hospitality and satisfaction (Galton, 1888; Pearson and Lee, 1903; Spearman, 1904). Conversely, path analysis seeks to construct a path diagram to establish the causal relationship between variables (Wright, 1934; Irzik and Meyer, 1987). In the early 1970s, SEM (Jöreskog, 1967, 1969, 1970a, 1970b, 1973; Jöreskog and Goldberger 1975; Jöreskog & Sörbom, 1974) was widely used in a variety of fields, including social science, medical science, and natural science (Jöreskog, 1969, 1970, 1973; Jöreskog & Goldberger 1975; Fan et al., 2016).

### 2.1 Sample demographics

In this study, the respondents who answered the questionnaire were from 230 small and medium-sized enterprises. Most of them (153 or 66.5%) had Thai nationality shareholders. Some 18.7% of the respondents had mixed nationalities. The non-Thai shareholders were from Japan (36), China (9), Malaysia (7), Taiwan (6), USA (6), Singapore (5) and others (8).

### 2.2 Latent and observed variables

The questionnaire used a 1-5 Likert scale to measure the level of practices or level of agreement. In the scale, '1' indicated 'least', '5' indicated 'strongly agree'. The relationships among the variables are shown in the Table below. The latent variable 'Lean', consisting of nine Lean practices, is the exogenous variable. The endogenous variable, namely product customisation (PC), consisted of five questions. The endogenous variable, operational performance (OP), was made up of ten questions.

To estimate latent constructs, SEM makes use of a process known as confirmatory factor analysis. Since it is a commonly derived factor of other variables, and could imply a model's cause or effect, the latent variable or construct was excluded in the dataset (Boomsma, Hoyle and Panter, 2012; Hoyle, 1995, 2011; Grace, Scheiner and Schoolmaster, 2015; Kline, 2010; Byrne, 2013). The following Table shows the list of the variables used in this present study. The variables have been classified into observed and latent variables.

**Table 1**

Latent and observed variables used in the study

No.	Latent variable	Observed	Definition	Mean	Std. Deviation
1	Lean	Lean_1	Just in time inventory system (JIT)	2	1.350
		Lean_2	Total productive maintenance (TPM)	2	1.356
		Lean_3	Automation	2	1.322
		Lean_4	Value stream mapping (VSM)	2	1.312
		Lean_5	Kaizen	2	1.358
		Lean_6	Material requirement planning or MRP	3	1.329
		Lean_7	Kanban	2	1.403
		Lean_8	5S (Sort, Straighten, Shine, Standardise, and Sustain)	3	1.133
		Lean_9	Waste elimination/ single-minute exchange of die or SMED	3	1.233
2	PC (Product customisation)	PC1	Modification to the customer needs	4	0.970
		PC2	Level of product customisation	3	1.044
		PC3	The need to be product-customised	2	1.141
		PC4	Increased mobility	3	0.927
		PC5	Reduces lead-times in the production line	3	0.942
3	OP (Operational performance)	OP1	Build good relationships between suppliers and customers	3	0.894
		OP2	Responded quickly to engineering changes	3	0.902
		OP3	Increase competitiveness	3	0.835
		OP4	Increase the time-efficiency of the machine & equipment	3	0.902
		OP5	Employees work more efficiently	3	0.897
		OP6	Increase efficiency in inventory management	4	0.896
		OP7	Increase efficiency in the use of equipment machine (cost-effective)	3	0.925
		OP8	Increase the turnover of inventories	4	0.934
		OP9	Teamwork efficiency	3	0.884
		OP10	Reduce large lots purchase size	3	0.946

The present study explored nine common Lean practices. They are: JIT, TPM, Automation, VSM, Kaizen, MRP, Kanban, 5S, and SMED. The data revealed that the respondents mostly used 5S, waste elimination and MRP with means of 3.70, 3.14, and 3.12 out of 5.0, respectively.

For product customisation (PC), there were five observed variables. Three of them are: PC1, increase the capacity to respond to the needs of the customers; PC2, increase the levels of product modification; and PC 3, increase the number of ways in which customers can modify the products. The mean for PC 1 was the highest, 4.05 out of 5.0.

Ten observed variables focused on operational performance (OP). These ten observed variables determine operational performance. Three are: close supplier/customer relations, fast response to engineering changes, and improved competitive position. The highest mean was OP8 – increase the turnover of inventories, with a mean of 4.10. This was followed by OP6 – increase efficiency in inventory management, 4.07, and OP10 – reduce purchase size of large lots, 3.97.

### 3. Results

#### 3.1 Lean – Confirmatory factor analysis (Lean-CFA)

The Pearson correlation coefficient measures the linear association between two scale variables. The correlation between Lean5 and Lean7 is high, 0.803 with a p-value < 0.01. When tested for multicollinearity and reliability, these two variables passed all the strict criteria.

Cronbach's alpha, a measure for internal consistency, measures how closely related a set of items are as a group. The measure of scale reliability for Lean 1 to Lean 9 equals 0.932, a very high relationship.

It is important to examine also the diagonal elements of the anti-image correlation matrix (MSA). A value above 0.5 is acceptable. However, if the value is less than 0.5 it is recommended that it be excluded. Table 3 shows that all parameters are above 0.5. This indicates that all of the parameters are suitable and can be factor analysed.

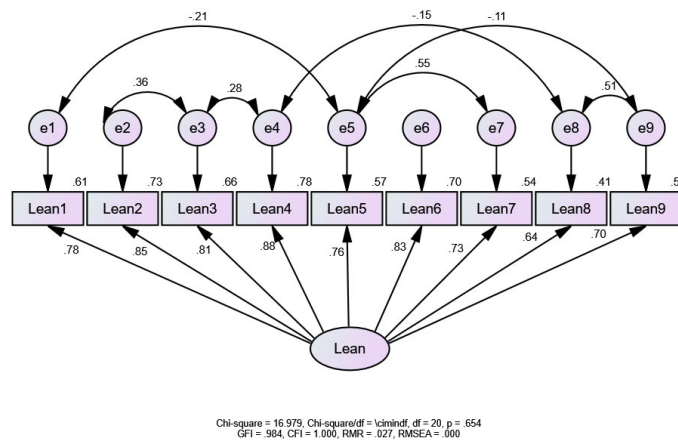
The value of anti-image matrices presenting measures of sampling adequacy (MSA) presented in Table 3 by which all parameters are above 0.5 and indicates that all parameters are suitable and can be factored analysed. See Table 2.

