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Developing and validating lean manufacturing constructs: an SEM approach

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Abstract

Purpose – The purpose of this paper is to provide valid and reliable constructs for lean manufacturing (LM) for assessing its implementation level in order to target areas of improvement.
Design/methodology/approach – Based on an extensive review on LM literature and content validity assessment from practitioners and academicians, nine LM constructs were identified. Measurement items for each construct were developed to become a complete questionnaire. The questionnaire booklets were distributed to large and discrete manufacturing companies in Indonesia. Out of 1,000 survey questionnaires sent, 236 usable responses were returned giving response rate of 23.60 percent. Subsequently, an empirical assessment on the constructs was done by using structural equation modeling approach.
Findings – The study identified the valid and reliable LM constructs, consisting of nine LM constructs and 64 measurement items. The study found that all the constructs are complementary and mutually supportive with each other. Indeed, it suggests the holistic implementation of all the LM practices.
Research limitations/implications – Owing the time and resource constraint, this study only involved large and discrete process manufacturing industries in Indonesia. Hence, the generalization of the result is slightly limited. More studies in several different contexts are required.
Practical implications – This study provided a valuable tool for researchers for gaining deeper understanding regarding the LM and its implementation. For practitioners, it is useful to evaluate the degree of LM employment in their companies, to target area of improvement, as well as to take possible actions in attempting to enhance the organizational performance. More importantly, practitioners should adopt all the LM practices in a holistic manner.
Originality/value – This study is the first attempt to develop LM constructs for evaluating the LM implementation in Indonesia.

Keywords Indonesia, Lean manufacturing, Lean manufacturing constructs, Lean manufacturing practices
Paper type Research paper

Introduction

In the today's global competitive business, lean manufacturing (LM) has been playing an important role to enhance companies' performance, not only performance at the operations levels but also at the business level. Several studies noted this fact as a consensus that the appropriate implementation of LM would subsequently leverage companies' performance (Jasti and Kodali, 2016; Nawanir *et al.*, 2013; Sharma *et al.*, 2015; Uhrin *et al.*, 2017). Hofer *et al.* (2012) acknowledged LM as a gold standard of modern operations management. This fact indicates that the waste elimination concept emphasized by an LM system has successfully conveyed the significant impact to various industries. Nowadays, LM has been proven to be a valuable manufacturing strategy far beyond its original industry (i.e. automobile industry); it has recently been applied in a wide variety of industries, not only automobile industry, but also other sectors like textile, machinery equipment, electrical, electronics, and even wood and furniture industries (Furlan, Dal Pont and Vinelli, 2011).

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Even though a number of studies have highlighted the significant effects of LM on organizational performance, there is less agreement regarding the concept and primary constructs constituting under LM. Different authors offered different concepts and constructs. The constructs of LM have varied based on the authors' background. A number of studies have offered their own measurement instruments to assess the level of LM implementation, such as Sakakibara *et al.* (1993) and Shah and Ward (2007). However, to some extent, the measurement instrument did not capture the overall aspects of LM. According to Wan and Chen (2008), this was because the less attention has been paid on "how the lean system is" compared to "how to become leaner." In addition, it was also because most of the practitioners only used their own measurement instrument to portray the current status of their own manufacturing system, without emphasizing whether or not their systems have met the principles of LM itself. An extensive review noted that a comprehensive measure to assess the LM has not been established. In other words, the need to evaluate the overall leanness has not been fully addressed. Moreover, an empirical study supporting a comprehensive use of manufacturing activities representing multiple aspects of LM is still lacking.

In short, the literature indicates that an integrated measure of overall leanness has not been taking place. The study on developing and validating the integrated and comprehensive LM constructs is definitely required. This study becomes important because practitioners can use the important LM practices and activities to obtain a more rigorous knowledge on the current status of LM implementation. In addition, it can be used to assign responsibilities within a company for accomplishing organization-wide enhancements in LM implementation. Further, to measure the extent of LM implementation, the measurement items developed in this study could be used to assess and justify the practices that should be applied and improved in order to enhance organizational performance. The measurement is valuable to determine the company's areas that need more attention.

This study is aimed at: identifying the LM constructs, developing the measurement instrument for LM constructs and validating the measurement instrument empirically by using data from manufacturing companies. The paper proceeds with definition and basic concept of LM, development of LM practices and complementarity among the practices. Subsequently, research methodology and empirical assessment on the constructs will be presented. The paper will discuss the findings and implications of the study. Finally, the paper will be ended with limitation and suggestion for future research.

Definition and basic concept of LM

Although the concepts of LM were endlessly expanding and evolving as the LM concept is being more globally accepted (Goyal and Deshmukh, 1992; Jasti and Kodali, 2016), there was a consensus that the fundamental objective of LM is to leverage organizational performance through waste elimination. Considering the definitions of LM from several literature (Cheng and Podolsky, 1993; Eswaramoorthi *et al.*, 2011; Nawanir *et al.*, 2010; Shah and Ward, 2007), this study defined LM as "a comprehensive and holistic approach synergistically addressing to enhance organizational performance through waste elimination." Following Womack and Jones (2003), waste was defined as "all the activities that utilize resources, but create no value."

Based on the definition, LM primarily emphasizes on eliminating the consumption of resources that adds no value to products and processes. As formerly presented by Ohno (1988), there are seven types of cardinal waste, which LM attempts to eliminate. They are over productions, unnecessary inventory, defects (or poor quality), unnecessary motions (movement), over processing (i.e. doing more work than necessary), waiting (delay) and transportation. Additionally, Womack and Jones (2003) introduced another type of waste known as behavioral waste, which is related to underutilized human capital. These eight types of waste are all attempted to be eliminated through the deployment of LM. In short, LM focuses on how to eliminate all types of waste in a production system to enhance organizational performance.

Developing LM constructs

Construct is frequently defined as concepts that are abstract, complex and cannot be directly observed (Hair *et al.*, 2014). It is a variable that is not directly measured, which is frequently called as latent variable. Constructs were categorized into higher-order construct and lower-order construct. The higher-order construct is a statistical method to confirm that the theorized construct in a study loads into a certain number of underlying lower-order constructs. Measurement items (also called as indicators or manifest variables) are used to indicate a construct, which are the direct indicators that contain the raw data. As an example, flexible resource is a construct, which is directly non-measurable. To measure the construct, a set of manifest variables (measureable items) must be used, such as the use of multi-skilled employees, the employment of general-purpose machines, etc. All the manifest variables should sufficiently indicate their underlying construct.

For LM to perform well in eliminating everything that does not add value to product, process and service; some fundamental practices must be in place. The triumph of LM depends on the employment of its practices (Ramarapu *et al.*, 1995). Chen and Tan (2011), Mackelprang and Nair (2010) revealed that although many studies have been addressed to identify the fundamental practices of LM, there was a lack of agreement among the scholars regarding the importance of each practice. The differences are the reason why scholars offered different set of practices to operationalize the LM concept. The practices varied widely based on the researchers' background and the different collection of features (Ramarapu *et al.*, 1995).

