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# A Review on Lean Assessment Models and Performance Measures

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**Abstract** – *This review paper presented comprehensive literature on lean assessment models and its association with various performance measures. Both local and overseas publications are included within this review. From the literature analysis, most discussed lean practices by previous researchers are extracted and adapted to establish a new assessment model for finding relationship between the extracted lean practices with the main objective of lean production system. By investigating the relationship between lean practices and lean objective, the effectiveness of each lean practice to improve manufacturing operation proposed in the new model can be determined as the significance of this reviewed process.* 

**Keywords:** Lean adoption status, Manufacturing industries, Leanness assessment, Malaysia

## 1.0 INTRODUCTION

Lean production system was originated in Japan which was founded by Taichi Ono an engineer in Toyota, after he studied the concept of Ford Production System (FPS). However the term "lean" was first introduced and used by John Krafcik [1] to describe the Toyota Production System (TPS) established by Ono. After the Second World War, Toyota realized that they could not afford to invest much due to lack of resources and thus contributed to the birth of TPS. Toyota Production System (TPS) was developed in order to survive in an environment with minimum amount of resources, therefore its main objective is to reduce waste in every section and step across the production timeline [2]. Womack, Jones and Roos [3, 4] described a lean manufacturer typically as uses less of everything (half the inventory, half the defects, half the manpower, time to market and manufacturing space) to become more responsive to customer demand while producing quality products in the most efficient and economical manner.

Karlsson and Ahlstrom [5] stated that the ultimate goal of implementing lean production system in an operation is to increase productivity, enhance quality, shorten lead times and as well as reducing cost. Despite the great potential of lean strategy in minimizing resource consumption and saving production cost, in certain situation it might sometimes lead to increment of waste, production cost and time of a manufacturer due to inappropriate implementation or misperception of the strategy [6]. Therefore, it is crucial to measure the degree of leanness in a production system in order to realize the benefits of lean and ensure whether a production firm has been implementing the right lean practice to improve its performance.

Leanness is simply defined as the performance measure of lean practices by Vinodh and Chinta [7] while Comm and Mathaisel [8] described leanness as a relative measure of whether a company is "lean" or not. Leanness also interpreted as a measure which focused on re-utilizing lesser input to better achieve more output so as the goals of an organization [9]. Singh, Garg and Sharma [10] stated that leanness can be an assessment parameter to measure the lean status of any firm and accordingly firm can be addressed as lean, leaner or leanest. Regardless of how leanness is defined by various researchers, all carried the same key meaning which is "measure". In order to measure the leanness, researchers usually adapted existing or establish a new framework or model as their guideline. Therefore, the purpose of this review article is to present, make comparison between the existing leanness models and performance measures developed by previous researchers and lastly proposed a new framework to be used in the upcoming research. The new framework is established based on lean production best practices and lean production objective.

## 2.0 METHODOLOGY

Fig.1 shows the flow of preparing this review article and proposing a conceptual framework for upcoming research. The process start with searching for literature sources using online databases. Keywords such as "degree of leanness", "lean performance", "lean assessment", "lean measurement", "lean metrics" and "lean indicators" have been used throughout the literature survey on various databases such as Google scholar, Emerald, Science Direct and ProQuest.

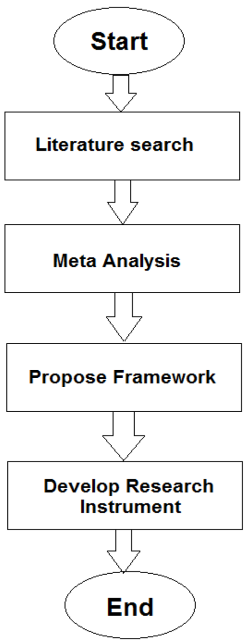


**Figure 1:** Preliminary research flow chart

From the accessed online resources, over sixty (60) papers (combination of articles, journals and full thesis) are screened and refined but the focus are on survey-based or hypotheses testing studies. The downloaded resources are then classed according to the method of the study as

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shown in Table 1. Column with the label “H” represents hypotheses testing method, label “F” stands for fuzzy logic and “O” is classified as others. Models included in category “O” are mostly quantitative model which used archival data instead of perceptual data collected by distributing questionnaire forms. After the refining and sorting step, meta-analysis for comparing the conceptual model between hypotheses testing researches is done. From the analysis, the independent and dependent variables from the models are extracted. Referring previous models, modification and justification are made for proposing the new conceptual model. Lastly, research instrument for assessing the variables from the proposed framework are outlined.

