RESEARCH ARTICLE

Development of a Composite Lean Index to Measure Lean Implementation in Philippine Manufacturing Companies

Willy F. Zalatar and Anna Bella D. Siriban-Manalang
De La Salle University, Manila, Philippines

Abstract: Lean manufacturing has been gaining worldwide popularity as a means of reducing waste, improving quality, and increasing the competitiveness of manufacturing firms. This paper aims to develop a composite lean index (CLI) which can be used to measure the degree of lean adoption in Philippine manufacturing companies. The lean index employs actual quantitative data, rather than subjective assessment, which is more prevalent in the literature. Fifteen performance indicators divided into process and equipment, manufacturing planning and control, human resources, and supplier and customer relationships are proposed and then validated using empirical data. Results showed that a CLI, which yields a single value from 0 to 1, can be computed from the 15 metrics formulated using multi-attribute value theory. Manufacturing companies can utilize this index for monitoring progress of lean implementation through the years as well as for benchmarking purposes with other firms. On the other hand, academicians can benefit from this index since most statistical analyses in researches require numerical values as inputs.

***Keywords*:** Composite Lean Index, Lean Performance Indicators, Lean Manufacturing, Multi-Attribute Value Theory

JEL classifications: L, L0, L2, M, M10, M11

Lean manufacturing (LM) is defined as the "systematic approach to identify and eliminate the waste (non-value added activities) through continuous improvement and synchronizing the production process to such an extent that flow of the product can be possible at the pull of the customer with emphasized focus on perfection (quality) in the pursuit of manufacturing excellence" (Mahapatra & Mohanty, 2007, p. 19).LM traces its origins to the Toyota production system (TPS)—the process-oriented approach to manufacturing pioneered by Taiichi Ohno of Toyota Motor Company of Japan during the 1950s. TPS gained worldwide attention after becoming the subject of the International Motor Vehicle Program (IMVP)—a five-year research program spearheaded by the Massachusetts Institute of Technology. The term "lean production" (LP) was coined by John Krafcik, one of the leading researchers of the IMVP.

Pertinent results of the said research program were later published in the seminal book entitled *"The Machine that Changed the World."* (Womack, Jones, and Roos, 1990)

Piercy and Rich (2015) noted that "a focus on lean operations as a specific subset of world-class operational practices is a recurrent theme in the operations literature" (p. 282). However, Singh, Garg, and Sharma (2010) observed that "the extant literature fails to provide an efficient method to measure leanness of any manufacturing firm" (p. 46). Measuring the degree of leanness is useful for performance evaluation and benchmarking which form part of the continuous improvement activity so integral to the practice of lean.

Most of the early articles gauge lean adoption by counting the number of lean tools implemented by the companies (James-Moore & Gibbons, 1997; Lewis, 2000; Sohal & Egglestone, 1994). From a list of LM practices we prepared, the respondent companies were asked to select the practices being implemented in their firms. The degree of leanness was computed by dividing the number of practices adopted by the total LM practices.

A weakness of this methodology is its failure to capture the extent of adoption of the various lean initiatives inside a manufacturing firm. A company could be practicing a given LM tool, but it is possible that only certain areas or product lines are involved.

A number of articles measured lean implementation through the use of the Likert scale (Panizzolo, 1998; Rahman, Laosirihongthong, & Sohal, 2010; Shah & Ward, 2003). This enabled us not only to determine the LM tools most frequently adopted but also the extent of implementation.

A Likert scale ranging from 1 (not adopted at all) up to 5 (adopted to a great extent) is usually employed. The respondent companies specify the degree of adoption of the various LM practices by selecting the most appropriate number in the Likert scale. The average value computed from the chosen numbers signify the degree of leanness of the companies.

A limitation of this methodology is that no actual quantitative data were used and there were no strict guidelines in distinguishing the numbers in the Likert scale.

Another group of articles assessed leanness through the use of various scoring systems (Lucato, Calarge, Loureiro, & Calado, 2014; Singh et al., 2010; Taj, 2005). More sophisticated compared to the Likert scale, the scoring systems involve structured guidelines or rubrics which are to be followed in giving scores to the LM practices.

A weakness of this technique is that the degree of leanness is computed based on the scores given by the evaluators and not on actual quantitative data. Singh et al. (2010) pointed out that the scoring system "used the views of experts and may contain human judgement error" (p. 46).