As the concept that is constantly evolving and widening, it is not easy to formulate the consistent practices of LM. However, based on the literature review, several scholars strongly agreed that potential benefits of LM cannot be fully realized until all the practices are implemented integrally and holistically (Cheng and Podolsky, 1993; Goyal and Deshmukh, 1992; Jasti and Kodali, 2016). Even, Shah and Ward (2007) noted that LM must be applied as a total system, implementation of any part of them will not be successful to convey a company to an outstanding position. Borrowing the terms used by Ramarapu *et al.* (1995), piecemeal adoption will only create "island of LM" but would not significantly contribute to the company-wide improvement that increases its competitiveness. These implied that all the practices should be implemented to achieve outstanding performance. These may have encouraged several studies in LM, such as Dal Pont *et al.* (2008), Furlan, Vinelli and Dal Pont (2011) and Shah and Ward (2003, 2007), to formulate the concept of LM bundles, suggesting that the whole practices must be implemented as a bundle, instead of in isolation.

Through an in-depth literature review, this study attempted to produce the bundle of LM practices that have been proven as effective practices to enhance companies' performance. A number of conceptual and empirical studies were identified and used to develop LM practices by considering their significant impact on performance. In selecting the practices, the common practices from 32 articles published within 1993–2016 were compiled. Subsequently, the practices were regrouped based on their similarity into nine related practices as exhibited in Table I. Even though this study did not comprise some of the practices discussed in previous studies as separated components, many were incorporated into related practices.

Flexible resources

Resources are often recognized as an essential determinant factor of enhancing performance and competitive advantage. Chauhan and Singh (2013) stated that sustainable competitive

Lean practices	Literature
1. Flexible resources	
Training for multiple tasks	1, 3, 4, 7, 9, 10, 13, 19, 20, 22, 23, 25, 26, 30, 31
Multi-skilled workers	2, 4, 5, 6, 7, 8, 23, 24, 25, 26, 27, 30
Multi-functional machines	2, 9, 11, 30
2. Cellular layouts	
Cellular manufacturing/Group technology/JIT layout	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 24, 25, 26, 27, 29, 30, 31, 32
3. Pull/Kanban system	
Kanban system	1, 2, 4, 5, 7, 8, 10, 11, 12, 13, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32
Pull system	1, 6, 10, 11, 14, 18, 20, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32
4. Small lot production	
Small lot production/Lot size reduction	1, 2, 3, 6, 9, 11, 13, 17, 18, 21, 22, 23, 24, 25, 27, 30
5. Quick setups	
Setup time reduction	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 31, 32
Training for quick setup	3, 4, 10, 11, 12, 13, 16, 19, 20, 21, 28, 31
6. Uniform production level	
Daily schedule adherence	1, 2, 7, 11, 13, 14, 18, 21, 22, 23, 24, 25, 26, 27, 29, 30
Repetitive production	2, 4, 11, 12, 14, 18, 21, 24, 25, 27, 28, 29, 30
Uniform workload	2, 4, 5, 8, 11, 12, 23, 25, 27, 29, 30
7. Quality control	
Quality at the source	2, 3, 4, 5, 8, 10, 13, 16, 17, 22, 23, 24, 25, 26, 27, 29, 30, 31, 32
Statistical quality control	2, 3, 4, 5, 8, 10, 13, 19, 22, 24, 25, 26, 29, 30, 31
Training for quality control	3, 4, 9, 10, 13, 19, 20, 21, 29, 31
Quality circle	2, 3, 4, 20, 25, 26, 29, 30
8. Total productive maintenance (TPM)	
Preventive maintenance	1, 2, 3, 4, 6, 9, 10, 12, 17, 18, 19, 23, 24, 25, 27, 29, 30, 31, 32
Training for maintenance activities	3, 4, 10, 13, 19, 20, 21, 30, 31
9. Supplier networks	
JIT delivery by suppliers	1, 2, 4, 5, 7, 8, 9, 10, 11, 12, 13, 18, 19, 21, 22, 23, 25, 26, 27, 28, 30, 31
Supplier involvement	2, 3, 4, 5, 7, 8, 9, 10, 15, 21, 23, 24, 25, 26, 29, 30, 31
Supplier development program	2, 3, 4, 5, 8, 9, 10, 15, 23, 24, 25, 26, 29, 30, 31
Long-term agreement with supplier	2, 3, 4, 5, 8, 9, 10, 11, 23, 24, 25, 26, 29, 30, 31

Notes: 1 = Sakakibara *et al.* (1993); 2 = Lee and Paek (1995); 3 = Ramarapu *et al.* (1995); 4 = Callen *et al.* (2000); 5 = Fullerton and McWatters (2001); 6 = Shah and Ward (2003); 7 = Ahmad *et al.* (2003); 8 = Fullerton *et al.* (2003); 9 = Kannan and Tan (2005); 10 = Shah and Ward (2007); 11 = Matsui (2007); 12 = Abdallah and Matsui (2007); 13 = Dal Pont *et al.* (2008); 14 = Hallgren and Olhager (2009); 15 = Jayaram *et al.* (2008); 16 = Fullerton and Wempe (2009); 17 = Rahman *et al.* (2010); 18 = Mackelprang and Nair (2010); 19 = Taj and Morosan (2011); 20 = Yang *et al.* (2011); 21 = Furlan, Dal Pont and Vinelli (2011); 22 = Furlan, Vinelli and Dal Pont (2011); 23 = Chen and Tan (2011); 24 = Eswaramoorthi *et al.* (2011); 25 = Marodin and Saurin (2013); 26 = Khanchanapong *et al.* (2014); 27 = Belekoukias *et al.* (2014); 28 = Al-Zu'bi (2015); 29 = Sharma *et al.* (2015); 30 = Jasti and Kodali (2016); 31 = Godinho Filho *et al.* (2016); 32 = Zahraee (2016)

Table I. Practices of LM

advantage could be established through the use of flexible resources. Review on the LM literature indicated that manufacturing flexibility could be achieved through the use of multi-skilled workers, and multi-functional machines and equipment.

Chauhan and Singh (2013) stated that optimum deployment of resources can be accomplished through flexible workers, who are able to perform multiple tasks. Thus, they can involve in multiple activities. To augment workers' flexibility, they must undergo trainings in order to be able to perform multiple jobs and possess redundant capabilities (Furlan, Vinelli and Dal Pont, 2011; Rahman *et al.*, 2010; Uhrin *et al.*, 2017). Besides human resources-related activities, the use of multi-functional machines and equipment is preferable in an LM system to increase manufacturing flexibility (Bartezzaghi and Turco, 1989; Jasti and Kodali, 2016). Consequently, waste caused by movement to other machines, setting up machines and waiting would be eliminated admirably. For these purposes, the flexible resources should be supported by cellular layouts.

Cellular layouts

Literature emphasized the importance of this practice to increase shop floor flexibility. Finch (2008) stated that this practice combines flexibility of process layout with efficiency of product layout based on the concept of group technology. Using this type of layout, dissimilar machines are grouped into workstations that process families of products with the similar requirements such as sizes, shapes, routing or processing (Fullerton and Wempe, 2009; Hofer *et al.*, 2011). In other words, workstations, machines and equipment are sequenced in order to support smooth flow of materials with minimum transport and delay.

Cellular layout is attractive because of the following reasons: first, workstations and machines are arranged in relation to each other. This minimizes transportation, material handling and storage (Matsui, 2007; Monden, 2012); second, machines are laid out in close proximity to each other (Matsui, 2007; Sakakibara *et al.*, 1993). This abridges workers to handle multiple operations; third, cells tend to utilize small-scale equipment (Finch, 2008). Thus, layout is easily relocated to adapt to variations in volume, design or product developments; and fourth, this layout eliminates material movements through distance reduction, inventory minimization and space requirement reduction (Matsui, 2007; Sakakibara *et al.*, 1993). Sakakibara *et al.* (1993) included this practice as a major driving force of outstanding company's performance.