**Table 2**  
Correlation and Anti-Image Correlation Matrices of Lean

		Lean1	Lean2	Lean3	Lean4	Lean5	Lean6	Lean7	Lean8	Lean9
Correlation	Lean1	1.000								
	Lean2	.704***	1.000							
	Lean3	.684***	.799***	1.000						
	Lean4	.678***	.742***	.792***	1.000					
	Lean5	.486***	.649***	.586***	.668***	1.000				
	Lean6	.629***	.694***	.674***	.752***	.631***	1.000			
	Lean7	.541***	.641***	.572***	.654***	.803***	.605***	1.000		
	Lean8	.495***	.536***	.508***	.503***	.484***	.543***	.472***	1.000	
	Lean9	.566***	-.571	.563***	.617***	.480***	.613***	.518***	.731***	1.000
Anti-image Correlation	Lean1	<b>.948<sup>a</sup></b>								
	Lean2	-.247	<b>.927<sup>a</sup></b>							
	Lean3	-.139	-.419	<b>.906<sup>a</sup></b>						
	Lean4	-.136	-.029	-.394	<b>.916<sup>a</sup></b>					
	Lean5	.154	-.137	.003	-.162	<b>.858<sup>a</sup></b>				
	Lean6	-.107	-.122	-.020	-.289	-.137	<b>.957<sup>a</sup></b>			
	Lean7	-.117	-.089	.055	-.080	-.609	-.003	<b>.878<sup>a</sup></b>		
	Lean8	-.044	-.067	-.055	.129	-.132	-.071	.024	<b>.863<sup>a</sup></b>	
	Lean9	-.093	.006	.008	-.178	.111	-.130	-.103	-.565	<b>.873<sup>a</sup></b>

\*, \*\*, \*\*\* Correlation is significant at the .05, .01, .001 level (2-tailed)  
a. Measures of Sampling Adequacy(MSA)

To analyse whether the data are suitable to test for validity and reliability, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is performed. This statistic demonstrates the level of variance in the variables due to underlying factors. High values (near 1.0) indicate that factor analysis is likely to be valid and helpful in interpreting the results. On the contrary, if the values are less than 0.50, the results are unlikely to be valid. The correlation matrix illustrates whether the variables are either redundant or well suited for structure is tested by Bartlett's test of sphericity. Factor analysis may be useful with the data if the significance level is lower than 0.05. The KMO is 0.904, and the approximate chi-square of Bartlett's test of sphericity is 1628.43, the degree of freedom (df) is 36. Thus, it is statistically significant (p-value < 0.01) and suitable as Lean practice items. For correlation analyses, initial communalities are the proportion of variance accounted for each variable. Extraction communalities are estimates of the variances of each variable in the factor solution. Small-value variables are weak and unfit to be considered and eliminated from the procedure. The extraction communalities for this solution are acceptable, with Lean 4 having the highest extraction of 0.779 and Lean 8 having the lowest extraction of 0.503. When the total variance is considered, it was discovered that only one element in the initial solution had eigenvalues greater than one. It accounts for 66.135 per cent of the initial variables' variability. This information indicates that Lean practices are associated with one latent effect, but there is still room for some unknown variation. Confirmatory factor analysis (CFA) was used to evaluate the structural model's validity. The first was the Lean construct. It is based on the findings of the previous investigation. Each factor loading which shaped one latent variable – Lean – is explained in the diagram below. The most crucial parameter is Lean 4 (value stream mapping or VSM), which has a factor loading of 0.88, followed by Lean 2 (total productive maintenance or TPM), which has a factor loading of 0.85, and Lean 6 (material requirement planning or MRP), which has a factor loading of 0.83. This CFA has a chi-square of 16.979,  $\chi^2/df$  of 0.849, the p-value of 0.654 (p-values greater than 0.05 are acceptable), NFI of 0.990, RFI 0.982, IFI of 1.002, GFI of 0.984, and CFI of 1.00 (all measurements that above 0.90 are statistically acceptable). The structural equation modelling includes all parameters with factor loadings greater than 0.6 (Barclay et al., 1995).



Chi-square = 16.979, Chi-square/df =  $\chi^2/df$ , df = 20, p = .654  
GFI = .984, CFI = 1.000, RMR = .027, RMSEA = .000

**Fig. 1.** Confirmatory factor analysis of Lean

### 3.2 Product customisation (PC) – Confirmatory factor analysis (PC-CFA)

The correlation matrix of PC is illustrated in the upper section of Table 3. Some variables are correlated, while PC2 and PC3 do not show a significant correlation. Cronbach's alpha of five items, PC1-PC5, is 0.853. Also, the KMO and Bartlett tests reconfirmed their correlation as being suitable variables. The KMO value is 0.678, and the approximate chi-square of Bartlett's test is 378.916, the degree of freedom (df) is 10, and is statistically significant (p-value < 0.01). All parameters show a high potential to be included in the factor analysis. The anti-image matrices of PC1-PC5, presented in the lower section of Table 3, in the diagonal elements, show that all elements have values above 0.50. It is worth noting that PC2 and PC3 have the anti-image correlations close to 0.50 (0.518 for PC2 and 0.519 for PC3). At this stage, all of them are suitable to be included in the factor analysis. See Table 3.

