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VALIDATION OF LEAN MANUFACTURING MEASUREMENT INSTRUMENT

Gusman Nawanir
Lim Kong Teong
Siti Norezam Othman
School of Technology Management and Logistics
Universiti Utara Malaysia, Kedah, Malaysia

ABSTRACT

This study is intended to provide a valid and reliable measurement instrument for lean manufacturing practices. It is important as lack of consensus regarding the valid and comprehensive measure of lean manufacturing implementation was observed in lean manufacturing literature. 182 large and discrete process manufacturers in Indonesia were involved in this study. A structural equation modeling approach was applied to validate the instrument. The study led to the conclusion that the measurement instrument is valid and reliable. In addition, the study suggested that lean manufacturing practices should be implemented holistically and simultaneously because they are interdependent.

Keywords: *Lean manufacturing, measurement instrument, indonesia*

RESEARCH BACKGROUND

Quoting an avowal of Russell and Taylor (2011), there was a bit difference between Toyota Production System (TPS), just-in-time (JIT) and lean manufacturing (LM) in practice. Consequently, the terms TPS, JIT and LM were frequently used interchangeably in the subject-related literature (Heizer & Render, 2011). A number of studies have noted the similarity between TPS, JIT, and LM. For instance, Slack, Chambers, and Johnston (2010) discovered that the practices of LM and JIT are similar. Correspondingly, Arif-Uz-Zaman and Ahsan (2014) specified that the substance of LM is TPS, which is based on JIT. On top of that, according to Papadopoulou and Özbayrak (2005), LM is purely an Americanized version of the TPS or similarly the JIT. Likewise, Chavez, Gimenez, Fynes, Wiengarten, and Yu (2013), and Thanki and Thakkar (2014) also affirmed that LM referred to a manufacturing system initiated by Toyota, which was branded as TPS. In this study, the term of LM is used to cover all the related approaches and techniques.

Even though a number of recent studies claimed the similarity between LM, TPS, and JIT; a number of practitioners and academicians have postulated that there was no consensus on definition and set of practices of LM in the literature (Pettersen, 2009; Shah & Ward, 2007). The definitions and practices are varied widely based on the authors' background. Lack of agreement on LM concept is a major problem that may be a reason why LM succeeded in some firms and failed in some others (Fullerton & Wempe, 2009; Hadid & Mansouri, 2014; Pettersen, 2009). A number of possible consequences may be caused by this issue, such as difficulties in describing objectives of the concept, hard to claim implication of LM implementation, and difficulties in evaluating effectiveness of the practices (Nawanir, Lim, & Othman, 2015).

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As an attempt to overcome this issue, the present study reviewed the related literature to redefine the concept of LM, offer a set of practices, and provide a set of measurement instrument for assessing LM practices. Subsequently, the measurement is validated by applying a structural equation modeling (SEM) approach.

LITERATURE REVIEW

An extensive review on LM literature revealed that sometimes LM was usually summarized in very brief statements (Ahmad, Schroeder, & Sinha, 2003), while the LM is a complex subject. Occasionally, the essential information being absent, in such a way it instigated misunderstanding in realizing the concept. A number of studies have attempted to produce several definitions of LM. Some of the definitions are as follows,

a. LM is an holistic approach to continuous improvement based on the concept of abolishing non value added activities in a manufacturing process (Sakakibara, Flynn, Schroeder, & Morris, 1997).
b. LM is an integrated management system that synergistically addressed improvement of operations performance in the production system (Bartezzaghi & Turco, 1989).
c. LM is a manufacturing philosophy, which involves having the right items with right quality and quantity in the right place and at the right time, in such a way, it is related to higher productivity, higher quality, lower costs, and higher profits (Cheng & Podolsky, 1993).