**Table 1**: Classification of Literature Sources

| No | Authors | H | F | O |
|---|---|---|---|---|
| 1 | Karlsson & Åhlström (1996) | | | X |
| 2 | Cua, McKone & Schroeder (2001) | X | | |
| 3 | Sanchez & Perez (2001) | X | | |
| 4 | Soriano-Meier & Forrester (2002) | X | | |
| 5 | Shah & Ward (2003) | X | | |
| 6 | Olsen (2004) | X | | |
| 7 | Lynch (2005) | X | | |
| 8 | Chen (2006) | | | DEA |
| 9 | Bhasin (2007) | | | DMP |
| 10 | Shah & Ward (2007) | X | | |
| 11 | Bayou & DeKorvin (2008) | | X | |
| 12 | DalPont, Furlan & Dinelli (2008) | X | | |
| 13 | Degirmenci (2008) | | | SAE |
| 14 | Sanati & Seyedhosseini (2008) | | | ADM |
| 15 | Anand & Kodali (2009) | | | BM |
| 16 | Fullerton & Wempe (2009) | X | | |
| 17 | Humbert (2009) | X | | |
| 18 | McLeod (2009) | X | | |
| 19 | Puvanasvaran, Megat, Tang, Rosnah, Muhamad & Hamouda (2009) | X | | |
| 20 | AbdRashid, Shaari, Zakwan & Basri (2010) | | | VSM |
| 21 | Jeyaraman & Teo (2010) | X | | |
| 22 | Nordin, MdDeros & AbdWahab (2010) | X | | |
| 23 | Rahman, Laosirihongthong & Sohal (2010) | X | | |
| 24 | Singh, Garg & Sharma (2010) | | X | |
| 25 | Stone (2010) | X | | |
| 26 | Taggart (2010) | X | | |
| 27 | Zanjirchi, Tooranlo & Nejad (2010) | | X | |
| 28 | Asadi & Panahi (2011) | | | DAM |
| 29 | Aurelio, Grilo & Cruz-Machado (2011) | | | X |
| 30 | Behrouzi & Wong (2011) | | X | |
| 31 | Bhasin (2011) | | | X |
| 32 | Daud & Zailani (2011) | X | | |
| 33 | Demeter & Matyusz (2011) | X | | |
| 34 | Eroglu & Hofer (2011) | X | | |
| 35 | Eswaramoorthi, Kathiresan, Prasad & Mohanram (2011) | X | | |
| 36 | Taj & Morosan (2011) | X | | |
| 37 | Vinodh & Chinta (2011) | | X | |
| 38 | Yang, Hong & Modi (2011) | X | | |
| 39 | Agus & Hajinoor (2012) | X | | |
| 40 | Ahmad, Zakuan, Jusoh & Takala (2012) | X | | |
| 41 | Azevedo, Govindan, Carvalho & Cruz-Machado (2012) | | X | |
| 42 | Balaguer (2012) | X | | |
| 43 | Calarge, Pereira, Satolo & Diaz (2012) | X | | |
| 44 | Chauhan & Singh (2012) | X | | |
| 45 | Ghosh (2012) | X | | |
| 46 | Harris (2012) | X | | |
| 47 | Hofer, Eroglu & Hofer (2012) | X | | |
| 48 | AbRahman, Saibani & Zain (2013) | X | | |
| 49 | Dora, VanGoubergen, Kumar, Molnar & Gellynck (2013) | X | | |
| 50 | Anvari, Zulkifli & Yusuff (2013) | | X | |
| 51 | Alemi & Akram (2013) | | X | |
| 52 | Gupta, Acharya & Patwardhan (2013) | | | ISM |
| 53 | Habidin & Yusof (2013) | X | | |
| 54 | Karim & Arif-Uz-Zaman (2013) | | | CPM |
| 55 | Malmbrandt & Åhlström (2013) | X | | |
| 56 | Nawanir, Teong & Othman (2013) | X | | |
| 57 | Rahman, Sharif & Esa (2013) | | | X |
| 58 | Ravikumar, Marimuthu, Parthiban & AbdZubar (2013) | X | | |
| 59 | Shamah (2013) | X | | |
| 60 | Subashini & Kumar (2013) | X | | |
| 61 | Susilawati, Tan, Bell & Sarwar (2013) | | | PMIS |
| 62 | Todorova (2013) | X | | |
| 63 | Vienazindiene & Ciarniene (2013) | | | X |
| 64 | Wahab, Mukhtar & Sulaiman (2013) | | | X |
| 65 | Kull, Yan, Liu & Wacker (2013) | X | | |
| 66 | Lucato, Calarge, Junior & Calado (2014) | X | | |
| 67 | Pruthvi & Sreenivasa (2014) | | | TL |
| 68 | Sadaghiani (2014) | X | | |