Pull system

The LM plants apply pull system. Its basic idea is to produce only when requested, move to precisely where required just as it is needed (Al-Zu'bi, 2015; Chen and Tan, 2013). In the final process, finished goods are pulled by customer demand (Shah and Ward, 2007). In this system, kanban is used to authorize production and material movement (Rahman *et al.*, 2013). Kanban refers to the work signaling system to trigger actions (Chen and Tan, 2011). A kanban specifies the material order point, how much it is required and to where it should be delivered (Russell and Taylor, 2011). Nowadays, to ease operations, kanban is modified in several forms, depending upon the context where it is used. So that, albeit it is named as kanban, other verbal signals (e.g. empty container, electronic message, flag, etc.) are used as the alerts that it is time to start producing or transferring materials (Rahman *et al.*, 2013).

Kanban is also used to release orders from suppliers. It is known as supplier kanban (Aziz and Hafez, 2013). Recently, electronic kanban (e-kanban) has widely been used to facilitate interaction with suppliers (Monden, 2012; Powell, 2013). Thus, the manufacturer does not pass any kanban cards manually to the handlers who are responsible for moving parts and materials, but uses information technology to release orders to suppliers (Powell, 2013).

According to Sakakibara *et al.* (1993), pull system and application of kanban (or e-kanban) are extremely important in an LM system. By pull system, overproduction could be avoided; only necessary quantities are produced, which are defined by shop floor operations, not by schedule prepared in advance. Hence, inventory could be eliminated admirably.

Small lot production

Lot size refers to a quantity of items that are produced together (Agus and Hajinoor, 2012). In an LM system, producing in small lot size is preferable to match production to demand rate (Finch, 2008) as well as to achieve the ideal lot size of one (Agus and Hajinoor, 2012). Besides production, LM also emphasizes reducing purchasing lot size (Bartezzaghi and Turco, 1989). The ability of suppliers to deliver the products in small lot size is essential in an LM system.

Even though lot size of one may be infeasible for certain context, reducing lot size must be emphasized. Nowadays, a number of scholars categorized small lot production as a key practice of LM. It could bring companies to enjoy the following benefits: reducing lead time (i.e. processing time, moving time, waiting time, queuing time and setup time) (Fullerton and McWatters, 2001); improving quality because quality problems are easier to detect, and workers have fewer tendencies to let poor-quality passes (Fullerton and McWatters, 2001); reducing inventory level (Chen and Tan, 2013; Lee and Paek, 1995), because the average level of inventory is a function of quantity produced in a batch; and enhancing manufacturing flexibility, in terms of product mix, volume, routing and layouts (Fullerton and McWatters, 2001).

Quick setup

Quick setup is a technique of reducing times it takes to setup or changeover a process from processing one specific product to another (Chen and Tan, 2011). Small lot production can only be realized when the setups are performed quickly (Chen and Tan, 2013; Fullerton and Wempe, 2009). For this purpose, the principle of single-minute exchange of die is frequently applied. Its basic idea is to separate internal and external setups, and subsequently convert most of the internal setups to external setups (Al-Zu'bi, 2015; Russell and Taylor, 2011). Therefore, most of the setup processes are performed while the machine is running.

To support the quick setup, Hirano (2009) and Fynes and Voss (2002) highlighted the importance of waste elimination of searching tools by keeping them in a normal storage location. It aims to avoid any troubles in finding tools that may extend the setup time. Additionally, according to Dal Pont *et al.* (2008) and Matsui (2007), training for quick setup is essential to ensure the effectiveness and efficiency of setup processes.

Agus and Hajinoor (2012) summarized the benefits of quick setup as follows: it enables the shop floor to perform setup in an efficient way; it reduces total costs; it shortens lead times; it reduces inventory; it increases productivity; it increases flexibility to adapt to demand variations; and it allows mixing of product without incurring higher costs.

Uniform production level

An LM system attempts to maintain uniform production levels in the final assembly line (Russell and Taylor, 2011). It endeavors to reduce variability caused by demand fluctuations. Using this practice, production is managed by leveling production by volume and product types to guard against variability of demand (Coleman and Vaghefi, 1994; Jones, 2006). It is critical to create the LM system because it is the key of achieving stability of a production system.

To achieve the stability, mixed-model production should be applied (Mackelprang and Nair, 2010) through producing several different models daily. Monthly demand is divided into daily and spread out as evenly as possible. Therefore, the same amount of each item is produced each day, and items produced are mixed throughout the day in small lot size. To ensure the steady production, the plant must be able to meet its daily production schedule (Ahmad *et al.*, 2003). In addition, implementing this practice may encourage steady production, increase flexibility and support pull system implementation. It also enables a predictable process as well as a smooth flow of products throughout the processes with minimum inventory.

Quality control

In an LM system, quality must be ensured at the very beginning of each process to guarantee that only good quality of product can be passed to the subsequent workstation. For this purpose, quality at the source is implemented (Sharma *et al.*, 2015; Zahraee, 2016). When an abnormality happens, machines are automatically stopped, and sources of the problem can be observed accurately and producing defects can be avoided (Agus and Hajinoor, 2012).

To support the quality at the source, visual control systems are used to make the abnormalities observable (Karim and Arif-Uz-Zaman, 2013). Thus, immediate corrective actions could be performed. To ensure that the abnormalities are noticeable, visual control tools (e.g. *pokayoke*, *andons*, control charts, etc.) are used (Godinho Filho *et al.*, 2016; Karim and Arif-Uz-Zaman, 2013; Sharma *et al.*, 2015). The use of the tools would encourage operators to deal with the early signals of abnormalities. Hence, it ensures that each process supplies defect-free units to its subsequent process. Besides the visual control, LM requires statistical quality control to monitor the outputs and processes (Godinho Filho *et al.*, 2016; Shah and Ward, 2007; Zelbst *et al.*, 2010).

More importantly, quality circle plays an important role to assist manufacturers to increase quality (Callen *et al.*, 2000; Fullerton *et al.*, 2003; Lee and Paek, 1995; Monden, 2012). By meeting regularly, quality problems could be discussed, strategies of problem solving could be designed and some suggestions could be addressed to management to acquire superior quality. Moreover, to support the quality control activities, production workers should undergo trainings related to quality control (Cheng and Podolsky, 1993; Kaynak, 2002).

Total productive maintenance (TPM)

TPM aims to support and sustain the LM system because availability and efficient use of equipment are pre-requisite of LM implementation (Ahuja and Khanba, 2007). Nakajima (1988) stated that the word "total" refers to total effectiveness, total maintenance system and total participation of employees. Nakajima (1988) postulated the following attributes of TPM: it establishes a total planned maintenance system consisting of preventive maintenance and improvement-related maintenance; it aims at getting the most efficient use of equipment; it involves total participation of all workers at all management levels; and it implements planned maintenance based on autonomous and small-group activities.

According to Nakajima (1988), preventive maintenance is a main element of TPM involving periodic inspections and services to identify any potential failures and make minor adjustments to avoid major operating problems. To ensure the total workers involvement, they must be familiar with both production and maintenance activities (Nakamura *et al.*, 1998). For this purpose, training related to maintenance tasks is absolutely required. Bakerjan (1994) noted that the lack of sufficient training is a major cause of failure in the TPM implementation. Therefore, training is essential to support the success of TPM.