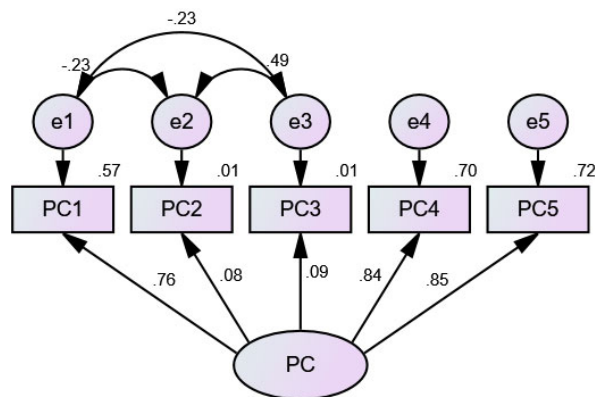
**Table 3**  
Correlation and anti-image Matrices of PC

		PC1	PC2	PC3	PC4	PC5
Correlation	PC1	1.000				
	PC2	-.091	1.000			
	PC3	-.080	.489***	1.000		
	PC4	.629***	.073	.095	1.000	
	PC5	.643***	.062	.058	.708***	1.000
Anti-image Correlation	PC1	.747 <sup>a</sup>				
	PC2	.120	.518 <sup>a</sup>			
	PC3	.110	-.466	.519 <sup>a</sup>		
	PC4	-.341	-.044	-.098	.712 <sup>a</sup>	
	PC5	-.369	-.067	-.019	-.492	.707 <sup>a</sup>

\*\* Correlation is significant at the 0.001 level (2-tailed)

a. Measures of Sampling Adequacy (MSA)

Extraction communalities of product customisation (PC) are estimates of the variance in each variable accounted for by the factors in the factor solution. All community extractions are close to 1; the least extraction is PC1 of 0.763, and the highest extractions are PC2 and PC3, both equal to 0.995. When considering the total variance explained, it is found that there are two components in the initial solution that have eigenvalues greater than 1. Two components account for 66.72% of the variability in the original variables, and there remains room for some unexplained variation. The highest rotated components with the extraction principal component method are PC5 (0.892), PC4 (0.885) and PC1 (0.861). Confirmatory factor analysis (CFA) for the product customisation parameters was carried out to check the validity of the structural model. The second conducted CFA was the PC construct. Fig. 2 below explains each factor loading for the one latent variable – PC. The most influential parameter is PC5 (reduces lead time) with a factor loading of 0.85, followed by PC4 (increase mobility) with a factor loading of 0.84 and PC1 (modification to the customer needs) with a factor loading of 0.76. While PC2 and PC3 have factor loadings lower than 0.5 (0.08 and 0.09 respectively) and insignificant p-values of 0.278 and 0.222, respectively. These two parameters were excluded in the structural equation modelling. This CFA had a chi-square of 0.597,  $c^2/df$  of 0.298 and p-value of 0.742 (p-value above 0.05 is acceptable), NFI of 0.998, RFI of 0.992, IFI of 1.004, GFI of 0.999, and CFI of 1.00 (all measurements that above 0.90 are statistically acceptable). All of the parameters, except PC 2 and PC3, have factor loadings over 0.5 and are included in the structural equation modelling.



Chi-square = .597, Chi-square/df = .298, df = 2, p = .742  
GFI = .999, CFI = 1.000, RMR = .008, RMSEA = .000

**Fig. 2.** PC Confirmatory Factor Analysis

3.3 Operational Performance (OP) – Confirmatory factor analysis (OP-CFA)

Considering the correlation of the parameters of Operational Performance (OP), the highest correlation is between OP3 and OP6 with a correlation of 0.772 (p-value <.001), while the lowest correlation is between OP1 and OP8, p-value < 0.001. When tested for multicollinearity and reliability, these variables passed all the criteria. Cronbach's alpha OP1 – OP10, all 10 items equaled 0.946. An examination of the diagonal elements of the OP anti-image correlation matrix found that all parameters have values above 0.5 and are acceptable and included in the factor analysis. See Table 4.

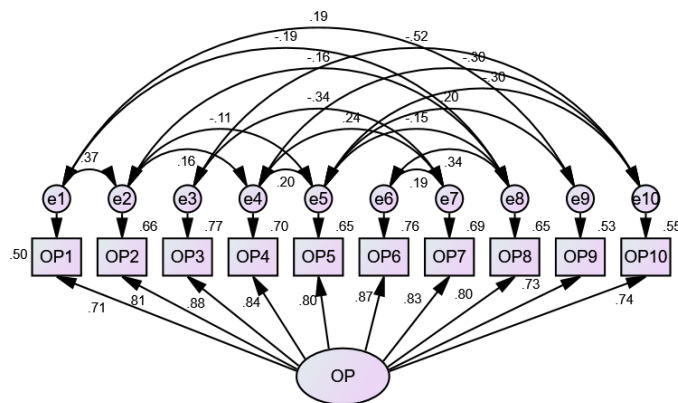
**Table 4**  
Correlation and Anti-Image Correlation Matrices of Operational Performance (OP)

Correlation	OP1	OP2	OP3	OP4	OP5	OP6	OP7	OP8	OP9	OP10	
OP1	1										
OP2	.725***	1									
OP3	.668***	.724***	1								
OP4	.602***	.731***	.721***	1							
OP5	.606***	.617***	.705***	.736**	1						
OP6	.577***	.665***	.772***	.722***	.696***	1					
OP7	.567***	.680***	.655***	.782***	.658***	.776***	1				
OP8	.473***	.573***	.669***	.665***	.589***	.811***	.701***	1			
OP9	.605***	.586***	.639***	.634***	.675***	.628***	.588***	.607***	1		
OP10	.475***	.604***	.506***	.511***	.477***	.652***	.577***	.626***	.537***	1	
Anti-image Correlation	OP1	.927 <sup>a</sup>									
	OP2	-.385	.926 <sup>a</sup>								
	OP3	-.195	-.241	.937 <sup>a</sup>							
	OP4	.062	-.282	-.120	.930 <sup>a</sup>						
	OP5	-.114	.070	-.147	-.291	.948 <sup>a</sup>					
	OP6	.000	.033	-.327	.021	-.161	.929 <sup>a</sup>				
	OP7	-.046	-.113	.120	-.364	-.039	-.285	.946 <sup>a</sup>			
	OP8	.103	.085	-.115	-.117	.088	-.411	-.095	.944 <sup>a</sup>		
	OP9	-.211	.043	-.081	-.077	-.266	.049	.024	-.149	.960 <sup>a</sup>	
	OP10	-.021	-.218	.117	.090	.026	-.140	.079	-.100	-.057	.927 <sup>a</sup>