## 3.0 LEAN ASSESSMENT MODELS

Earliest model found from literature survey was developed by Karlsson and Ahlstrom [5] dated in 1996. They had developed an operationalized model for assessing the progress of a manufacturing firm in the effort to adopt lean production. The basis of this model was derived from three (3) lean core principles (identify value, elimination of waste and generation of smooth flow) contained in the book entitled *The Machine that Changed the World* written by Womack, Jones and Roos [3]. This operationalized model consist of nine (9) measurable determinants which are elimination of waste (EW), continuous improvement (CI), zero defects (ZD), just in time (JIT), pull instead of push (PULL), multifunctional teams (MIT), decentralized responsibilities (DEC), integrated functions (IF) and vertical information system (VIS). The model had been tested in an international manufacturing firm producing mechanical and electronic office equipment. This model was then adapted by later researchers, Soriano-Meier and Forrester in 2001.

Soriano-Meier and Forrester [11] had adapted this model to verify actual changes made by firms that claim to have adopted lean production principles via hypotheses testing and statistical

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methods. The original model developed by Karlsson and Ahlstrom is more like a checklist which can be used as indicator to assess whether a firm had fulfilled the suggested determinants or not in their journey of adopting lean into their system. Soriano-Meier and Forrester tuned the checklist into a set of seven (7) point scale questionnaire. Soriano-Meier and Forrester introduced degree of adoption (DOA) and degree of leanness (DOL) as the extension to the nine (9) determinants listed in the original model. The respondents from tableware industry were asked to rate all 53 items inside the questionnaire set derived from the nine (9) determinants introduced by Karlsson and Ahlstrom earlier. The mean and standard deviation were computed according to the scores of the nine (9) determinants rated by those respondents. The computed mean value represents the degree of adoption (DOA) while the mean values of the nine separate determinants in the model are to measure the degree of leanness (DOL). Results of the hypotheses testing using statistical analyses showed that correlations between each of the determinants and the degree of adoption (DOA) were all significant. Besides correlational analyses, authors also investigated the strength of the relationship between the nine (9) determinants with DOA and between DOL and performance measure (PERFORMANCE). Among all nine (9) determinants, VI explained forty percent (40 %) of the variance in DOA while DOL was the most important variable which affected PERFORMANCE compared to other tested variables, degree of commitment (DOC) and supporting manufacturing infrastructure (SMI).

Puvanasvaran, Megat, Tang, Rosnah, Muhamad & Hamouda [12] also adapted the modified model in their study on leanness achievement of Kitting Department in an aerospace company. Researchers purposed were to validate the effectiveness of People Development System (PDS) implementation on the case company key performance indicators (KPIs). People management, business management, and lean process are integrated elements consist in PDS. Therefore, researchers adapted Soriano-Meier and Forrester's model to check the improvement in degree of adoption (DOA), degree of leanness (DOL) and top management commitment (DOC) of the case company after the implementation of PDS. The result showed lean practices adoption had been make improvement for the kitting department with the employees' problem solving capabilities in eliminating waste which contribute to KPIs achievement such as scrap and downtime reduction, lesser overtime working hours and higher attendance rate. All these achievement also contributed to cost reduction.