All three methodologies described previously are considered in the literature as qualitative means of assessing lean implementation since no actual quantitative data were utilized. Ray, Zuo, Michael, and Wiedenbeck (2006) stated that "a data-driven analytical methodology is more likely to be effective in gauging [lean] transformation than subjective assessment schemes or anecdotal evidence so often cited in the literature" (p. 239).

Ray et al. (2006) developed 10 operational lean metrics employing actual quantitative data specifically for the wood products industry. An overall lean index can be computed from these metrics but they cannot be applied to other manufacturing industries. Furthermore, Ray et al.'s (2006) metrics concentrated on material and energy usage which disregarded other important aspects of lean such as defect prevention, multifunctional teams, and so forth.

Duque and Cadavid (2007) formulated 21 lean metrics divided into five categories (elimination of waste, continuous improvement, continuous flow and pull-driven systems, multifunctional teams, and information systems) which manufacturing companies can use to monitor the progress of lean implementation.

However, the metrics yield numerical values expressed in different units and percentages. This prevents the firms from coming up with a single value which reflects the degree of lean implementation in their companies. An overall measure of leanness is useful for comparing a firm's performance through the years or when benchmarking performance with other companies.

Problem Statement and Objectives of the Study

The review of related literature highlighted two major weaknesses of existing methodologies: (a) they are subjective assessments of leanness and not based on actual quantitative data, and (b) those that employ actual quantitative data do not yield a single quantity as a measure of overall leanness.

Given these limitations, there is a need for a quantitative means of assessing the degree of leanness of manufacturing companies that makes use of actual data rather than subjective evaluations.

This paper aims to develop an integrated or composite lean index which can be utilized to measure the extent of lean adoption in manufacturing firms. According to Searcy (2009), "a single-composite measure would assist management in better evaluating their company's lean implementation" (p. 39).

Following are the specific objectives of this research:

1. To formulate lean performance indicators for the pertinent LM practices,
2. To compute for the CLI based on the various lean performance indicators, and
3. To validate the CLI developed by using empirical data.

Theoretical Framework

Karlsson and Ahlstrom (1996) operationalized the LP concept by formulating 36 measurable determinants which can be used to assess changes in lean implementation. On the other hand, Duque and Cadavid (2007) integrated 21 lean metrics proposed by various authors corresponding to the different stages of lean implementation. However, the performance indicators suggested by the two articles yielded numerical values expressed in varying units such as dollars/pesos, hours/minutes, percentages, and so forth. This prevents the companies from coming up with a single value which reflects the extent of lean adoption inside their firms.

Lucato et al. (2014) further noted that the works of Karlsson and Ahlstrom (1996) and Duque and Cadavid (2007) "have two practical limitations: they do not establish a single measure to determine the degree of implementation of the complete set of variables/metrics considered and comparison between two different companies would only be possible if the same set of variables/metrics would be used for both" (p. 534).

In the area of sustainable development, a composite sustainability index (CSI) is typically computed from several sustainability indicators (Salvado, Azevedo, Matias, & Ferreira, 2015; Zhou, Tokos, Krajnc, & Yang, 2012). The CSI is a single value from 0 to 1 reflecting a firm's sustainable performance with respect to the economic, social, and environmental dimensions. According to Zhou et al. (2012), the CSI "aggregate[s] multidimensional issues into one index, thus providing comprehensive information" (p.789).

This paper is based on the combined theories of Karlsson and Ahlstrom (1996), Duque and Cadavid (2007), Lucato et al. (2014) and Salvado et al. (2015). Quantitative performance indicators are first formulated for the various LM practices. The scores for these metrics are later aggregated into a CLI which possesses both theoretical and practical values.

Research Methodology

The review of literature on measuring the degree of leanness indicated that three common means are employed: counting the number of LM tools being practiced, using the Likert scale, or using a scoring system. However, these methods are all considered as subjective means of gauging the extent of lean implementation.

Another group of articles employed quantitative metrics in assessing the degree of leanness. However, they yielded values of varying units which prevent them from being aggregated into a single quantity, they are only applicable to a certain industry, or they were not applied to actual manufacturing companies.

Fifteen lean metrics reflecting the pertinent LM practices are first extracted from existing literature. These metrics are formulated as fractions to yield a numerical value from 0 to 1. To aggregate the various metrics into a single value, a weighted summation or linear additive model is constructed using multi-attribute value theory (MAVT).