Synthesizing the definitions given by previous studies led to the conclusion that albeit the concepts of LM are endlessly escalating, the scholars in this subject matter agreed that the basic underlying objective of LM is to eliminate non-value added activities in a production system, not only in the production plant but also in the entire supply chain networks. The non-value added activities were commonly recognized as waste of production, including over production, defects, unnecessary movement, over processing, inventory, transportation, and delay. These types of non-value added activities were called seven cardinal waste by Ohno (1988). In general, based on the definitions, it is appropriate to define LM as *"an approach synergistically addressing to eliminate waste in a production system to increase companies' performance."*

Currently, the concept, scope and focus of LM are continually expanding. A review of several key studies indicated that although a large body of empirical studies had been conducted in LM, different authors offered different set of LM practices. The practices of LM were varied based on the author's background and experience (Ramarapu, Mehra, & Frolick, 1995). Sometimes, practices of LM have frequently been understood quite roughly. Even, Fullerton and Wempe (2009) stated that the wide-ranging nature of the interpretation of LM in literature seems to be a foremost reason of misunderstandings among the scholars in this topic. Hence, in order to be able to grab essential benefits of LM in enhancing the companies' performance, the precise practices must be taken place and well-established. This is reasonable as Ramarapu et al. (1995) stated the triumph of LM is contingent on the employment of its practices. However, albeit a number of studies have attempted to pinpoint the fundamental practices of LM, there was still no agreement among the practitioners and academicians with respect to the importance of each practice. The absence of the consensus may be the focal reason why the scholars presented the diverse set of practices to cover the concept (Belekoukias, Garza-Reyes, & Kumar, 2014).

Several studies have noted that LM practices must be employed holistically as a total system (Cheng & Podolsky, 1993; Furlan, Vinelli, & Dal Pont, 2011; Singh & Ahuja, 2014). Applying the LM practices in isolation is highly not recommended, because the prospective benefits of LM may not be grasped until all the practices are employed in a holistic manner (Cheng & Podolsky, 1993; Furlan et al., 2011; Singh & Ahuja, 2014). In other words, applying the practices in a selective manner (or piecemeal) may fail a company to enhance its desired performance Nawanir, Lim, and Othman (In Press).

Recently, a number of scholars, such as Shah and Ward (2003, 2007), Furlan et al. (2011), and Nawanir, Lim, and Othman (2013) have even developed a concept of bundle or complementarity of LM practices. Through an in-depth review on literature, this study endeavors to produce a bundle of LM practices those have been formerly established in a number of previous studies to augment the companies' performance. Numerous past conceptual and empirical researches were used to pinpoint the LM practices by considering its substantial impact on performance. In picking the practices, the common practices from the prior studies were collected by regrouping them into nine practices as follows,

a. Flexible resources. It is an LM practice, which focuses on achieving manufacturing flexibility through the use of multi-functional machines and equipment, multi-skilled workers, and trainings (Russell & Taylor, 2011).
b. Cellular layouts. This practice is addressed to ensure flexibility of facility layout by combining flexibility of process layout with efficiency of product layout based on the concept of group technology (Finch, 2008).
c. Pull system. It is a production system applying the concept of demand-based. In other words, production and material movement are only being conducted based upon request from customer (Stevenson, 2012).
d. Small lot production. This practice is addressed to match production rate to demand rate (Finch, 2008) as well as to achieve the ideal lot size of one (Russell & Taylor, 2011).
e. Quick setup. It a practice of LM aimed to reduce setup time from running one specific product to another. It ultimately enables a company to respond to variability in customer demand quickly (Sakakibara et al., 1997).
f. Uniform production level. This practice aims to reduce variability at production level caused by fluctuations in customer demand, which may cause greater incidence of creating waste (Russell & Taylor, 2011).
g. Quality control. The main objective of this practice is to ensure quality at the beginning of each process. It guarantees that the product being passed to subsequent workstation is high quality, no defect, no reject, and conforms the required specification (Shah & Ward, 2007).
h. Total productive maintenance (TPM). It is implemented for supporting the LM system. It ensures the availability and efficient use of equipment (Ahuja & Khanba, 2007).
i. Supplier networks. It is to ensure suppliers' ability to deliver the products as promised, just as it is needed, in the right quantity at the right time in the right place (Shah & Ward, 2007).