In more recent study, once again this model had been revised and adapted by Chauhan and Singh [13]. This time the new authors' contribution was determining the relative weight for each of nine (9) determinants from the previous model using analytical hierarchy process (AHP). Three experts (industrial manager, academician and author himself) were involved in this analytical hierarchy process. As the result, they found that the most important determinant among the nine (9) determinants included in Karlsson and Ahlstrom was *elimination of waste (EW)*, with the weighting of 35.15 percent, followed by *just-in-time deliveries (JIT)* with 19.56 percent and *multifunctional teams (MFT)* with a weighting of 12.59 percent. Other six (6) determinants had a weighting of less than 10 percent. On the contrary, the result of the conducted survey upon fifty two (52) companies showed that the mean score for EW implementations were only 0.699. Authors stated that the mean score that can be termed as "good" was at least 0.70. However, the weight of importance rated by experts on JIT and MFT practices seemed accurate since both practices had the mean score of 0.922 and 0.820 respectively.

Another degree of adoption (DOA) model adaptation study was done by Subashini and Kumar [14] to validate influence of industry size on the lean production principles. In their study,

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industry size was classified into three (3) categories namely *ancillary, small* and *medium* size within the scope of kitchenware industry in Chennai, Tamilnadu. Authors revealed the result from one-way ANOVA test that there was significant difference of DOA respected to industry size. Medium size industries dominated the results by gaining highest DOA for all nine (9) determinants and followed by small and ancillary size industries respectively except for CI determinant which ancillary size slightly exceeded small size industries DOA score. In addition, results from Friedman t-test showed that EW determinant was ranked first for all three sizes of industry which also implies it as predominant principle practiced regardless of industry size within kitchenware sector. As conclusion, authors suggest micro, small and medium enterprises (MSMEs) to be more innovative in their production process by implementing lean practices so they can stay competitive in current dynamic manufacturing environment and sustain their business.

Shah and Ward [15] proposed a model for examining the probability of implementing twenty two (22) manufacturing practices which are considered as the key elements in lean production system. The postulated hypotheses were that three (3) contextual factors include; unionization status, size and age of plant were influencing the implementation probability. Those twenty two (22) manufacturing practices were classified under four (4) bundles which are total quality management (TQM), total productive maintenance (TPM), just-in-time (JIT) and human resource management (HRM). As the results, the unionized plants were more likely to implement lean practices than non-unionized plant, only eight (8) out of twenty two (22) practices had significant relationship with plants' age and large plants were more likely to implement lean practices compare to small plants. Aside from validating relationship between lean practices and plant context, authors also verified that lean bundles (TQM, TPM, JIT and HRM) had affected operational performance measure for twenty three percent (23%).

Similar to Karlsson and Ahlstrom model, Shah and Ward's model was adapted by many later researchers including study done by DalPont, Furlan and Dinelli [16]. Even the researchers used the same exactly model proposed by previous researcher, validating more detail association between lean bundles (TQM, TPM, JIT and HRM) and operational performance was their rational and contribution. They were focusing on direct and mediating effect of each lean bundle upon operational performance. Survey that was conducted involved 266 plants from three (3) distinct industries (electronic, machinery and automotive suppliers) located across nine (9) countries. Results showed that *just-in-time (JIT)* and *total quality management (TQM)* had positively direct effect on operational performance while *human resource management (HRM)* had mediated effect on it. Based on these results, authors also suggested some HRM components such as multi-tasking training need to be provided to employees before implementing JIT bundles. This suggestion was supported by researchers' previous study on JIT failure factors. Firms claimed to be failed in JIT implementation due to insufficient of foundation training programs provided for their employees.