\*, \*\*, \*\*\* Correlation is significant at the .05, .01, .001 level (2-tailed)

a. Measures of Sampling Adequacy (MSA)

This present study found that the KMO of OP 0.933 and the approximate chi-square of Bartlett’s test of sphericity was 2513.945, 66 degrees of freedom (df), which is statistically significant (p-value < 0.01). Thus, the suitability of the data regarding the operational performance (OP) items is confirmed. Extraction communalities of each parameter are high. The smallest value is on the parameter OP9 (0.631), and the highest value is on the parameter OP9 (0.874), which indicates that all parameters fit well with the factor solution and can be included in the factor analysis. When the total variance is considered, there are two factors in the initial solution which have eigenvalues greater than 1. This fact accounts for 57.373% of the variability in the original variables. Confirmatory factor analysis (CFA) was next carried out to check the validity of the structural model. The CFA for operational performance (OP) was performed. Fig. 3 below explains each factor loading for the one latent variable – OP. The most influential parameter was OP3 with the factor loading 0.88, followed by OP6 with factor loading 0.87, and OP4 with factor loading 0.84. All of the parameters have loading factors over 0.60 (Barclay et al., 1995). The chi-square for CFA is 26.827, c<sup>2</sup>/df of 1.412, a p-value of 0.109 (p-value above 0.05 is acceptable), NFI of 0.986, RFI of 0.968, IFI of 0.996, GFI of 0.978, CFI of 0.996 (all measurement that above 0.90 are statistically acceptable). All of the parameters have factor loadings over 0.5 and are included in the structural equation modelling.



Chi-square = 26.827, Chi-square/df = 1.412, p = .109  
GFI = .978, CFI = .996, RMR = .015, RMSEA = .042

**Fig. 3.** OP Confirmatory Factor Analysis

### 3.4 Structural Equation Modelling

The following Table shows the evidence of fitness indices for the three latent variables prior to building the structural equation modelling. Having shown the evidence of fitness, next reliability and validity of data were considered. Coefficients of Cronbach's alpha (a coefficient of reliability, or consistency) is presented in Table 5 (see below). The outcome was that these statistics passed all the recommendations (the alpha coefficient should have a value above 0.7 – however, 0.6 is acceptable according to Barclay et al., 1995. The alpha coefficient for the nine Lean items is .932; the five PC items is 0.853; and, for the ten OP items is 0.943. These scores indicate that all of the items have a high level of internal consistency. In most social science research contexts, a reliability coefficient of .70 or higher is considered acceptable. Therefore, in this present study, when Lean 1 to Lean 9 variables are considered, they all have a loading factor higher than 0.6. They form a latent variable which can be termed 'Lean'. This approach can be seen to be the same as for 'PC' product customisation, in which the observed variables PC1, PC4 and PC5 passed the required criteria. Only OP2 and OP3 do not pass the criteria threshold. Thus, OP1, and OP4 – OP10 can be used to form latent variable 'OP'. After performing those tests, further statistical validity checks and analyses were carried out. Confirmatory factor analysis (CFA) was used to measure the alignment of the CFA model with its variables. Each construct has degrees of freedom (df) for a chi-square goodness of fit test. (Degrees of freedom (df) greater than 1 indicates that the model is identifiable). Statistics for overall model fitness measures are Chi-square ( $\chi^2$ ), also called CMIN in SEM, relative chi-square (CMIN/DF or  $\chi^2$ /df), goodness-of-fit index (GFI), adjusted goodness-of-fit index (AGFI), normed fit index (NFI), relative fit index (RFI), incremental fit index (IFI), comparative fit index (CFI), and root mean square error of approximation (RMSEA). Some of these statistics for the overall model fit indicators are presented in Table 5. All of these statistics passed the recommended criteria (see notes under Table 5 for more explanations).

**Table 5**  
Summary of the fitness indices of the three latent variables.

Constructs	Cronbach's alpha	Fitness indices					
		NFI (Note 1)	RFI (Note 1)	IFI (Note 1)	CFI (Note 1)	RMSEA (Note 2)	$\chi^2$ /df (Note 3)
Lean*	0.932	0.990	0.982	1.002	1.000	0.000	0.849
PC**	0.853	0.998	0.992	1.004	1.000	0.000	0.298
OP***	0.946	0.986	0.968	0.996	0.996	0.042	1.412

Number of the parameters: \* = 9; \*\* = 5; \*\*\* = 10

Note 1: NFI, RFI, IFI, and CFI close to 1.0 is accepted if more than or equal to 0.95 is great (Hair et al., 2010)

Note 2: RMSEA should be less than or equal to 0.05 ( $\leq 0.05$ ) (Arbuckle, 2009, 2012; Awang, 2012); however, if RMSEA less than or equal to 0.10 ( $\leq 0.10$ ) is considerably better (Brown and Cudeck, 1993)

Note 3: CMIN/DF or  $\chi^2$ /df should be less than or equal to 2.0 ( $\leq 2$ ) (Byrne, 2010)

The SEM analyses show that the impact of Lean on product customisation (OP) is significant. Especially on Lean4 (value stream mapping, VSM), Lean2 (total productive maintenance, TPM) and Lean6 (material requirement planning, MRP) with the loading factors of 0.87, 0.85 and 0.83, respectively. As already noted, other Lean practices also have high factor loadings (above 0.60), they, too, are considered significant.

There is a significant (and positive) impact of Lean on product customisation (PC). The analysis shows that a one percent change in Lean will result in a 0.50 percent change in product customisation (PC). The three parameters of product customisation (PC), PC4 (increased mobility), PC5 (reduces lead-times), and PC1 (modification of the customer needs), are statistically significant in forming PC latent variables. Loading factors of OP1-OP10 exceed 0.6. The parameter that contains the highest factor loading is OP6 (inventory efficiency); factor loading 0.87, followed by OP7 (cost efficiency in equipment & machines), loading factor 0.86; OP4 (time-efficiency of machines & equipment) and OP9 (teamwork efficiency) both having a factor loading of 0.82. All of the loading factors have a p-value of lower than 0.05, which means they are statistically significant. These results confirm a positive impact between the PC and OP; the coefficient of PC to OP shows a loading factor of 1.00. This reveals that the PC change is entirely or 100% impacting the firms' operational performance.