A questionnaire (see Appendix) was designed containing the metrics for the LM practices being implemented by the respondent companies. Fifteen metrics divided into four categories (process and equipment, manufacturing planning and control, human resources, and supplier and customer relationships) were included. The respondents indicated their responses by specifying a percentage value ranging from 0 to 100% for each of the metrics.

A field study was then conducted to validate the proposed CLI where empirical data from three manufacturing firms are entered into the model to test its efficacy.

The study can be classified as methodological research since the paper proposes a novel approach to measuring the degree of leanness of manufacturing companies using actual quantitative data through the CLI.

Lean Performance Indicators

The lean performance indicators formulated are divided into four categories: process and equipment, manufacturing planning and control, human resources, and supplier and customer relationships (see Table 1). This approximates the classifications done by Panizzolo (1998), Doolen and Hacker (2005), and Nordin, Deros, and Wahab (2010) which cover the different areas of a typical manufacturing firm.

Process and Equipment

Five performance indicators are included under process and equipment: setup reduction, cellular manufacturing, rigorous preventive maintenance, error-proof equipment, and orderliness and cleanliness in the plant.

LM requires companies to produce in small lot sizes which, in turn, is achieved by devising ways of reducing setup time to a minimum value. According to Taj (2005), "quick setup or changeover is a must for a lean production system" (p. 632). To measure setup reduction, the following formula is proposed by Bonavia and Marin (2006):

$$\text{Set up Reduction} = \frac{\text{Change over Activities which have been Analysed in Detail}}{\text{Total Change over Activities}} \quad (1)$$

The cell configuration is highly encouraged in lean implementation as it "offers many unique features that allow lean processes to flow" (Brown, Collins, & McCombs, 2006, p. 6). To assess cellular manufacturing, the following metric is suggested by Bonavia and Marin (2006):

$$\text{Cellular Manufacturing} = \frac{\text{Plant Space Organized by Cells}}{\text{Total Plant Space}} \quad (2)$$

Another requirement of LM is to improve the reliability of machines through consistent maintenance regimens. Taj (2005) stated that "preventive maintenance must be even stricter in [LM] since losing any equipment due to unexpected downtime in a cell would result into stopping the operation in the cell" (p. 631). As a means of gauging rigorous preventive maintenance, the following performance indicator is proposed by Sanchez and Perez (2001):

$$\text{Rigorous Preventive Maintenance} = \frac{\text{Preventive Maintenance}}{\text{Total Maintenance}} \quad (3)$$

LM advocates defect prevention rather than fault rectification (James-Moore & Gibbons, 1997). This can be achieved through autonomation or the "automatic shut-down of a process, line or machine in the event that a defect is detected" (Abdulmalek, Rajgopal, & Needy, 2006, p. 16). The following metric is suggested by Karlsson and Ahlstrom (1996) as an indicator of defect prevention:

$$\text{Error - Proof Equipment} = \frac{\text{Number of Inspection Carried Out by Autonomous Control}}{\text{Total Number of Inspections}} \quad (4)$$

Lastly, becoming lean means reducing the clutter and inefficiency in a typical production environment. The main technique employed to address this is 5S – "a waste reduction process consisting of sorting, straightening, sweeping and cleaning, systematizing, and standardizing" (Abdulmalek et al., 2006, p. 17). To gauge cleanliness and orderliness in the plant, the following formula is proposed by Bonavia and Marin (2006):

$$\text{Orderliness \& Cleanliness in the plant} = \frac{\text{Plant Space Practicing 5S}}{\text{Total Plant Space}} \quad (5)$$

Manufacturing Planning and Control

Four metrics are categorized under manufacturing planning and control: production lot size, pull production, visual control of shop floor, and documented procedures.