Rahman, Laosirihongthong and Sohal [17] then adapted thirteen (13) out of those twenty two (22) practices identified by Shah and Ward to find the impact of lean practices upon operational performance of Thai manufacturing companies. They excluded the practices which related to total quality management (TQM) and human resource management (HRM) bundles. Their rational, TQM and quality management programs are included as different sets of practice from lean strategy while HRM is regarded as higher level approach as their focused was only on operations level (impact of lean practice at operation level on operation performance). From factor analysis, three (3) main constructs namely, JIT, Waste Minimization and Flow Management were established from the thirteen (13) adapted practices. Regression analyses proved that all three constructs were significantly related to operational performance with *JIT* as most significant construct for Large Enterprises (LEs) and *Waste Minimization* for SMEs (Small-Medium Enterprises). JIT construct also was highly significant to all three types of companies with respect to ownership (Local, Foreign and Joint-Venture). The authors also criticized that most LEs had given more focus on "hard" techniques of lean which involved new process technology and caused the result of lower significance level for *Waste Minimization* construct compare to SMEs as minimizing waste is what differentiate lean strategy with traditional production methods.

Demeter and Matyusz [18] had outlined six (6) lean manufacturing (LM) practices namely Process Focus, Pull Production, Quality Programs, Equipment Efficiency, Continuous Improvement and Form of Lean Organization based on four (4) lean bundles introduced by Shah and Ward [15]. Their study was to validate relation between LM practices and inventory turnover (throughput, delivery and possession) with respect to different production systems, product variety and ordering policy. As the results, researchers found significant relationship between LM practices and inventory turnover. Concerning studied contingency factors, *production systems* gave most significant on inventory turnover and with respect to forms of inventory (raw material, WIP and finished goods), WIP was highly affected. *Ordering policy* was the second most significant factor, which affected raw material and finished goods inventory and followed by product variety factor which seemed not so influencing to all three forms of inventory. Authors concluded that their findings fit the logic of LM, therefore considered as important contribution. Based on their findings, manufacturers might gain insight which forms of inventory need to be focused according to their manufacturing context (production systems, product variety and ordering policy) and authors also critic *cellular layout* as the best facility layout to be adopted by lean practitioner.

In year 2007, Shah and Ward [19] published another study on operational measure of lean production and provide a framework that identifies its most noticeable dimensions. Their operational measure was deemed to be more comprehensive than previous lean operational measurement model developed by earlier researchers as it comprised both internal and external dimensions of lean landscape. There are ten (10) dimensions lies within their suggested model which are flow (FLOW), total preventive maintenance (TPM), employee involvement (EMPINV), customers involvement (CUSTINV), setup time reduction (SETUP), statistical process control (SPC) pull production systems (PULL), JIT delivery by suppliers (SUPPJIT), suppliers feedback (SUPPFEED), and supplier development (SUPPDEVT). Customers' involvement (CUSTINV), JIT delivery by suppliers (SUPPJIT), supplier development (SUPPDEVT) and suppliers' feedback (SUPPFEED) are external dimensions while the rest are the internal dimensions. Internal dimensions also can be interpreted as technical factors which include FLOW, TPM, SETUP, PULL, JIT and SPC while external dimensions or social factors are SUPPDEVT, SUPPJIT, SUPFEED and CUSTINV. EMPINV however was classified as social factors but one of internal dimension of lean production system. Researchers had conducted empirical test such as exploratory and confirmatory analysis of their suggested model to ensure that it was reliable and meets established criteria for assessing validity. In addition, they also conducted statistical inter-correlation analysis between these ten (10) dimensions to support their argument against previous study which proposed different models to assess leanness. Authors conclude that their validated proposed model is a useful instrument for both managers and researchers to evaluate status of lean implementation of a firm. For managers they might use it as self-assessment of their firm progress in implementing lean and for researchers it might be useful for hypotheses testing on lean production association with firm performance with regard to firm characteristics or context.

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Few years later, McLeod [20] redeployed the same instrument developed by Shah and Ward [19] to 12, 000 Small and Medium Manufacturers (SMMs) in Indiana state. Author presumed that this instrument model fit to be revalidated since the sample respondents in previous study were too small (63 respondents) and lack of reliability according to his literature. It was due to reverse coding and low corrected item to correlation (CITC) scores before the previous researchers discarded seven (7) out of forty eight (48) items from their proposed model. In spite of that, researcher agreed with Shah and Ward's definition of lean which emphasized on social and technical factors integration as their basis in establishing the model. Therefore, the researcher wanted to revalidate this model and this time to a larger population. The result of this research showed that SMMSs in Indiana were not intensive and holistic practitioners of lean practices. Their size and types of product were the reason why they only implemented some small portion of lean. Lean implementation was first triggered by them when their competitors started to produce similar but cheaper products.