There was a consensus that preventive maintenance is critical to LM success (Abdallah and Matsui, 2007; Chen and Tan, 2011; Matsui, 2007; Taj and Morosan, 2011) because it may increase labor and machine productivities, equipment operating ratio and inventory turnover ratio. At the same time, it decreases equipment breakdowns, tools replacement time and cost of defects.

Supplier networks

Supplier network is a critical factor for the LM success (Furlan, Vinelli and Dal Pont, 2011; Mackelprang and Nair, 2010; Matsui, 2007; Shah and Ward, 2007). Nowadays, practitioners give much attention to the role of suppliers to support a company's operations. Close relationships with suppliers are indispensable for the triumph of LM. An LM system requires buyers and suppliers to work together as a strategic collaborator for mutual benefits with a goal of eliminating waste.

One of the most important requirements of LM system is on-time delivery from suppliers (Godinho Filho *et al.*, 2016; Shah and Ward, 2007; Sharma *et al.*, 2015). Suppliers must be able to deliver materials in the JIT basis. For this purpose, the buyer must design a transportation system compatible with JIT delivery. These facilitate the suppliers to deliver their products as promised. Another attribute of supplier networks is long-term relationship with suppliers (Godinho Filho *et al.*, 2016; Sharma *et al.*, 2015). Rahman *et al.* (2010) suggested to maintain long-term relationship with fewer suppliers that have been proven credible and certified for quality. Numerous aspects, such as enhanced quality of materials, improved product quality, reduced lead time and increased productivity, are important benefits of long-term relationship with fewer suppliers (Kaynak, 2002).

More importantly, LM system requires high capability of suppliers to ensure the smoothness of production. To ensure their capability, supplier development programs should regularly be conducted by a lean manufacturer (Jayaram *et al.*, 2008; Shah and Ward, 2007). Through the programs, the suppliers can be more involved in various parts of focal company's activities.

Complementarity relationships among the LM practices

The complementarity theory was invented by Edgeworth (1881) who defined organizational activities or practices as complementarity as "if doing (more of) any one of them increases the returns to doing (more of) the others." It assumes that separate practices cannot be independently fine-tuned to realize outstanding performance, and thus considering complementarity among the practices is substantial from the perspective of their influence on performance. Furlan, Vinelli and Dal Pont (2011) highlighted that the two practices are complementary when adoption of one will increase marginal returns of another practice and vice versa. Some practices tended to be adopted together because they are complementary or mutually supportive with each other (Milgrom and Roberts, 1990, 1995). Hence, it is suspected that the total impact to ongoing improvement will be marvelously greater than adopting as standalone practice. Even, according to Tanriverdi (2005), implementing a single practice without implementing others may not lead to the desired performance; it may even reduce overall performance.

Interestingly, in line with the complementarity concept; Lee *et al.* (2010) provided idea of super-additive value and sub-additive cost. According to them, two practices may enjoy super-additive value synergies if their joint value is greater than the sum of their individual values. It can be represented as the value $(a, b) >$ value (a) + value (b). The super-additive value synergies may produce a super-modular return (Milgrom and Roberts, 1990, 1995). In terms of cost reduction, a company may enjoy sub-additive cost if the implementation of practices simultaneously reduces joint production costs in a greater extent than the sum of their individual cost reduction (Lee *et al.*, 2010; Tanriverdi, 2005). In short, cost reduction $(a, b) >$ cost reduction (a) + cost reduction (b). Hence, the sub-additive cost synergies may produce sub-modular costs as presented by Milgrom and Roberts (1990, 1995). In other words, based on the theory, complementarity among manufacturing practices may create super-modular return and generate sub-modular costs. Subsequently, a company could potentially improve its performance through super-modular return and sub-modular cost advantages. According to Lee *et al.* (2010), companies those gain superior performance through complementarity of organizational practices are expected to sustain the advantage over long periods of time.

Similar to Dal Pont *et al.* (2008), Shah and Ward (2003) highlighted that although the practices diverse, they tend to be inter-related to each other. Shah and Ward (2007) stated that complementarity of the highly correlated LM practices contributed to the superior ability to achieve multiple performance measures. Albeit each of distinct practice can contribute to certain performance; the holistic practices are able to enhance more comprehensive performance outcomes. The more the LM practices are concurrently implemented, the more the performance measures may be achieved. Thus, the simultaneous implementation of LM may increase the ability to compete through inimitable practices and capabilities.

Papadopoulou and Özbayrak (2005) stated that the practices constituting under LM, such as small lot production, quick setup and pull system are complementary practices. They are inseparable parts of LM to enhance performance. The viability of LM implementation depends on a number of complementary practices (Papadopoulou and Özbayrak, 2005). In this study, the authors attempted to rely on the complementarity theory to provide useful and in-depth perspective to understand the relationship among the LM practices. This theory provides the basis to understand how various practices are inter-related (Milgrom and Roberts, 1990, 1995). The complementarity concept rigorously explains how a combination of synergistic and mutually reinforcing practices leads to the better performance and competitive advantage.

Methodology

Measurement development

To enhance the objectivity of measurement, data were collected by using a set of a close-ended questionnaire with ordered choice questions. Each measurement item was addressed to measure a specific content that was adopted and adapted from several sources. Table AI provides the items used to measure the extent of LM practices. The perceptual scale from 1 (i.e. strongly disagree) to 6 (strongly agree) is used in this study.

Content validity

Once the instrument had been developed based on the literature searches, each item and the questionnaire as a whole was validated before the final administration. It is critical to refine measures prior to confirmatory testing (Hair *et al.*, 2014). If the content of a construct or questionnaire is faulty and inappropriate, the result of the study will be defective, even though statistical construct validity and reliability are sufficed.

To ensure and further enhance the content validity, readability and brevity, the instrument was pre-tested and reviewed by 7 academicians and 11 practitioners who were specialists in LM. This alerted the authors to any potential problems that may be caused by questionnaire design. It included consultation and interviews with the participants to examine the following aspects of the measurement scales: whether there are any questions that need to be included or excluded; whether the content of the instrument is sufficient; whether the right questions being asked; and whether the questions are easy to understand. The feedback from the participants were used to develop the better instrument by clarifying the wordings, and some measurement items were added, discarded or modified. The revised instrument resulted from the pre-test was used to investigate the relationship between the variables.

Data collection

The directory published by BPS-Statistics Indonesia (2010) provided the data of 6,790 large manufacturers in Indonesia. A company is considered large if having more than 100 employees (BPS-Statistics Indonesia, 2010; Furlan, Dal Pont and Vinelli, 2011). The original list was reduced to 3,091 by eliminating sectors that are mostly non-discrete process industries, such as chemical, food and beverage, etc. Using stratified random sampling procedure, 1,000 companies were selected and mailed the questionnaire.

It was addressed to the middle and top management positions within the production division, such as production manager, head of department, director and other related positions. The completed survey booklets were returned in the enclosed self-address envelope with stamp, which was provided by the researchers.