Karlsson and Ahlstrom (1996) stated that an "efficient way of keeping inventory down is through reducing lot sizes. A reduction of lot sizes has other

Table 1. *Sources of Lean Manufacturing Practices*

LM Practices	Sources
Process & Equipment	
1. set up reduction	Bonavia & Marin (2006); Cusumano (1994); Jina, Bhattacharya, & Walton (1997); Motwani (2003); Nordin et al. (2010); Panizzolo (1998); Rahman et al. (2010); Shah & Ward (2003); Upadhye, Deshmukh, & Garg (2010)
2. cellular manufacturing	Nordin et al. (2010); Panizzolo (1998); Shah & Ward (2003); Upadhye et al. (2010)
3. rigorous preventive maintenance	Bonavia & Marin (2006); Nordin et al. (2010); Panizzolo (1998); Rahman et al. (2010); Shah & Ward (2003); Soderquist & Motwani (1999); Upadhye et al. (2010)
4. error proof equipment	Cusumano (1994); Nordin et al. (2010); Panizzolo (1998); Rahman et al. (2010); Soderquist & Motwani (1999); Upadhye et al. (2010)
5. order and cleanliness in the plant	Bonavia & Marin (2006); Nordin et al. (2010); Panizzolo (1998); Upadhye et al. (2010)
Manufacturing Planning & Control	
6. production lot size	Cusumano (1994); Jina et al. (1997); Nordin et al. (2010); Panizzolo (1998); Rahman et al. (2010); Shah & Ward (2003)
7. pull production	Billesbach (1994); Bonavia & Marin (2006); Cusumano (1994); James-Moore & Gibbons (1997); Karlsson & Ahlstrom (1995); Motwani (2003); Nordin et al. (2010); Panizzolo (1998); Rahman et al. (2010); Shah & Ward (2003); Soriano-Meier & Forrester (2002); Upadhye et al. (2010)
8. visual control of shop floor	Billesbach (1994); Bonavia & Marin (2006); Nordin et al. (2010); Panizzolo (1998)
9. documented procedures	Duque & Cadavid (2007); Rao (2004); Sanchez & Perez (2001)
Human Resources	
10. multifunctional workers	Bonavia & Marin (2006); Cusumano (1994); James-Moore & Gibbons (1997); Karlsson & Ahlstrom (1995); Panizzolo (1998); Sanchez & Perez (2001); Shah & Ward (2003); Sohal & Egglestone (1994); Soriano-Meier & Forrester (2002)
11. expansion of autonomy and responsibility	Krafcik (1988); Panizzolo (1998); Shah & Ward (2003); Soriano-Meier & Forrester (2002)
12. worker involvement in continuous quality improvement programs	James-Moore & Gibbons (1997); Nordin et al. (2010); Panizzolo (1998)
13. worker training	Billesbach (1994); Nordin et al. (2010); Panizzolo (1998); Perez & Sanchez (2002)
Supplier & Customer Relationships	
14. parts delivered JIT by suppliers	Nordin et al. (2010); Panizzolo (1998); Taj (2008)
15.customer orders delivered JIT	Nordin et al. (2010); Panizzolo (1998); Taj (2008)

positive effects such as increasing flexibility, since it is possible to switch between different parts more often" (p. 28). The following is the metric proposed by Duque and Cadavid (2007) to gauge production lot size:

$$\text{Production Lot Size} = \frac{\text{Average Production Lot Size Per Order}}{\text{Average Customer Order}} \quad (6)$$

According to Brown et al. (2006), "a lean system utilizes a pull philosophy rather than the traditional batch manufacturing push philosophy" (p. 4). The pull approach is "characterized by the manufacture of a product only when a customer places an order" (Worley & Doolen, 2006, p. 230). To measure pull production, the following indicator is put forward by Duque and Cadavid (2007):

$$\text{Pull Production} = \frac{\text{Number of Line Processes that Pull their Inputs from their Predecessors}}{\text{Total Number of Line Processes}} \quad (7)$$

In LM, "information is important in order for the multifunctional teams to be able to perform according to the goals of the company" (Karlsson & Ahlstrom, 1996, p. 38). Sanchez and Perez (2001) noted that "the aim is to deliver timely and useful information down to the production line" (p. 4). Two performance indicators are proposed by Bonavia and Marin (2006) and Duque and Cadavid (2007), respectively, in relation to information dissemination inside the factory:

$$\text{Visual Control of the Shop Floor} = \frac{\text{Work Area where there are Updated Graphs and Panels}}{\text{Total Work Area}} \quad (8)$$

$$\text{Documented Procedures} = \frac{\text{Number of Procedures that are Documented in the Company}}{\text{Total Number of Line Processes}} \quad (9)$$

Human Resources

Four performance indicators are included under human resources: multifunctional workers, expansion of autonomy and responsibility, worker involvement in continuous improvement, and worker training.