Once again, Shah and Ward's model had been adapted by more recent researchers in the later study. Hofer, Eroglu & Hofer [21] conducted a study on relationship of lean production with financial performance and which focusing on mediating effect of inventories. Researchers had administered the survey instrument developed by Shah and Ward [19] for measuring firms lean production level to Association for Operations Management (APICS) members. On the other hand, firms financial and inventory level data were obtained from Standard & Poor's COMPUSTAT database and inventory leanness was measured using Empirical Leanness Indicator (ELI) developed by the researchers themselves. All these data then analyzed using statistical method (descriptive and correlational). As this study focused on mediating effect of inventory leanness, regression analysis was also done upon ELI. The results showed that inventory leanness did have positive relation to financial performance but only the leanness level of the inventory only explained twenty five percent (25%) of the financial performance. As Shah and Ward classified factors in their survey instrument into internal and external, the authors also use this classification to significantly distinguish their findings. Inventory leanness only mediates the link between lean practices respect to internal factors and financial performance partially. On the contrary, external lean practices had insignificant direct association with financial performance. Authors concluded that even their findings were not consistent with most previous researches, there might be at least slightest possibility lean production may lead to inventory retaining and associated cost referring to study done by Wu (2002).

Besides Hofer, Eroglu and Hofer, Shah and Ward's model also had been adapted by Dora, VanGoubergen, Kumar, Molnar & Gellynck [22]. Dora and fellow authors conducted a study on the implementation of lean manufacturing practices by small and medium-sized enterprises (SMEs) within the food sector in Europe countries. Authors' rational for adapting Shah and Ward's model was due to the holistic factor of the model. Holistic meant by the authors is the model comprised of both internal and external factors as well as both people and process elements. The ten (10) dimensions suggested by Shah and Ward were simplified into only eight (8) lean manufacturing practices, by the authors since they combined (SUPPJIT), suppliers feedback (SUPPFEED), and supplier development (SUPPDEVT) into only one (1) practice named *Supplier Related*. The other seven (7) practices are customer related, total productive maintenance, statistical process control, flow, pull, set up, and employee involvement. The result of conducted descriptive analysis showed, European SMEs were more likely to practice lean activities related to customer, supplier and total productive maintenance than flow, pull, set up, and employee related. *Statistical process control* was the lowest implemented practice by European SMEs. Through Friedman's non parametric test result, Dora and fellow

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researchers explained the possible reason of such variation in degree of implementation might be because some lean manufacturing practices especially like statistical process control was relatively difficult to be applied in SMEs food production sector. Researchers also revealed the significant difference in lean practices implementation concerning two (2) control variables which are plant size and country origin, from inferential statistical analysis results. Kruskall-Wallis test results demonstrated implementation level of lean practice related to employee involvement had the biggest difference between micro and medium sized enterprises. Consistent with the common sense assumption, micro-sized enterprises involved their employee more which may be due to short of workforce. Another expected result was, micro-sized enterprises are less likely to implement *pull production* and *setup time reduction* practice. Result concerning country of origin showed that Germany and Hungarian enterprises more extensive practitioner of lean practices compare to Belgian enterprise.