In sum, when considered the structural equation modelling of these three constructs, the result favours and supports the model. The chi-square value of this model is 227.323, and the chi-square/degree of freedom is 1.337 (less than or equal to 2 is strongly recommended by Byrne, 1989), which passes the criteria by which chi-square must not be significant. The fitness of the model on several factors also confirms the reliability and model fitness. The RMSEA is .038 (less than or equal to .10 is highly recommended by Browne and Cudeck, 1993, less than or equal to .05 is recommended by Arbuckle, 2012; Awang, 2012). While GFI, AGFI, NFI, CFI and TLI have a value close to 1 (normally .90 is acceptable according to Hair et al., 2010), the values of this measurement are 0.917 (GFI), 0.951 (NFI), 0.987 (CFI) and 0.982 (TLI). See Fig. 4.



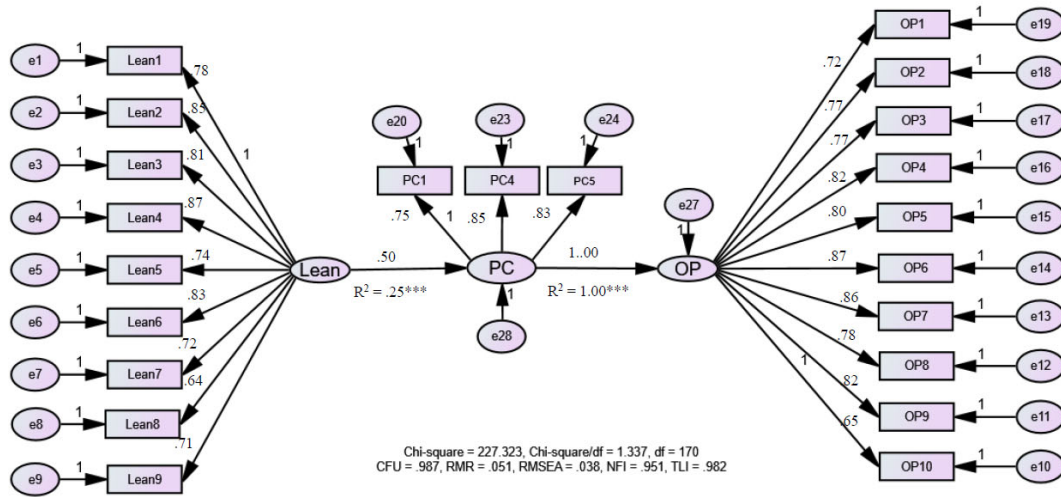


Fig. 4. Structural Equation Modelling of the study

#### 4. Discussion

For SMEs, Lean implementation can be discussed at the micro-level, which includes in-house production or operational processes. Lean implementation in SMEs are associated with productivity-type incentives, such as stock reductions, storage reductions, time reductions (i.e. substitution time, delivery time, lead time, and throughput time), and commodity price reductions, all of which, if practical, may offer significant benefits to SMEs. The structural equation modelling for Thai medium firms has been tested and confirmed: Lean is an essential tool which allows firms to increase the operational performance mediated by product customisation. Lean allows firms to respond to the fast-changing requirements of their customers. The loading factor for Lean to product customisation with a loading factor of 0.50 (a significant level with a p-value  $<.05$ ), confirms the relationship between the two latent variables. However, the most impactful Lean practice concerning product customisation is value stream mapping (VSM). Both 5S and waste elimination are the two practices that have less impact on product customisation. When the latent product customisation is studied, the parameters with high loading factors are only three. These parameters are mobility, lead-time reduction and modification to the customer needs. The other two parameters are not included because they do not pass minimum acceptance criteria. When operational performance is considered, the most impactful parameter is increased 'efficiency in inventory'. This finding is supported by previous studies: most SMEs Lean practices focus on inventory management Gupta and Jain, 2013; Hakim, 2016; Kaneko and Nojiri, 2008; Kyobe, 2004; Liu et al., 2017; Meckelprang and Nair, 2010; Phogat and Gupta, 2019; Randhawa and Ahuja, 2017; Upadhye, Deshmukh and Garg, 2010). Structural equation modelling identified the relationship between the three latent variables. Also, it was noted that the model fits well between the data and the structural model. Thus, this present study supports the recommendation that SME managers can be assured that Lean implementation can and will impact their companies' operational performance.

#### 5. Conclusions, limitations and recommendations for further research

##### 5.1 Conclusions

This paper aims to study the relationship and effect of Lean on operational efficiency in medium-sized Thai manufacturing firms. Some nine strategies were the focus. In analyzing the data, a verification approach that included correlations, confirmatory factor analysis, and structural equation modelling. Among the findings were the following: value stream mapping (VSM) had the most significant effect on product customisation among the nine Lean practices. Many researchers (Pavnaskar et al., 2003; Zahraee, Hashemi, Abdi, and Shahpanah, 2014; Pavnaskar et al., 2003; Pavnaskar et al., 2003) also revealed the significant effect of Lean practices on operational efficiency. For example, practising Lean increases mobility, shorter lead times and increases the capability to modify the products to meet customers' needs. This practice contributes to improving the operating performance of Thai medium-sized manufacturing businesses. Previous research has shown similar links between Lean: product customisation, and operational efficiency (e.g. Bhasin, 2012; Boyer & Pagell, 2000; Lewis, 2000; Garza-Reyes et al., 2012; Sparrow, Hird & Cooper, 2015). While the relevance and effect of Lean on organisational efficiency, previous research has shown that it is not uncommon for findings to vary due to a different business context, a different data collection method, or the number of variables considered, for example.