METHODOLOGY

Measurement

Overall, there are 64 measurement items used to assess the employment of LM practices in this study. Sample items are depicted in Appendix A. Each item was addressed to measure a specific content that was adapted from several recent literatures. The measurements used perceptual scale with six-point Likert scale; strongly disagree (1) to strongly agree (6). The use of this scale was rationalized by Krosnick and Fabrigar (1991) who postulated that the five, six, and seven-point Likert scales are more valid and reliable than the shorter and longer scales. In addition, Krosnick (1991) also recommended using the six-point Likert scale because it prevents the respondents from answering the neutral point or a midpoint, which is considered as an ambiguous response. According to him, it may affect to the decreasing of measurement quality in terms of construct validity and reliability. Therefore, the use of six-point scale helps to increase construct validity and reliability of instrument through controlling social desirability bias of answering in a neutral point.

Content Validity

Once it has been developed, the instrument as a whole was validated and evaluated before the final administration (de Vaus, 2002). To ensure and further enhance the content validity, readability, and brevity; the instrument was pre-tested and reviewed by several academicians and practitioners who are specialist in operations management, especially LM. Experts consisting of five academicians and three practitioners were involved. The pre-test alerts the researcher to any probable harms that may be affected by the instrument. A series of consultation and structured interviews had been performed to examine whether there are any questions that need to be included or excluded from the instrument; whether the content of the instrument is adequate; whether the accurate questions being asked; and whether the questions are easy to understand. The responses and comments were used to develop a better instrument through clarifying the wordings, and some items may be added, discarded, or modified.

Data Collection

After revising the instruments based the feedbacks obtained from the pre-test, the data was then collected. The data collection was started in February 2013 and was ended in August 2013 in large and discrete process industries in Indonesia. Besides because of the industries are the most commonly selected industries in the LM past studies, the selection was rationalized by the assumption that LM is more appropriate to be implemented in the discrete process industries. In other words, the implementation of LM in the discrete process company is different from the continuous process industries. Hence, it may reduce variability of level of implementation of LM in this study. The industries involved in this study are as follows, textiles; wearing apparel; tanning and dressing of leather; wood and products of wood except furniture and plaiting materials; machinery and equipment; electrical machinery and apparatus; radio, television and communication equipment and apparatus; medical, precision and optical instruments, watches and clocks; motor vehicles, trailers and semi-trailers; other transport equipment; and furniture.

By applying the stratified random sampling procedure, 1000 questionnaires were distributed. 206 manufacturing companies have successfully returned the completed questionnaire booklet, leading to 20.60% response rate. However, 24 responses were not included into the following data analyses because of several reasons; such as an inappropriate person to answer the questionnaire, incomplete response, a lot of missing values, irrelevant business nature, and unsuitable type of production process employed in the companies. Finally, 182 data sets were usable for the further data analyses, leading to 18.20% effective response rate.

FINDING AND DISCUSSION

Construct Validity and Reliability

After revising the measurement instruments based the feedbacks obtained from the pre-test, the measurement models were assessed by using SEM approach. AMOS 21 software package was used for this purpose. In an SEM approach, assessment on measurement models is addressed to assess the relationship between manifest variables (i.e., observed variable from the questionnaire) with their underlying construct (i.e., latent variable). This assessment is important to ensure how well manifest variables represent a latent variable. It was done by applying confirmatory factor analysis (CFA) separately (i.e., per construct or indicator) because of the constraint of sample size (Hair, Black, Babin, & Anderson, 2010).

Measurement model of each practice of LM was assessed in terms of convergent validity and goodness of fit (GOF). Convergent validity confirms that measurement items of a specific construct converge together and share a high proportion of variance in common (Hair et al., 2010). In other words, convergent validity reflects unidimensionality of the measurement items. For this purpose, factor loadings, average variance extracted (AVE), and composite reliability (CR) were assessed. Besides convergent validity, GOF indicating how closely the data fit the model was also assessed. Hair et al. (2010) stated that model fit compared the theory to reality through assessment of similarity between estimated covariance matrix (theory) and observed covariance matrix (reality). In this study, the χ^2 statistics, χ^2/df, RMSEA, SRMR, CFI, and NNFI were used as the indicators of GOF.