Sohal and Egglestone (1994) identified three human resources-related elements of LM: cross-functional development teams, multi-skilled operators taking a high-degree of responsibility for work within their areas, and active shopfloor problem-solving structures central to continuous improvement.

Multifunctional teams are composed of "workers [who] are flexible and thus are able to perform more than one task in the team" (Karlsson & Ahlstrom, 1995, p. 81). Following is the metric suggested by Karlsson and Ahlstrom (1996) to gauge multifunctional workers:

$$\text{Multifunctional Workers} = \frac{\text{Number of Employees Working in Teams}}{\text{Total Number of Employees}} \quad (10)$$

Boyer (1996) stated that "another key to successful [LP] is worker empowerment [which is] giving workers more responsibility and control of the manufacturing process" (p. 13). To assess the expansion of autonomy and responsibility, the following indicator is suggested by Karlsson and Ahlstrom (1996):

$$\text{Expansion of Autonomy \& Responsibility} = \frac{\text{Number of Functional Areas that are Responsibility of Teams}}{\text{Total Number of Functional Areas}} \quad (11)$$

According to Karlsson and Ahlstrom (1996), "involving everyone in the work of improvement is often accomplished through quality circles. These are activities where operators gather in groups to come up with suggestions on possible improvements" (p. 29). To measure worker involvement in continuous improvement, the following metric is proposed by Taj (2005):

$$\text{Worker Involvement in Continous Improvement} = \frac{\text{Employees who are Members of Quality Circles \&/or Problem-Solving Teams}}{\text{Total Number of Employees}} \quad (12)$$

Successful LM implementation is anchored on well-trained employees. Boyer (1996) noted that "training is necessary to develop a workforce which is capable of shouldering the increased responsibility which is required, to develop multi-skilled workers who can perform more than a single job, and to create an environment in which workers have the skills and ability to push for continuous improvement" (p. 13). The following performance indicator is suggested by Duque and Cadavid (2007) for worker training:

$$\text{Worker Training} = \frac{\text{Number of Skills a Team Member Possesses}}{\text{Number of Skills Needed in a Team}} \quad (13)$$

Supplier and Customer Relationships

JIT philosophy is a major component of LM which "implies the delivery of any part in the necessary quantity and at the right time" (Sanchez & Perez, 2001, p. 3). This requires the involvement of the entire value chain—from the supplier down to the customer. Sohal and Egglestone (1994) stated that two core characteristics of lean are "close, shared destiny relations with suppliers and retailing and distribution channels which provide close links to the customers" (p. 35). Two metrics are suggested by Sanchez and Perez (2001) and Taj (2005), respectively, in connection with supplier and customer relationships:

$$\text{Parts Delivered JIT by Suppliers} = \frac{\text{Number of Parts Delivered JIT by Suppliers}}{\text{Total Number of Parts}} \quad (14)$$

$$\text{Customer Orders Delivered JIT} = \frac{\text{Annual Value/Through put that this Delivered JIT to Customers}}{\text{Total Annual Value Through put}} \quad (8)$$

Composite Lean Index

The lean performance indicators formulated in the earlier section all yield a value from 0 to 1. Therefore, a weighted summation or linear additive model can be set up to aggregate all the lean metrics to a single value which also ranges from 0 to 1. This is the CLI and it represents the extent of lean implementation inside the company. A CLI score of 0 means that the company is not lean at all while a score of 1 means that the firm is very lean.

$$CLI_k = \sum_{i=1}^{I}\sum_{j=1}^{J} v_{ij} x_{ijk}^{+} + \sum_{i=1}^{I}\sum_{j=1}^{J} v_{ij}(1 - x_{ijk}^{-})$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} v_{ij} = 1$$

$$v_{ij}, x_{ijk}^{+}, x_{ijk}^{-} \geq 0$$

where:

I = total number of lean performance indicators in a category
J = total number of leanness categories
K = total number of companies being evaluated
v_{ij} = weight assigned to lean performance indicator i under category j
x_{ijk}^{+} = score for lean performance indicator i under category j for company k and which has a positive impact on leanness
x_{ijk}^{-} = score for lean performance indicator i under category j for company k and which has a negative impact on leanness

The sum of the weights v_{ij} to be given to the lean metrics must be equal to 1. The simplest form is to assign equal weights to all the performance indicators, or another option would be to extract the weights from importance rating techniques such as the analytical hierarchy process (AHP).