Previous studies have pointed out that the 5s (sort, straighten, shine, standardise, and sustain) are the most common company strategies but actually they make only minor contributions to product customisation, for example. Two strategies, Kanban and Kaizen, are not widely used or practised by medium-sized businesses. They, too, make only a minor contribution to operational performance according to reports from respondents in this present study. According to Olivencia (2019), they are largely ineffective. One potential reason is that employees appear to be skeptical about the value of such strategies and

workers lack commitment. However, 5S can be viewed as a system or technique which can provide a foundation for further Lean manufacturing endeavours (Randhawa & Ahuja, 2017; Upadhye, Deshmukh, & Garg, 2010), so this practice is not new to the Thai workforce, nor to Thai nationality firms or others. The 5S practice can be implemented for both manufacturing and non-manufacturing businesses. However, like Kanban and Kaizen, these practices do not contribute significantly to product customisation nor indirectly to the firm's operational performance. Also, the data of the present research project show that Kanban and Kaizen are unlikely to be seen in Thai companies unless those companies are managed by Japanese nationals or have a Japanese counterpart. New practices are difficult to initiate unless firms have specific policies that promote advanced thinking. It is worth noting that the Just-in-time (JIT) inventory system, which is a crucial component of Lean manufacturing, did make a significant contribution to product customisation. This finding was similar to those in previous research (Ahmed, Hassan & Taha, 2004; Rocha-Lona et al., 2013; Kumar, 2010; McLachlin, 1997; Liu et al., 2017, Womack and Jones, 2003). Finally, the technique of structural equation modelling confirmed that practising Lean has at the very least an indirect effect on organisational efficiency, with product customisation acting as a mediator. The core values of Lean practices work together in building a structured, high-quality system which can respond quickly to consumer demand which, in turn, results in high levels of business operational performance.

### 5.2 Managerial and theoretical implications

The research presented in this paper can help companies and their managers better understand the relationship and the impact of Lean on the performance of their operations. Some examples are: better Lean practices aligned with product customisation will help generate sales growth and efficiency of operational performance; operational performance can be enhanced by increasing the efficiency of product customisation to serve better fast-changing customer requirements. Also, Lean managing of inventories will result in a higher turnover, and also release costly storage space for other purposes, all of which will lead to higher synergy levels of the staff. These are important outcomes. Using this knowledge, managers can more confidently make Lean changes. Owners and investors of medium-sized manufacturing companies will want to encourage their managers to make Lean a priority in order to improve performance metrics. Theoretically, this present study adds to contemporary organisational literature which focuses on Lean and its contribution to performance. It also provides detailed links with similar studies carried out in other industries and contexts. Previous studies had not considered all of the strategies that are subsumed under the term 'Lean'. In addition, this present study used a larger battery of statistical procedures to explore and confirm reliability and establish concrete performance metrics related to the value of Lean.

### 5.3 Limitations and further study

The study, as do most studies, has some limitations which, hopefully, future studies may address. This present study, for example, is limited to medium-sized manufacturing companies, not large or small companies. Also, only Thai companies were included in the sample. Additionally, the data came from volunteers. Future studies could consider companies in other sectors, such as companies in the service sector, or in the trading sector (wholesale and/or retail). This present study did not take the nationality of the major shareholder into account. Some Lean practices are implemented in companies which have a predominance of foreign shareholders. For example, Kaizen is implemented in Japanese-controlled companies, while other companies may implement Kaizen but modify it. Regulations governing companies may vary significantly from one country to another. Researchers may choose to focus on different latent variables. And, some researchers may wish to focus on other factors which impact on operational performance. Last, but not least, future research could compare customer satisfaction data on companies' financial performance before and after implementing Lean. The list of possible further study topics continues to become longer. Clearly, Lean is important in this present economic environment. Much more research is encouraged.

## References

- Ahmed, S., Hassan, M.H., & Taha, Z. (2004). State of implementation of TPM in SMIs: a survey study in Malaysia. *Journal of Quality in Maintenance Engineering*, 10(2), 93–106.
- Åhlström, P. (1998). Sequences in the implementation of lean production. *European Management Journal*, 16(3), 327-334.
- Aigbedo, H. (2007). An assessment of the effect of mass customization on suppliers' inventory levels in a JIT supply chain. *European Journal of Operational Research*, 181(2), 704–715.
- Alkhorraif, A., Rashid, H., & McLaughlin, P. (2019). Lean implementation in small and medium enterprises: Literature review. *Operations Research Perspectives*, 6. <https://doi.org/10.1016/j.orp.2018.100089>.
- Arbuckle, J.L. (2009). Amos 18.0 User's Guide. USA: Amos Development Corporation.
- Arbuckle, J. L. (2012). IBM SPSS Amos 21 Users Guide. Chicago, IL: IBM Software Group.
- Awang, Z. (2012). Structural Equation Modeling Using Amos Graphic: UiTM Press.
- Brah, S.A., & Chong, W.K. (2004). Relationship between total productive maintenance and performance. *International Journal of Production Research*, 42(12), 2383-2401.
- Belekoukias, I., Garza-Reyes, J. A., & Kumar, V. (2014). The impact of lean methods and tools on the operational performance of manufacturing organisations. *International Journal of production research*, 52(18), 5346-5366.
- Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin*, 107(2), 238-46. doi:
- Bhasin, S., & Burcher, P. (2006). Lean viewed as a philosophy. *Journal of Manufacturing Technology Management*, 17(1), 56-72.