Respondent profile

A total of 262 responses were returned. However, because of a few missing values and outliers, only 236 responses were usable, leading to an effective response rate of 23.60 percent. The companies represent a wide variety of industries: they are electrical machinery and equipment (8.90 percent); machinery and equipment (11.86 percent); medical, optical instruments, watches and clocks (9.32 percent); motor vehicles, trailers, semi-trailers and other transport equipment (12.71 percent); radio, television and communication equipment (6.36 percent); tanning and dressing of leather (5.08 percent); textiles and wearing apparel (28.81 percent); and wood, products of wood (including furniture) and plaiting materials (16.95 percent). Based on the usable responses; a total of 158 (66.85 percent) respondents are production manager, 44 (18.64 percent) are head of production departments and 21 (8.90 percent) are production directors. Else, 13 (5.51 percent) were appointed in other middle management positions under production department, such as LM implementer (three respondents), production internal auditor (four respondents) and Six Sigma Master Black Belt (three respondents).

Empirical assessment of the construct

The data were analyzed by using structural equation modeling (SEM) with AMOS 22. Measurement model was assessed simultaneously by using second-order confirmatory factor analysis (CFA) for all the latent constructs. LM is the second-order construct, and its practices are first-order constructs. This stage was aimed to assess goodness of fit (GOF) and construct validity. GOF measures and all factor loadings of each measure are presented in Figure 1.

Goodness of fit

GOF is intended to examine how closely the data fit the model through comparing the estimated covariance matrix (theory) and the observed covariance matrix (reality) (Hair *et al.*, 2014). Hair *et al.* (2014) suggested that using three or four fit indices provides adequate evidence of model fit, because they are often redundant. Figure 1 indicates that all the indices are in the acceptable level, whereby χ^2/df is 1.74, which is less than 3.00 (Bagozzi and Yi, 1988). RMSEA is 0.06, which is less than 0.08 (Browne and Cudeck, 1992); RMR is 0.07, which is also lower than 0.08 (Hu and Bentler, 1998). In addition, NNFI and CFI are 0.90 and 0.90, respectively, which are also at the acceptable level (Bentler and Bonett, 1980). Hence, the measurement model fits the data well.

Construct validity

Construct validity ensures that instrument accurately measures what is intended to measure (Hair *et al.*, 2014). Thus, the conclusion from a research can be shared confidently (Garver and Mentzer, 1999). Three of the most widely reported forms of construct validity are convergent, discriminant and criterion-related validity.

Convergent validity refers to the extent to which the multiple measures of the specific construct converge together and share a high proportion of variance in common (Hair *et al.*, 2014). Following Hair *et al.* (2014), convergent validity was assessed based on factor loading, average variance extracted (AVE) and composite reliability (CR). As exhibited in Table II, for the first-order constructs, all the factor loadings are greater than 0.70.

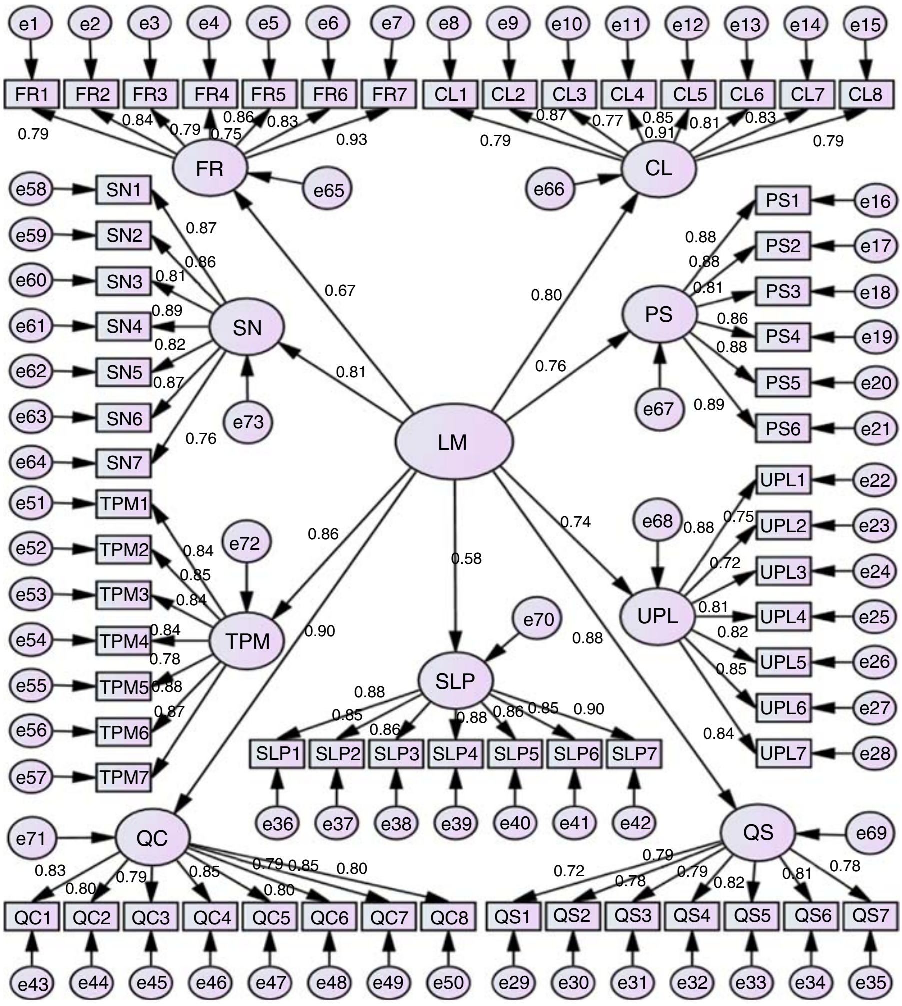

Figure 1.
Second-order CFA

Notes: Fit values: $p=0.00$; (χ^2/df $=1.74$; RMSEA $=0.06$; RMR $=0.07$; NNFI $=0.90$; CFI $=0.90$

Similarly, for the second-order construct, all the factor loadings are greater than 0.60 except for one (i.e. small lot production, 0.58), but still in the acceptable level. Equally important, AVEs indicating the amount of variation in the multiple items explained by the latent variable are also acceptable, as all the AVEs of both first- and second-order constructs exceed 0.50 (Bagozzi and Yi, 1988; Fornell and Larcker, 1981). Besides factor loading and AVE, CR is a common criterion of convergent validity to indicate homogeneity of the manifest variables in the latent variable, or the first-order constructs in their second-order construct. Table II shows that CRs of all the constructs are acceptable, which exceeds the benchmark of 0.60 (Bagozzi and Yi, 1988). In conclusion, factor loadings, AVEs and CRs indicated that the convergent validity is satisfactory.

Besides convergent validity, discriminant validity is another important criterion of construct validity, which provides evidence whether or not, a construct is unique and

Item no.	FR	CL	PS	SLP	QS	UPL	QC	TPM	SN
1st-order constructs									
1	0.79	0.79	0.88	0.88	0.72	0.88	0.83	0.84	0.88
2	0.84	0.87	0.88	0.85	0.79	0.76	0.81	0.85	0.86
3	0.79	0.77	0.81	0.86	0.78	0.72	0.79	0.84	0.81
4	0.75	0.85	0.86	0.88	0.79	0.81	0.85	0.84	0.89
5	0.86	0.91	0.88	0.86	0.82	0.82	0.80	0.79	0.82
6	0.83	0.81	0.89	0.85	0.81	0.85	0.79	0.88	0.87
7	0.93	0.83		0.90	0.78	0.84	0.86	0.87	0.77
8		0.79					0.80		
AVE	0.69	0.68	0.74	0.75	0.62	0.66	0.67	0.71	0.71
CR	0.94	0.95	0.95	0.96	0.92	0.93	0.94	0.95	0.95
2nd-order construct									
Factor loading	0.67	0.80	0.76	0.58	0.88	0.74	0.90	0.86	0.81
AVE					0.61				
CR					0.93				

Table II. Convergent validity

distinct from others. It was assessed by determining whether the square root of AVE for each construct is higher than its correlations with any other constructs (Fornell and Larcker, 1981). As exhibited in Table III, all the square roots of AVE are higher than the correlation estimates among the latent variables. Hence, this indicates an adequate level of discriminant validity.