On the other hand, the lean metrics can either have a positive or a negative impact on leanness depending on how the formula was constructed. For instance, the lean metric for Setup Reduction can be considered as having a positive impact on leanness since the formula is the number of changeover activities analyzed divided by total changeover activities. This means that a high value is desired for this performance indicator. In contrast, the metric for Production Lot Size can be considered as having a negative impact on leanness since the formula is average lot size per order divided by average customer order. Since lean encourages small lot sizes, then a low value is preferable for this metric. Performance indicators belonging to this latter category need to undergo an additional step to reverse the negative effect before being entered into the weighted summation model.

Field Study

To validate the CLI formulated, a field study was conducted on three manufacturing companies in the Philippines where the respondent companies were asked to fill out the questionnaire. Using the formulas suggested in this paper, Table 2 shows the scores given by the companies to the 15 lean performance indicators included in the study.

Entering the scores assigned to the lean metrics into the linear additive model by assuming equal weights, Co. A obtained a CLI of 0.573, Co. B got a CLI of 0.712, and Co. C received a CLI of 0.690 which represent the extent of lean adoption inside the firms. This means that Co. B is the "leanest" while Co. A is the "least lean" among the three firms as far as the 15 lean metrics are concerned.

Table 2. *Field Study Results*

Performance Indicator	Co. A Score	Co. B Score	Co. C Score
Process & Equipment			
Setup Reduction	0.200	0.850	0.740
Cellular Manufacturing	0.500	0.800	0.200
Rigorous Preventive Maintenance	0.600	1.000	1.000
Error-Proof Equipment	0.600	0.850	0.150
Orderliness & Cleanliness in the Plant	1.000	0.800	0.760
Manufacturing Planning & Control			
Production Lot Size	1.000	0.800	0.500
Pull Production	0.300	0.800	0.690
Visual Control of Shop Floor	1.000	0.900	1.000
Documented Procedures	0.850	0.980	1.000
Human Resources			
Multifunctional Workers	0.300	0.700	0.250
Expansion of Autonomy and Responsibility	0.300	0.300	0.730
Worker Involvement in Continuous Improvement	0.550	0.500	1.000
Worker Training	0.500	0.400	0.500
Supplier & Customer Relationships			
Parts Delivered JIT by Suppliers	0.950	0.800	0.930
Customer Orders Delivered JIT	0.950	0.800	0.900
CLI	**0.573**	**0.712**	**0.690**

The composite lean index is considered superior to current methodologies in measuring the degree of leanness of companies since it makes use of actual quantitative data instead of subjective assessments. Actual data such as plant space organized by cells, number of employees working in teams, and number of parts delivered JIT by suppliers are all needed to come up with the CLI value. Aside from this, the CLI allows for a single value to be computed based on 15 different metrics.

Computing for the CLI every year will assist the firm in monitoring the progress of lean implementation or it can be compared with the CLI of other companies for benchmarking purposes. Comparison, however, must be done between or among homogenous firms for the comparison to be more meaningful.

Conclusion

The purpose of this article is to develop a CLI using MAVT from several lean performance indicators formulated. The CLI has three distinct advantages over existing methodologies in the lean literature.

The CLI uses actual quantitative data such as the number of changeover activities analyzed, average production lot size per order, number of employees working in teams, and so forth, instead of a subjective assessment of leanness which is more prevalent in the literature. The index gives a more accurate measure of leanness since actual numerical figures are utilized instead of qualitative evaluations which are prone to subjectivity and human error.

The composite index is flexible enough to allow for any finite number of performance indicators belonging to different categories to be included in the model and it will still yield a single value from 0 to 1. This is beneficial for companies just starting their lean journey with a few indicators or for those that have been implementing lean for a long time with several indicators to monitor.

The CLI yields a single value from 0 to 1 which represents the extent of lean implementation inside a manufacturing firm. This is useful both in the practice of and research on lean. In actual manufacturing companies, the CLI can be utilized to monitor the firms' progress through the years or to benchmark performance with other companies. In the field of research, the CLI makes it easier to measure the degree of lean implementation and relate it with other variables since most statistical analyses essential in technical papers require numerical values as inputs.

The field study conducted proved that a single numerical value ranging from 0 to 1 can indeed be computed from several lean performance indicators. The CLI not only employs actual quantitative data, but it is also useful to researchers and lean practitioners for a number of reasons enumerated earlier. Companies need only to keep important information such as the number of employees working in teams, the number of documented procedures in the company, and so forth to enable them to compute for the CLI.