The results of CFA of the measurement model of each practice of LM are reported in Table 1. Based on the table, nine items must be discarded from the subsequent data analysis. The reasons of deleting the items are either as follows (1) low factor loading. High factor loading is required to achieve unidimensionality among the measurement items. Low factor loading may also lead to poor GOF; (2) redundancy among the items. Redundancy among the items was examined through the modification indices (MIs) table resulted by AMOS software. The MIs statistically indicate the covariance between each pair of items, which is shown through the correlated error of the respective measurement items.

Table 1 shows that all factor loadings are acceptable, which are greater than .700. Based on the factor loadings, AVE and CR were computed. The AVEs of LM practices ranges between .610 and .745, and are high in magnitude. Similarly, CR of all the constructs indicating internal consistencies of measurement items are also in high level. CR values of LM practices are greater than .851. Based on the factor loadings, AVEs, and CRs, the criteria of convergent validity are successfully fulfilled for all the LM practices. In conclusion; for each construct, all the items are unidimensional and converge or share a high proportion of variance in common.

The results of assessment on GOF are also presented in Table 1. The *p*-values indicating the significance level of χ^2 are significant at .05 for the majority of the measurement models, except for three constructs (i.e., flexible resources, pull system, quick setups). However, according to Hair et al. (2010), the χ^2 is sensitive to sample size. Due to this sensitivity, Hair et al. (2010) suggested not to use χ^2 as a sole criterion of GOF. As indicated in Table 1, the other criteria of GOF (i.e., χ^2/df, RMSEA, SRMR, CFI, and NNFI) are satisfactory. Based on the table, χ^2/df is less than 3.00 (Bagozzi & Yi, 1988), RMSEA is less .10 (Chen, Curran, Bollen, Kirby, & Paxton, 2008), SRMR is less .08 (Hu & Bentler, 1998), and NNFI and CFI are greater than .90 (Bagozzi & Yi, 1988). Thus, all the measurement models are considered fit the data. In short, no difference between theory and reality.

Although in a factor analysis, normality assumption is not critical and rarely used (Hair et al., 2010), this study attempted to ensure that the data used in the CFA are normally distributed because normality is a critical assumption for SEM, especially for maximum likelihood estimation. According to Hair et al. (2010), it is more efficient and unbiased when this assumption is met. As shown in Table 2, all the skewness and kurtosis values fall within the acceptable level of ±2 for skewness and ±7 for kurtosis (Curran, West, & Finch, 1996; West, Finch, & Curran, 1995). In other words, the data are approximately distributed normally.

Table 1
Summary of CFA of measurement item (n = 182)

Construct*	Deleted Items	Factor Loading**	AVE	CR	Goodness of Fit Indices				
					χ^2/df	RMSEA	SRMR	NNFI	CFI
Flexible resources (7)	FR5	.748 - .901	.688	.901	1.170	.057	.019	.989	.993
Cellular layouts (8)	None	.769 - .916	.682	.921	2.697	.085	.025	.969	.978
Pull system (6)	PS6	.831 - .894	.745	.916	1.275	.034	.011	.997	.999
Small lot production (7)	SLP7	.827 - .889	.743	.928	2.923	.090	.019	.977	.986
Quick setup (7)	QS5	.754 - .820	.610	.851	1.811	.059	.022	.984	.991
Uniform production level (7)	UPL2	.713 - .879	.677	.895	2.902	.090	.024	.972	.983
Quality control (8)	None	.778 - .866	.665	.913	2.470	.079	.026	.971	.979
TPM (7)	None	.778 - .889	.712	.925	2.156	.070	.020	.983	.988
Supplier networks (7)	None	.755 - .895	.708	.923	1.916	.062	.019	.986	.991

Note. *Number in bracket is number of item before deletion. **Range of factor loading for all the retained items.