Finally, to measure the extent to which all the constructs that are theoretically related are actually empirically related, the criterion-related validity was assessed. Hair *et al.* (2014) stated that it suggested whether the relationships between the constructs make sense and agree with theory. Inventory minimization, lead time reduction and manufacturing flexibility during the past three years were used as the criterion variables, which were measured by using a six-point interval scale. The results indicated that the LM is positively correlated with inventory minimization ($r = 0.72$), lead time reduction ($r = 0.73$) and manufacturing flexibility ($r = 0.77$), which are significant at 0.01 level (one-tailed). Therefore, it could be concluded that LM has a good criterion-related validity.

Discussion

Generally, the purpose of this study is to develop and validate the measurement instrument of LM. A thorough review on recent literature has been accomplished. Subsequently, a systematic validity process has also been fruitfully completed to ensure

	FR	CL	PS	SLP	QS	UPL	QC	TPM	SN
FR	*0.83*								
CL	0.54	*0.83*							
PS	0.51	0.60	*0.86*						
SLP	0.39	0.46	0.44	*0.87*					
QS	0.59	0.70	0.67	0.51	*0.79*				
UPL	0.50	0.59	0.56	0.43	0.66	*0.81*			
QC	0.61	0.72	0.68	0.52	0.78	0.67	*0.82*		
TPM	0.58	0.69	0.65	0.50	0.76	0.64	0.78	*0.84*	
SN	0.54	0.64	0.61	0.47	0.71	0.60	0.73	0.70	*0.84*

Notes: Diagonal values (italic) are square root of the AVE, whereas the off-diagonals are correlations

Table III. Discriminant validity

the content validity as well as construct validity of the measurement. Subsequently, the authors intend to discuss the findings of the research. First, the key identified practices of LM are discussed. Subsequently, implication, limitation and suggestion for future research are presented.

Key practices of LM

The seminal work from Sakakibara *et al.* (1993) was acknowledged as the first attempt to produce a valid and reliable measurement of LM. The study involved 41 plants in three industries (i.e. machinery, electronics and transportation components). However, there were very limited literature (i.e. published from 1981 to 1987) that were reviewed to construct the measurement. Sakakibara *et al.* (1993) compiled 16 practices through regrouping various LM-related activities, namely, setup time reduction, small lot size, JIT delivery from suppliers, supplier quality level, multifunction workers, small-group problem solving, training, daily schedule adherence, repetitive master scheduling, preventive maintenance, equipment layout, product design simplicity, kanban, pull system, MRP adaptation to JIT and accounting adaptation to JIT.

The next attempt came from an influential work by Shah and Ward (2007). The study attempted to re-define the LM concept as well as developing its measures. To develop the instrument, literature between 1993 and 2005 were used. The study considered all large manufacturing firms (ISIC 20-39) listed in the directory of Productivity Inc. as population, with the total sample, was 280 companies. However, selection of population and sample did not consider the type of production process, since the implementation of LM in the discrete process may be different from the continuous process industries. Consequently, the biasness caused by the large spectrum of type of production process was not to be avoided. Ten LM practices were identified in the study, namely, supplier feedback, JIT delivery from supplier, supplier development, customer involvement, pull system, continues flow, setup time reduction, TPM, statistical process control and employee involvement.

The key practices of LM used in this present study, as well as their measurement items, were developed based on an extensive review on literature published from 1993 to 2016. The measurement items have passed the content validity assessment done by practitioners and academicians in operations management. In this study, the researchers used a response sample of 236 large and discrete manufacturers in Indonesia. The respondents were managers, heads of department and directors in the production division. The reason of selecting large and discrete manufacturers is to reduce the bias caused by the large spectrum of type of production process. Subsequently, an empirical assessment on LM practices (i.e. construct validity) was carried out by employing an SEM approach. The assessment indicates that all the activities (i.e. measurement items) measure their underlying construct (i.e. first-order construct). In other words, all the activities contribute significantly on their particular practice. Similarly, all the LM practices (i.e. first-order constructs) measure their second-order construct (i.e. LM). This also hints that all the practices characterize the LM. These make this study particularly important when compared to the LM constructs developed by Sakakibara *et al.* (1993) and Shah and Ward (2007). In addition, the measurement resulted from the present study is more comprehensive and possesses higher validity than the two prior studies.

This study postulated that LM practices must be implemented in a holistic manner. Pearson's correlation analysis (see Table III) showed the highly positive and significant association among the practices (i.e. $0.39 \leqslant r \leqslant 0.78$). According to Cohen (1992), these r-values are considered practically significant and meaningful. In addition, factor loadings indicating the contribution of each manifest variable to its underlying latent variable are also high (i.e. greater than 0.70). These loading values are considered practically significant (Hair *et al.*, 2014). The high and positive correlation coefficients and high factor loadings indicated that implementation of a practice influences the others and vice versa. It, indeed, tends to suggest a holistic implementation of LM practices (Furlan, Dal Pont and Vinelli, 2011; Furlan, Vinelli and Dal Pont, 2011). In other words, in order to achieve a maximum return of LM implementation, all the practices are interdependent. Piecemeal adoption is not preferable.

The mutually supportive nature of relationship among the LM practices tends to encourage mutual dependency of all the practices to enhance performance. Chen and Tan (2011) claimed that no matter what kind of industry is, adoption of the aggregate bundle of LM practices significantly benefited company's performance. Similarly, Shah and Ward (2003), indeed supported by Mackelprang and Nair (2010) and Chen and Tan (2011), argued that integration among the LM practices leads to the improvement in companies' performance and competitive advantage. As the importance of holistic adoption of LM practices has been discoursed, Dal Pont *et al.* (2008), Furlan, Dal Pont and Vinelli (2011) and Furlan, Vinelli and Dal Pont (2011) highlighted interdependencies among the practices by relying on complementarity theory. Hence, this theory is useful to provide a rigorous explanation to synergic effects among LM practices. Through their studies, Furlan, Dal Pont and Vinelli (2011) and Furlan, Vinelli and Dal Pont (2011) provided evidence that implementation of LM practices in a holistic manner maximizes the overall operations performance. Similarly, Hofer *et al.* (2012) also found that the bundle of practices increases the ability of companies to minimize inventory, which, in turn, positively affects financial performance. In this study, the criterion validity assessment of the bundle of LM construct also indicates the positive association with inventory minimization, lead time reduction and manufacturing flexibility.

Nordin *et al.* (2012) provided a similar argument that if LM practices are implemented in a piecemeal approach, the potential benefits from its implementation could not be realized. Each practice is essential to the accomplishment of other practices' deployment. Hence, LM should be implemented comprehensively in terms of scope and content to achieve the desired performance level, instead of piecemeal. Hence, the findings highlighted that the mutually supportive nature among the LM practices is consistent with the basic ideas of complementarity theory (Edgeworth, 1881).