Future studies can look into the possibility of having a standardized set of lean metrics for a certain manufacturing industry to make comparisons between and among member firms more meaningful. Some metrics may be relevant to a given manufacturing industry but may be considered as irrelevant to another.

The likelihood of an LM practice having more than one performance indicator can also be explored by other researchers. For instance, cellular manufacturing can be assessed through plant space organized by cells or by the number of products produced in cells.

Lastly, the lean performance indicators can be related to the various operational benefits of lean or even to overall firm performance to determine which LM practice has the most positive impact to the company.

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Appendix

Data Collection Questionnaire

Part I: Company Profile

Respondent's Profile:* *(Optional)*

Name of Respondent:	Position:
Company Name and Address:	
Tel. No. or Mobile No.:	Email Address:

**This part of the questionnaire is simply for tracking purposes. Information here will be kept confidential and will not be used for the study.*

Instructions: Please provide the information being requested. Write your answers on the space provided or check box when necessary.

1. Firm Size (pls. check one):	2. Process Strategy (pls. check one):
□ Small (less than 100 employees) □ Medium (100-199 employees) □ Large (200 or more employees)	□ Customized/Job Shop □ Batch □ Repetitive/Assembly Line □ Continuous Process □ Others, pls. specify ________________________
3. Ownership (pls. check one): □ 100% Filipino-owned □ 100% Foreign-owned, pls specify country of origin ________________________ □ Joint Venture, pls. specify percentage and country of origin ________________________	4. Industry Type (pls. specify whether automotive industry, food & beverage industry, iron and steel industry, etc.): ________________________

Part II: Lean Manufacturing Practices

Please compute the indicators according to the formula beside it and write your answer on the 3rd column:

	PERFORMANCE INDICATORS	FORMULA	ANSWER
	Process & Equipment		
1	Setup Reduction	$\frac{\text{Changeover Activities which have been Analyzed in Detail}}{\text{Total Changeover Activities}}$	
2	Cellular Manufacturing	$\frac{\text{Plant Space Organized by Cells}}{\text{Total Plant Space}}$	
3	Rigorous Preventive Maintenance	$\frac{\text{Preventive Maintenance}}{\text{Total Maintenance}}$	
4	Error-Proof Equipment	$\frac{\text{Number 6 Inspections Carried Out by Autonomous Control}}{\text{Total Number 6 Inspections}}$	
5	Orderliness & Cleanliness in the Plant	$\frac{\text{Plant Space Practicing S} + 1}{\text{Total Plant Space}}$	
	Manufacturing Planning & Control		
6	Production Lot Size	$\frac{\text{Average Production Lot Size Per Order}}{\text{Average Customer Order}}$	
7	Pull Production	$\frac{\text{Number 6 Line Processes that Pull their Inputs from their Predecessos}}{\text{Total Number 6 Line Processes}}$	
8	Visual Control of Shop Floor	$\frac{\text{Work Area where there are Updated Graphs and Panels}}{\text{Total Work Area}}$	
9	Documented Procedures	$\frac{\text{Number 6 Procedures that are Documented in the Company}}{\text{Total Number 6 Procedures}}$	

	PERFORMANCE INDICATORS	FORMULA	ANSWER
	Human Resources		
10	Multifunctional Workers	$\frac{\text{Number of Employees Working in Teams}}{\text{Total Number of Employees}}$	
11	Expansion of Autonomy and Responsibility	$\frac{\text{Number of Functional Areas that are the Responsibility of Teams}}{\text{Total Number of Functional Areas}}$	
12	Worker Involvement in Continuous Improvement	$\frac{\text{Employees who are members of Quality Circles \& /or Problem - Solving Teams}}{\text{Total Number of Employees}}$	
13	Worker Training	$\frac{\text{Number of Skills a Team Member Possesses}}{\text{Number of Skills Needed in a Team}}$	
	Supplier & Customer Relationships		
14	Parts Delivered JIT by Suppliers	$\frac{\text{Number of Parts Delivered JIT by Suppliers}}{\text{Total Number of Parts}}$	
15	Customer Orders Delivered JIT	$\frac{\text{Annual Value/Throughput that is Delivered JIT to Customers}}{\text{Total Annual Value/Throughput}}$	