Shah and Ward's model not only feasible to be adapted in survey based or hypotheses testing research. Items comprised in the model also had been adapted in measuring leanness using fuzzy logic method by Zanjirchi, Tooranlo & Nejad [23]. Zanjirchi and fellow researchers had developed a methodology for measuring degree of leanness in manufacturing companies using fuzzy logic algorithm. Their rational for establishing this model to replace the previous assessment model because they believe human perceptions was unreliable due to uncertainty and vagueness. Fuzzy model as defined by Bojadziev and Bojadziev [24] use mathematical algorithm to represent the non-statistical, uncertain and linguistic values. Considering these deficiencies, they came up with an approach based on linguistic variables and fuzzy numbers for measuring leanness of a manufacturing organization. Similar to other researchers who had adapted the same model [20-22], Zanjirchi et.al also stated it as a comprehensive model. Comprehensiveness of items, power of research method used and time approximation with the present study, are authors justification to adapt Shah and Ward`s lean assessment model in their study. Other similar studies which used the same fuzzy logic idea for assessing lean implementation including Singh, Garg and Sharma [10] which was published on the same year, predecessor study by Bayou and DeKorvin [9], followed by Behrouzi and Wong [25], Vinodh and Chintha [7] and Azevedo, Govindan, Carvalho and Cruz-Machado [26] and the latest found, Alemi and Akram [27] as well as Anvari, Zulkifli and Yusuff [28].

In 2006, Chen [29] proposed a model to quantitatively measure leanness level of a manufacturing system called Slack-Based Measure (SBM). This SBM model used Data Envelopment Analysis (DEA) technique which measures the leanness level of each production process by comparing the process with an effective leanness benchmark called *the frontier of leanness* was claimed to be a better model for measuring leanness compared to other previous models developed by earlier researchers according to the author. The frontier of leanness is set based on *cost-time-value* analysis. Cost and time represent the input data while value is the output of the analysis. Author stated that performing the DEA-Leanness measurement requires detailed cost and time data for every production process which also requires extra time and effort.

Besides SBM and fuzzy leanness model, Sanati & Seyedhosseini [30] introduced another mathematical based model for measuring leanness called Axiomatic Design Methodology (ADM). Unlike previous reviewed model, this model was intended to evaluate leanness of a plant life cycle instead of manufacturing system. The authors described the leanness concept as elimination of wastes in the phases of developing a plant which are investment phase, designing and factory construction phase, as well as system design by the organization that would run the plant. In this quantitative model, the amounts of leanness in each phase were

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determined and combined to make a unique measure for total leanness. ADM model used mathematical formula called Design Matrix (DM) which describes the relationship between Functional Requirements (FRs) and Design Parameters (DPs), also Design Parameters (DPs) and System Variables (SVs) as well. Authors' defined manufacturing leanness as what are the customers wants. Regards to this subject, authors identified four (4) Functional Requirements (FR) in measuring manufacturing leanness which were lean investment, lean design-construction, lean organization-system designs, and lean production. Meanwhile, the Design Parameters (DPs) determined based on seven (7) types of waste in Toyota Production System (TPS). Authors concluded that this model useful for strategic planning application and industrial investment evaluation.

In 2009, Gurumurthy and Kodali [31] measured degree of lean implementation in an air conditioners manufacturing company in India. They used a method called benchmarking (BM), which sounded quite similar with SBM model developed by Chen [29]. Similar but still not alike, benchmarking method used by Gurumurthy and Kodali was much simpler and using data from external resources as comparison and reference, while SBM model created the effective leanness benchmark itself, using data of cost and time. In this case study, the authors referred Toyota and another company in the same sector as their benchmark companies since Toyota is the founder of lean philosophy while the other company was the market leader in air conditioner manufacturing sector. There are sixty five (65) lean manufacturing practices implemented by Toyota and the subject company in this study only implemented thirty nine (39) practices out of all. Another comparison made was in the term of performance measures where there were ninety (90) items, between Toyota and the market leader company. The comparison showed the market leader company achieved thirty four (34) out of all performance measured outlined by Toyota. This benchmarking result also showed that even the market leader company still got a lot more to improve which means the challenge for the subject company was far greater. Therefore, the authors suggested that the subject company need to start implement few more of these practices.

After a few years of SBM and ADM models had been introduced, Asadi and Panahi [32] had presented another quantitative model for evaluating leanness of a production system. This model was originated from Willis et.al [33] to measure performance of suppliers in JIT delivery. In this paper, a mathematical technique called Dimensional Analysis Model was used to assess lean factors in a buttermilk production line. These lean factors were the input for this model and obtained from the questionnaire forms. However, backgrounds of the respondents were not specified in this paper. Authors had identified six (6) factors from the distributed questionnaire forms and the weight of each factor was measured using by software called Expert Choose. The six (6) factors are Procurement Management, Quality Management, Information Technology, Maintenance Management, Production Process Management and Equipment & Hardware Management. These factors were then calculated using a mathematical formula to find the value of Degree of Adaptability (DOA). This DOA value represented the production line rate of adjustment with lean criteria.