Implication of study

The extensive review on the literature and comprehensive assessment by experts (i.e. practitioners and academicians) established content validity of the measurement constructs. Subsequently, the constructs were empirically validated by involving a large number of samples. There is an adequate empirical evidence that ascertained the content validity, construct validity and criterion-related validity of the measurement. Therefore, this study successfully identified comprehensive and validated measurement constructs of LM.

Practically, this study provided a valuable tool for researchers for gaining deeper understanding regarding the LM and its implementation. For practitioners, the measurement constructs validated in this study are useful to evaluate the degree of LM employment in their companies, as well as to take possible actions in attempting to enhance the organizational performance. The construct and measurement instrument developed in this study could be used in the future empirical studies on integral LM practices to examine the causal model of LM implementation effectiveness. Even though the study was conducted in the context of Indonesia, the LM constructs used in this study could be used by practitioners and academicians from other countries. The instrument outlined in this paper is a positive impetus to the adoption of a standard survey instrument for LM data collection within organizations to establish baseline measures for subsequent comparison, among companies to provide a relative ranking in terms of transformation to LM as well as a useful industry profile, and by LM researchers to investigate other proposed models.

The study conveyed the concept of complementarity among the LM practices. It is greatly suggested that manufacturers should not implement the practices in isolation. In its history, western manufacturers started to implement some of the practices in an isolated way, but did not achieve the expected results (Dombrowski *et al.*, 2012). Hence, the positive associations among the practices strongly suggest the interdependency among them. This implies that the practitioners cannot be selective in implementing certain LM practices and ignoring others. If the practices are not used together, then the potential benefits are reduced. In other words, optimization of the system is not feasible when fewer practices are implemented due to the complementary nature of the practices. Hence, the practices should be implemented holistically rather than picking one over the other.

Even though the holistic implementation of LM practices is suggested, it depends on some contextual factors, such as type of products, type of production process and technology used by the plants. These contextual factors could influence the way a company implementing LM as well as the extent of its implementation. The studies, such as Chen and Tan (2013) and Shah and Ward (2003), investigated influences of the contextual factors to the LM implementation as well as its effect on performance. The studies revealed that there is no single agreement regarding the influences of the factors. Conversely, the level of its implementation in each plant tends to be varied depending upon its context. However, addressing this issue in detail is beyond the scope of this study. It will be taken to future work.

More importantly, this study revealed LM as a second-order construct, whereas its practices are a set of first-order constructs. As a set of first-order constructs, all the practices are highly correlated. Consequently, using multiple regression technique to examine the effect of the LM practices on a dependent variable may not be appropriate as high correlations among the independent variables may cause multicollinearity issue in the analysis. Because of this issue, ascertaining the effect of any single variable owing to other inter-relationships is difficult (Hair *et al.*, 2014). Additionally, it may also produce biasness in interpreting the result (Nawanir *et al.*, 2016). Therefore, to test the effect of LM to any dependent variable, the use of SEM approach with second-order construct is highly recommended. Besides this approach, parceling technique with SEM could also be considered (Bandalos and Finney, 2009; Coffman and MacCallum, 2005). Even though there is a polemic among the scholars regarding this technique, its application in SEM is quite common (Bandalos and Finney, 2009; Martınez-Lopez *et al.*, 2013); there has been a growing interest of application of this technique. Moreover, the use of simple regression analysis between the dependent variable and the first saved principal component scores of LM practices could also be applied as an alternative of SEM techniques (Agus, 2000; Nawanir *et al.*, 2013, 2016).

Limitation and suggestion for future research

The data used in this study were mainly from large and discrete process industries in Indonesia. Thus, generalization of the results may be somewhat limited. However, this study represents the first attempt to develop LM constructs for evaluating the LM implementation in Indonesia. To gain the clearer picture of the LM implementation, more studies are required in several different contexts, such as SMEs, continuous process industries and other countries. In addition, as the concepts of LM are continuously expanding and focus on continuous improvement, some of the important practices or tools may not be deliberated in the present study. It seems that the practices need to be updated over time. In the future studies, some of LM tools or practices such as CAD/CAM, concurrent engineering, value stream mapping, etc., could be considered.

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(The Appendix follows overleaf.)

Appendix 1

No.	Item	Literature
Flexible resources		
FR1	If a particular workstation has no demand, production workers can go elsewhere in the manufacturing facility to operate a workstation that has demand	Finch (2008), Hirano (2009), Ketokivi and Schroeder (2004)
FR2	If one production worker is absent, another production worker can perform the same responsibilities	Finch (2008), Hirano (2009), Sakakibara *et al.* (1993)
FR3	Production workers are cross-trained to perform several different jobs	Shah and Ward (2007), Finch (2008), Furlan, Vinelli and Dal Pont (2011), Ketokivi and Schroeder (2004)
FR4	We use general-purpose machines, which can perform several basic functions	Russell and Taylor (2011), Hirano (2009)
FR5	Production workers are capable of performing several different jobs	Sakakibara *et al.* (1993), Russell and Taylor (2011), Ketokivi and Schroeder (2004)
FR6	When one machine is broken down, different type of machine can be used to perform the same jobs	Russell and Taylor (2011), Hirano (2009)
FR7	When one machine is stopped, production workers are not idle	Russell and Taylor (2011), Hirano (2009)
Cellular layouts		
CL1	Sequence of material flow can be changed in case of machine breakdown	Rogers (2008), Hirano (2009)
CL2	Machines are in close proximity to each other	Sakakibara *et al.* (1993), Matsui (2007)
CL3	Layout of workstations can easily be changed depending on sequence of operations required to make the product	Rogers (2008), Hirano (2009)
CL4	Production facilities are arranged in relation to each other, so that material handling is minimized	Russell and Taylor (2011), Hirano (2009)
CL5	Machines can be easily moved from one workstation to another	Sakakibara *et al.* (1993), Hirano (2009)
CL6	We group dissimilar equipment into a workstation to process a family of parts with similar requirements (such as shapes, processing or routing requirement)	Koufteros *et al.* (1998), Russell and Taylor (2011), Chase *et al.* (2004), Fullerton and Wempe (2009)
CL7	Production processes are located close together, so that material movement is minimized	Sakakibara *et al.* (1993), Abdallah and Matsui (2007), Matsui (2007)
CL8	Families of products determine our factory layout	Fullerton and Wempe (2009), Hofer *et al.* (2011)
Pull system		
PS1	Kanban system is used to authorize production (Kanban is a work signaling system such as cards, verbal signals, light flashing, electronic messages, empty containers, etc.)	Russell and Taylor (2011), Sakakibara *et al.* (1993), Flynn *et al.* (1995), Abdallah and Matsui (2007)
PS2	Production at a particular workstation is performed based on the current demand of its subsequent workstation	Koufteros *et al.* (1998), Shah and Ward (2007)
PS3	We produce an item only when requested for by its users	Russell and Taylor (2011), Shah and Ward (2007)
PS4	To authorize orders to suppliers, we use supplier kanban that rotates between factory and suppliers	Russell and Taylor (2011), Aziz and Hafez (2013)

Table AI. Measurement items of LM practices

(*continued*)