- Brown, M. W., & Cudeck, R. (1993). *Alternative Ways of Assessing Model Fit*. In K. A. Bollen, & J. S. Long (Eds.), *Testing Structural Equation Models* (pp. 136-162). Newbury Park, CA: Sage.
- Boomsma, A., Hoyle, R. H., & Panter, A. T. (2012). *The structural equation modeling research report*.
- Boyer, K.K., & Pagell, M. (2000). Measurement issues in empirical research: Improving measures of operations strategy and advanced manufacturing strategy. *Journal of Operations Management*, 18(3), 361-374
- Byrne, B.M. (2010). *Structural Equation Modeling with AMOS*. 2<sup>nd</sup> ed., Taylor & Francis Group.
- Chong, H., White, R.E., & Prybutok, V. (2001). Relationship among organizational support, JIT implementation, and performance. *Industrial Management & Data Systems*, 101(5/6), 273–281.
- Crute, V., Wickham, A., Johns, R. and Graves, A. (2008). Exploring competitive advantage through lean implementation in the Aerospace supply chain. *IFIP International Federation for Information Processing*, 257, 357–364.
- Cua, K. O., McKone, K. E., Schroeder, R. G. (2001). Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. *Journal of Operations Management*, 19(2), 675-694.
- Dombrowski, U., Crespo, I. & Zahn, T. (2010). Adaptive Configuration of a Lean Production System in Small and Medium-sized Enterprises. *Prod. Eng. Research Development*. 4, 341–348. <https://doi.org/10.1007/s11740-010-0250-5>
- Dombrowski, U., Mielke, T., & Schulze S. (2012) Employee Participation in the Implementation of Lean Production Systems. In: ElMaraghy H. (eds) *Enabling Manufacturing Competitiveness and Economic Sustainability*. Springer, Berlin, Heidelberg. [https://doi.org/10.1007/978-3-642-23860-4\\_70](https://doi.org/10.1007/978-3-642-23860-4_70)
- Dziuban, C. D., & Shirkey, E. C. (1974). When is a correlation matrix appropriate for factor analysis? Some decision rules. *Psychol. Bull.* 81, 358–361. doi: 10.1037/h0036316
- Fan, Y., Chen, J., Shirkey, G., John, R., Wu, S.R. Park, H., & Shao, C. (2016). Applications of structural equation modeling (SEM) in ecological studies: an updated review. *Ecological Process*, 5, 19 (2016). <https://doi.org/10.1186/s13717-016-0063-3>
- Forrester, P., Shimizu, U., Soriano-Meier, H., Garza-Reyes, J.A., Basso, L. (2010). Lean production, market share and value creation in the agricultural machinery sector in Brazil. *Journal of Manufacturing Technology Management*, 21(7), 853- 871.
- Galton, F. (1888) Co-relations and their measurement. *Proceedings of the Royal Society. London Series*, 45,135-145,
- Garza-Reyes, J. A., Oraifige, I., Soriano-Meier, H., Forrester, P., & Harmanto, D. (2012). The development of a lean park homes production process using process flow and simulation methods. *Journal of Manufacturing Technology Management*, 23, 178-197. 10.1108/17410381211202188.
- Grace, J. B., Scheiner, S. M., & Schoolmaster Jr, D. R. (2015). Structural equation modeling: building and evaluating causal models: Chapter 8. 10.1093/acprof:oso/9780199672547.003.0009.
- Gupta, S., & Jain, S. (2013). A literature review of lean manufacturing. *International Journal of Management Science and Engineering Management*, 8. 10.1080/17509653.2013.825074.
- Hair, J.F., Black, W.C., Babin, B.J., & Anderson, R.E. (2010). *Multivariate Data Analysis*. 7<sup>th</sup> ed. Prentice Hall, Upper Saddle River, New Jersey.
- Hakim, L. (2016). Implementation Just in Time Dalam Meningkatkan Produktivitas Efisiensi Biaya Produksi. *Journal of Research and Technology*, 1, 1.
- Hooper, D., Coughlan, J., & Mullen, M.R. (2008). Structural equation modeling: Guidelines for determining model fit. *Journal of Business Research Methods*, 6, 53–60
- Hoyle, R. H. (1995). *The structural equation modeling approach: Basic concepts and fundamental issues*. In R. H. Hoyle (Ed.), *Structural equation modeling: Concepts, issues, and applications* (p. 1–15). Sage Publications, Inc.
- Hoyle, R. H. (2011). *The SAGE library of methods in social and personality psychology. Structural equation modeling for social and personality psychology*. Sage Publications Ltd.
- Institute for Small and Medium Enterprises Development. (2006). SMEs' definition.
- Irzik, G., & Meyer, E. (1987). Causal Modeling: New Directions for Statistical Explanation. *Philosophy of Science*, 54(4), 495-514. Retrieved April 22, 2021, from <http://www.jstor.org/stable/187747>
- Jöreskog, K. G.A. (1967), Some contributions to maximum likelihood factor analysis. *Psychometrika*, 32, 443–482.
- Jöreskog, K. G. A. (1969). General approach to confirmatory maximum likelihood factor analysis. *Psychometrika*, 34, 183–202.
- Jöreskog, K. G. A. (1970a). General method for analysis of covariance structures. *Biometrika*. 57, 239–251.
- Jöreskog, K. G.A. (1970b). Estimation and testing of simplex models. *British Journal of Mathematical and Statistical Psychology*, 1970(23), 121–145.
- Jöreskog, K. G. Analysis of covariance structures. In P. R. Krishnaiah (Ed.) *Multivariate analysis—III*. New York: Academic Press, Inc., 1973, 263–285.
- Jöreskog, K. G. & Goldberger, A. S. (1975). Estimation of a model with multiple indicators and multiple causes of a single latent variable. *Journal of the American Statistical Association*, 10, 631–639.
- Jöreskog, K. G. & Sörbom, D. (1974). Some regression models useful in the measurement of change (Res. Rep. 74-3). Uppsala, Sweden: Department of Statistics, University of Uppsala.
- Kaneko, J., & Nojiri, W. (2008). The logistics of Just-in-Time between parts suppliers and car assemblers in Japan. *Journal of Transportation*, 1, 155–173.
- Kennedy, J., & Hyland, P. (2003). A comparison of manufacturing technology adoption in SMEs and large companies. In: *16th annual conference of small enterprise association of Australia and New Zealand, Ballarat, Australia, 1–10*.
- Kline, R. B. (2010). *Principles and practice of structural equation modeling*. 3<sup>rd</sup> ed., New York, New York: Guilford Press.
- Kyobe, M. (2004). Investigating the Strategic Utilization of IT Resources in the Small and Medium-sized Firms of the Eastern Free State Province. *International of Small Business Journal*, 22(2), 131–158.
- Kumar, V. (2010). JIT based quality management: concepts and implications in Indian context. *International Journal of Engineering Science and Technology*, 2(1), 40-50.
- Lewis, M.A. (2000). Lean production and sustainable competitive advantage. *International Journal of Operations & Production Management*, 20(8), 959-978. <https://doi.org/10.1108/01443570010332971>