Table 2
Summary of normality assessment (n = 182)

Construct	Statistics*	
	Skewness	Kurtosis
Flexible resources	.297 - .851	.071 - .857
Cellular layouts	.564 - 1.108	.015 - 1.244
Pull system	.660 - .957	.028 - .459
Small lot production	.182 - .473	.411 - .879
Quick setup	.261 - 1.020	.034 - .927
Uniform production level	.217 - .947	.136 - .653
Quality control	.614 - 1.295	.194 - 2.290
TPM	.426 - 1.147	.206 - 1.503
Supplier networks	.507 - 1.464	.111 - 2.968

*Range of skewness and kurtosis for all the retained items (all values are in absolute value)

Criterion-related Validity

As unidimensionality of the measurement items in each construct was successfully achieved, the measurement items can be parceled to become a single construct (Bandalos & Finney, 2009; Coffman & MacCallum, 2005). Unidimensionality indicates that all the remaining items in a particular construct share a high proportion of variance in common. In short, all the items within each parcel load on the same factor. In this study, summated scale was used to construct the parcels by aggregating a number of individual measures into a single composite variable (Hair et al., 2010), by taking the simple mean of a number of unidimensional items assumed to reflect their theoretical construct (Bou-Llusar, Escrig-Tena, Roca-Puig, & Beltran-Martin, 2009; Hair et al., 2010). Nine parcels (LM practices) were constructed. Based on the parcels, criterion-related validity was assessed.

Criterion-related validity provides evidence about how well the score of a variable correlates with the score of other variables that theoretically should be related (Kimberlin & Winterstein, 2008). Pearson's correlation analysis was used to assess this type of validity. As expected, correlation coefficients among the LM practices are positive and significant at .01 level (see Table 3). In addition, for the purpose of assessing criterion-related validity, all the LM practices were correlated with inventory minimization, which is one indicator of waste reduction in an LM system. The inventory minimization was indicated by reduction in inventory levels (i.e., raw material, work in process, and finished goods), reduction in storage space requirement, elimination in overproduction, and improvement in inventory turnover. As indicated in Table 3, the correlations between all the LM practices and inventory minimization are positive and significant at .01 level. Hence, this evidence indicates strong criterion-related validity (Sekaran & Bougie, 2009).

Table 3

Pearson's correlation among the LM practices

LM Practices	1	2	3	4	5	6	7	8	9
1. Flexible resource	1								
2. Cellular layouts	.782	1							
3. Pull system	.720	.703	1						
4. Small lots production	.888	.814	.795	1					
5. Quick setup	.783	.796	.727	.859	1				
6. Uniform production level	.826	.844	.841	.917	.879	1			
7. Quality control	.780	.749	.756	.881	.811	.881	1		
8. TPM	.797	.746	.728	.870	.793	.844	.854	1	
9. Supplier networks	.758	.741	.752	.840	.762	.862	.845	.810	1
Criterion: Inventory minimization	.568	.554	.512	.621	.584	.626	.603	.585	.551

Note. Correlations are statistically significant at the 0.01 level (1-tailed).

More importantly, the high correlations among the LM practices imply that all the practices must be implemented holistically, because the interdependent nature of relationship among them. This implies an inter-connectivity among the practices (Feld, 2001). In line with the finding, LM was conceptualized as a combination of manufacturing practices, which are endeavored to reduce waste in a manufacturing system. All the practices are critical for the success of LM deployment. Hence, practicing certain practices but ignoring some other practices are highly not recommended.

A number of authors, such as Dal Pont, Furlan, and Vinelli (2008), Furlan et al. (2011), Hofer, Eroglu, and Hofer (2012), and Shah and Ward (2003), observed that the divergent practices of LM may work together as a system because they complement each other. This finding is consistent with the complementarity theory (Milgrom & Roberts, 1990, 1995). This theory conceptualized that two practices are complementary when adoption of one practice may subsequently enhance the contribution of another and vice-versa. The theory also suspected that the total impact of complement practices to ongoing improvement will be remarkably larger rather than adopting as a standalone practice (Khanchanapong et al., 2014).