No.	Item	Literature
PS5	We use kanban system to authorize material movements	Russell and Taylor (2011), Monden (2012)
PS6	We use pull system (producing in response to demand from the next stage of production process) to control our production rather than schedule prepared in advance	Russell and Taylor (2011), Sakakibara *et al.* (1993)
Small lot production		
SLP1	We produce in more frequent but smaller lot size	Russell and Taylor (2011), Agus and Hajinoor (2012)
SLP2	We emphasize producing small quantity of items together in a batch	Sakakibara *et al.* (1993), Flynn *et al.* (1995), Matsui (2007), Agus and Hajinoor (2012)
SLP3	We aggressively work on reducing production lot sizes	Sakakibara *et al.* (1993), Zelbst *et al.* (2010)
SLP4	We emphasize producing in small lot sizes to increase manufacturing flexibility	Matsui (2007), Finch (2008), Furlan, Vinelli and Dal Pont (2011), Agus and Hajinoor (2012)
SLP5	We receive products from suppliers in small lot with frequent deliveries	Bartezzaghi and Turco (1989), Monden (2012)
SLP6	In our production system, we strictly avoid flow of one type of item in large quantity together	Matsui (2007), Agus and Hajinoor (2012)
SLP7	We produce only in necessary quantities, no more and no less	Russell and Taylor (2011), Cheng and Podolsky (1993)
Quick setups		
QS1	We converted most of machine setups to external setup that can be performed while the machine is still running with previous operation	Sakakibara *et al.* (1993), Abdallah and Matsui (2007), Ketokivi and Schroeder (2004)
QS2	Production workers perform their own machines' setups	Flynn *et al.* (1995), Abdallah and Matsui (2007)
QS3	We aggressively work on reducing machines' setup times	Shah and Ward (2007), Zelbst *et al.* (2010)
QS4	We emphasize to put all tools in normal storage location	Fynes and Voss (2002), Hirano (2009)
QS5	Production workers do not have trouble in finding the equipment they need	Fynes and Voss (2002), Hirano (2009)
QS6	Production workers are trained on machines' setup activities	Taj and Morosan (2011), Hirano (2009), Ketokivi and Schroeder (2004)
QS7	We can quickly perform our machines' setup if there is a change in process requirements	Russell and Taylor (2011), Hirano (2009)
Uniform production level		
UPL1	We produce more than one product model from day to day (mixed-model production)	Sakakibara *et al.* (1993), Russell and Taylor (2011)
UPL2	We emphasize on a more accurate forecast to reduce variability in production	Russell and Taylor (2011)
UPL3	Each product is produced in a relatively fixed quantity per production period	Cheng and Podolsky (1993), Jones (2006), Coleman and Vaghefi (1994)
UPL4	We emphasize to equate workloads in each production process	Coleman and Vaghefi (1994), Russell and Taylor (2011), Monden (2012)
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)
UPL6	We produce by repeating the same combination of products from day to day	Sakakibara *et al.* (1993), Russell and Taylor (2011)
UPL7	We always have some quantity of every product model to response to variation in customer demand	Russell and Taylor (2011), Coleman and Vaghefi (1994), Jones (2006)

(*continued*)

Table AI.

No.	Item	Literature
Quality control		
QC1	We use statistical techniques to reduce process variances	Ketokivi and Schroeder (2004)
QC2	We use visual control systems (such as *andon*/line-stop alarm light, level indicator, warning signal, signboard, etc.) as a mechanism to make problems visible	Russell and Taylor (2011), Hirano (2009), Chase *et al.* (2004)
QC3	Production processes on production floors are monitored with statistical quality control techniques	Russell and Taylor (2011), Shah and Ward (2007), Ketokivi and Schroeder (2004)
QC4	Quality problems can be traced to its source easily	Chase *et al.* (2004), Ketokivi and Schroeder (2004)
QC5	Production workers can identify quality problems easily	Russell and Taylor (2011), Hirano (2009)
QC6	Production workers are authorized to stop production if serious quality problems are occurred	Sakakibara *et al.* (1993), Russell and Taylor (2011), Chase *et al.* (2004), Ketokivi and Schroeder (2004)
QC7	We have quality focused teams that meet regularly to discuss about quality issues	Fullerton *et al.* (2003), Monden (2012)
QC8	Production workers are trained for quality control	Cheng and Podolsky (1993), Monden (2012)
Total productive maintenance		
TPM1	We ensure that machines are in a high state of readiness for production at all the time	Sakakibara *et al.* (1993), Ahuja and Khanba (2007)
TPM2	We dedicate periodic inspection to keep machines in operation	Koufteros *et al.* (1998), Ahuja and Khanba (2007)
TPM3	We have a sound system of daily maintenance to prevent machine breakdowns from occurring	Koufteros *et al.* (1998), Russell and Taylor (2011)
TPM4	We scrupulously clean workspaces (including machines and equipment) to make unusual occurrences noticeable	Russell and Taylor (2011), Ahuja and Khanba (2007), Cheng and Podolsky (1993)
TPM5	We have a time reserved each day for maintenance activities	Sakakibara *et al.* (1993), Koufteros *et al.* (1998), Shah and Ward (2007)
TPM6	Operators are trained to maintain their own machines	Nakamura *et al.* (1998), Bakerjan (1994)
TPM7	We emphasize good maintenance system as a strategy for achieving quality compliance	Koufteros *et al.* (1998), Sakakibara *et al.* (1993)
Supplier networks		
SN1	We facilitate suppliers to maintain a warehouse near to our plant	Russell and Taylor (2011), Monden (2012)
SN2	We strive to establish long-term relationships with suppliers	Sakakibara *et al.* (1993), Russell and Taylor (2011), Matsui (2007), Ketokivi and Schroeder (2004)
SN3	We emphasize to work together with suppliers for mutual benefits	Monden (2012), Russell and Taylor (2011)
SN4	We regularly solve problems jointly with suppliers	Monden (2012), Russell and Taylor (2011)
SN5	Development programs (such as engineering and quality management assistance) are provided to suppliers	Russell and Taylor (2011), Cheng and Podolsky (1993)
SN6	We rely on a small number of high-performance suppliers	Ketokivi and Schroeder (2004)
SN7	Our suppliers deliver materials to us just as it is needed (on just-in-time basis)	Abdallah and Matsui (2007), Shah and Ward (2007), Matsui (2007)

Table AI.

Appendix 2

No.	Item	Literature
Inventory minimization		
IM1	Work in process (WIP) inventory level has significantly reduced	Bhasin (2008), Chong *et al.* (2001), Taj (2008)
IM2	Raw material inventory level has significantly reduced	Claycomb *et al.* (1999), Bhasin (2008), Chong *et al.* (2001), Taj (2008)
IM3	Finished goods inventory level has significantly reduced	Bhasin (2008), Callen *et al.* (2000), Taj (2008)
IM4	Overall inventory level has significantly reduced	Bhasin (2008), Claycomb *et al.* (1999)
IM5	Storage space requirement has significantly reduced	Gurumurthy and Kodali (2009)
IM6	Inventory turnover has increased (inventory turnover is ratio of cost of goods sold and average aggregate inventory cost)	Chong *et al.* (2001), Bhasin (2008), Taj (2008), Fullerton and Wempe (2009)
IM7	Over productions that cause high inventory level have been successfully eliminated	Wong *et al.* (2009)

Table AII. Measurement items of criterion variables

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