- Liao, K., & Tu, Q. (2007). Leveraging automation and integration to improve manufacturing performance under uncertainty: An empirical study. *Journal of Manufacturing Technology Management*, 19, 38-51. 10.1108/17410380810843444.
- Liu, C., Niu, Z., Chang, P., & Zhang, B. (2017). Assessment approach to stage of lean transformation cycle based on fuzzy nearness degree and TOPSIS. *International Journal of Production Research*, 55(23), 7223-7235.
- Mackelprang, A., & Nair, A. (2010). Relationship between just-in-time manufacturing practices and performance: A meta-analytic investigation. *Journal of Operations Management*, 28, 283-302. 10.1016/j.jom.2009.10.002.
- Matt, D.T., & Rauch, E. (2013). Implementation of Lean Production in small sized enterprises. 8<sup>th</sup> CIRP Conference on Intelligent Computation in Manufacturing Engineering. *Procedia CIRP*, 12, 420-425.
- Mazanai, M. (2012). Impact of just-in-time (JIT) inventory system on efficiency, quality and flexibility among manufacturing sector, small and medium enterprises (SMEs) in South Africa. *African Journal of Business Manager*, 6(17), 5786-5791.
- McLachlin, R. (1997). Management initiatives and Just-in-Time manufacturing. *Journal of Operations Management*, 15(4), 271-292.
- Meybodi, M. Z. (2003). Using principles of just-in-time to improve new product development process. *Advances in Competitiveness Research*, 11 (1), 116-138.
- Mistry, J. J. (2005). Origins of profitability through JIT processes in the supply chain. *Industrial Management & Data Systems*, 105(5/6), 752-768.
- O'Connor, B. P. (2000). SPSS and SAS programs for determining the number of components using parallel analysis and Velicer's MAP test. *Behav. Res. Methods Instrum. Comput.* 32, 396-402. doi: 10.3758/bf03200807
- Olivencia, S. (2019). Kanban without Kaizen is pointless. *The lean global network journal*. <https://planet-lean.com/kanban-without-kaizen-pointless/>
- Pavnaskar, S.J., Gershenson, J.K., & Jambekar, A.B. (2003). Classification scheme for lean manufacturing tools. *International Journal of Production Research*, 41(13), 3075-3090.
- Phogat, S., & Gupta, A. (2017). Theoretical analysis of JIT elements for implementation in maintenance sector. *Uncertain Supply Chain Management*, 5(3), 187-200.
- Phogat, S., & Gupta, A. K. (2019). Expected maintenance waste reduction benefits after implementation of Just in Time (JIT) philosophy in maintenance (a statistical analysis). *Journal of Quality in Maintenance Engineering*, 25(1), 25-40.
- Prajogo, N. H., & Johnston, R.B. (1997). Barriers to just-in-time implementation in small manufacturing enterprises. Department of Business Systems, Monash University, 90-93.
- Randhawa, J.S., & Ahuja, I.S. (2017). 5S – a quality improvement tool for sustainable performance: literature review and directions. *International Journal of Quality & Reliability Management*, 34(3), 334-361. <https://doi.org/10.1108/IJQRM-03-2015-0045>
- Ramaswamy, N.R., Selladurai, V., & Gunasekaran, A. (2002). Just-in-time implementation in small and medium enterprises. *Work Study*, 51(2/3), 85-90.
- Rocha-Lona, L., Garza-Reyes J.A., Kumar, V. (2013), Building quality management systems: selecting the right methods and tools, Productivity Press, CRC Press, Taylor & Francis, Boca Raton, FL.
- Romero, D., Gaiardelli, P., Powell, D., Wuest, T., & Thürer, M. (2019). Rethinking jidoka systems under automation & learning perspectives in the digital lean manufacturing world. *IFAC-PapersOnLine*, 52(13), 899-903.
- Salaheldin, S. I. (2005). JIT implementation in Egyptian manufacturing firms: Some empirical evidence. *International Journal of Operations & Production Management*, 25(4), 354-370.
- Shingo, S. (1981), A study of Toyota production system: from an industrial engineering viewpoint, Japan Management Association, Tokyo
- Sparrow, P., Hird, M., & Cooper, C.L. (2015) Lean Management and Organizational Effectiveness. In: Do We Need HR?. Palgrave Macmillan, London. [https://doi.org/10.1057/9781137313775\\_4](https://doi.org/10.1057/9781137313775_4)
- Spearman, C. (1904). The proof and measurement of association between two things. *The American Journal of Psychology*, 15(1), 72-101.
- Steiger, J. H. (1990). Structural model evaluation and modification: an interval estimation approach. *Multivariate Behav. Res.* 25, 173-180. doi: 10.1207/s15327906mbr2502\_4
- Upadhye, N., Deshmukh, S.G., & Garg, S. (2010). Lean manufacturing in biscuit manufacturing plant: a case. *International Journal of Advanced Operations Management*, 2(1-2), 108-139.
- Wright, S. (1934). The Method of Path Coefficients. *The Annals of Mathematical Statistics*, 5(3), 161-215. Retrieved April 22, 2021, from <http://www.jstor.org/stable/2957502>
- Willmer, M., Westerberg, J. J., & Lindberg, M. (2019). Exploratory and Confirmatory Factor Analysis of the 9-Item Utrecht Work Engagement Scale in a Multi-Occupational Female Sample: A Cross-Sectional Study. *Frontiers in Psychology*, 10, 2771.
- Womack, J. P., & Jones, D. T. (1996). Lean thinking: Banish waste and create wealth in your corporation.
- Zahraee, S., & Hashemi, A., Abdi, A., & Shahpanah, A. (2014). Lean Manufacturing Implementation Through Value Stream Mapping: A Case Study. *Journal Teknologi*, 68, 119-124. 10.11113/jt.v68.2957.