IMPLICATION OF THE STUDY

The present study identified a comprehensive and validated measurement instrument for LM. The use of the measurement items allows future studies to investigate the level of implementation of LM more comprehensive and accurate. Practically, this study provided a valuable tool for practitioners to assess the level of LM implementation in their companies. It can be used to evaluate their companies quantitatively and take possible actions in order to enhance companies' performance. In addition, the study also conveys the idea of holistic implementation of LM as empirically supported by Pearson's correlation among the LM practices in this study. It implies that LM practices should be implemented simultaneously because they are interdependent, mutually supportive, and complement to each other. In other words, they are equally imperative in cultivating companies' performance. The absence of one practice may negatively affect the implementation of others. Thus, practicing LM in isolation (as a subset) may bring the companies to the unsuccessful implementation and fail to grab the potential benefits of its adoption.

LIMITATION AND SUGGESTION FOR FUTURE RESEARCH

This study is not without limitation. It is common in all survey-based research, which assumes that the respondents are knowledgeable enough to answer the research instrument. Other than that, the data used in the study is based on self-reporting, although there is no common method variance as indicated by Harman's single factor test (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003), data collection from multiple respondents from one company is suggested for future studies. In addition, this study was contextualized in large and discrete process manufacturing companies. Thus, the results of this study may be less valid for different context. Testing this instrument in a different context is suggested for future studies.

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Notes

1. Measurement instrument developed in this study is useful to guide manufacturing companies in implementing LM. It is also a suitable instrument to assess and justify the practices that should be applied. In addition, the instrument is valuable to determine the company's areas that need further attention, in order to enhance its performance.
2. Please contact the corresponding authors for the complete list of the measurement instrument.

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Appendix A: Sample of Measurement Items

Code	Question	Literature
Flexible Resources		
FR2	If one production worker is absent, another production worker can perform the same responsibilities.	Finch (2008); Hirano (1989); Sakakibara, Flynn, and Schroeder (1993)
FR4	We use general-purpose machines, which can perform several basic functions.	Russell and Taylor (2011); Hirano (1989); Nawanir et al. (2013)
Cellular Layouts		
CL4	Production facilities are arranged in relation to each other, so that material handling is minimized.	Russell and Taylor (2011); Hirano (1989); Nawanir et al. (2013)
CL5	Machines can be easily moved from one workstation to another.	Sakakibara et al. (1993); Hirano (1989); Nawanir et al. (2013)
Pull System		
PS3	We produce an item only when requested for by its users.	Russell and Taylor (2011); Shah and Ward (2007); Nawanir et al. (2013)
PS4	To authorize orders to suppliers, we use supplier kanban that rotates between factory and suppliers.	Russell and Taylor (2011); Nawanir et al. (2013)
Small Lot Production		
SLP1	We produce in more frequent but smaller lot size.	Russell and Taylor (2011); Finch (2008); Agus and Hajinoor (2012)
SLP6	In our production system, we strictly avoid flow of one type of item in large quantity together.	Ohno (1988); ; Agus and Hajinoor (2012)
Quick Setups		
QS2	Production workers perform their own machines' setups.	Sakakibara et al. (1993); Nawanir, Othman, and Lim (2010)
QS4	We emphasize to put all tools in normal storage location.	Hirano (1989)
Uniform Production Level		
UPL3	Each product is produced in a relatively fixed quantity per production period.	Cheng and Podolsky (1993); Jones (2006); Coleman and Vaghefi (1994)
UPL5	Daily production of different product models is arranged in the same ratio with monthly demand.	Russell and Taylor (2011); Jones (2006); Coleman and Vaghefi (1994)
Quality Control		
QC5	Production workers can identify quality problems easily.	Russell and Taylor (2011); Hirano (1989); Nawanir et al. (2013)
QC8	Production workers are trained for quality control.	Cheng and Podolsky (1993)
Total Productive Maintenance		
TPM2	We dedicate periodic inspection to keep machines in operation.	Ahuja and Khanba (2007); Nawanir et al. (2013)
TPM5	We have a time reserved each day for maintenance activities.	Sakakibara et al. (1993); Shah and Ward (2007)
Supplier Networks		
SN1	We facilitate suppliers to maintain a warehouse near to our plant.	Russell and Taylor (2011); Nawanir et al. (2010)
SN4	We regularly solve problems jointly with suppliers.	Heizer and Render (2011); Nawanir et al. (2013)

Note. Please contact the corresponding author for the complete list of the measurement items.