Agilean index was introduced by Azevedo et.al [26] to assess the agility and leanness of automotive supply chain involving four (4) Portuguese companies. One company was the automaker itself and three (3) others were its first-tier suppliers for plastic parts, front rear and exhaust system. Agilean index also a model which used mathematical formula like previous discussed models [7, 9, 13, 23, 25, 27, 29, 30] developed by earlier researchers. This mathematical formula is called additive weighting aggregation method. Delphi technique was used by eleven (11) experts in automotive research area to develop a series of weighted

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Agile and Lean supply chain management (SCM) practices. In addition, a statistical test of agreement named Kendall's Coefficient of concordance was applied to obtain a consistent measure rated by the 11 experts' responses. There were seven (7) agile and seven (7) lean practices evaluated in this study. The lists for the lean practices are as follow: just in time delivery by supplier, just in time delivery to customer, just in time automaker to supplier, pulls flow, total quality management, long-term relationship with suppliers and customer relationship. Authors had conclude that, computed Agilean index enabled managers to verified which type of agile and lean practices considered as most important to individual companies and also supply chain (SC) members. This index also useful as a benchmarking framework for companies to compare their performance in terms of agility and leanness with their supply chain (SC) members in order to become more competitive through waste minimization, cost minimization and also quick response to unpredicted changes.

In year 2008, Degirmenci [34] published a study on lean standardization and certification developed by Society of Automotive Engineers (SAE) known as J4000 and J4001. J4000 is a documented lean operation best practice while J4001 is a user manual for lean operation implementation. Both documents were published since August 1999 but were not recognize or aware among lean practitioners and were not implemented by eighty five percent (85%) of the respondents in a survey conducted by the researcher. The total respondents were 244 from across North America, Europe and Asia Pacific. The SAE J4000 document covers six (6) elements of lean implementation which are; Management/Trust, People, Information, Supplier-Organization-Customer chain, product and process/flow. Within these six (6) elements, lie fifty two (52) components which provide measurable ratings for successful lean implementation. Besides to discover on awareness among lean practitioners and recognition of this lean standard in manufacturing industry, the purpose of this study also to investigate the potential benefits and drawbacks of having standards as a guide in implementing lean for enterprise scope. As the results, there was an overall support for lean standardization but on the other hand, there were both positive and negative perceptions regarding the potential benefits and drawbacks of implementing lean standards as a guide.

Few years after Degirmenci's study on lean standard and certification awareness [34] was published, more researchers became to realize SAE J4000 standard existence and began to adapt it as a research model in their study. Among the researchers are Calarge et.al [35] and Lucato et.al [36]. Calarge adapted SAE J4000 standard to evaluate the degree of adherence to lean production system by several Brazilian and Spaniard companies in automotive industry. Authors addressed the leanness level of the company as the degree of adherence due to show that they were comparing the lean practices implementation of case companies with the standard and to show how close the case companies to the standard stated by Society of Automotive Engineers (SAE). The rational of the authors selected respondents from these two (2) countries in this exploratory survey based study was due to the fact that, Brazil being is a country with knowledge and know-how on the manufacturing of vehicles based on the use of bio-fuel such as ethanol while the Spain has been a European benchmark in automobile sector in terms of output volume, exportation, and consumption on the foreign market. From descriptive statistical analysis of the collected data, Spanish companies showed higher leanness adherence to the standard (SAE J4000) compared to the surveyed Brazilian ones, even companies from both countries presented very similar structural operational conditions. In addition to this, correlation analyses results demonstrate element 3 (information system) as the one which shows the lowest correlation coefficients, concerning the Elements 4 (Client-Supplier-Organization Relation) and 6 (Process Flow). This trend interprets that decisions made for the element 3 only had small degree of influence over the other related elements.

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Nevertheless, the most impacting elements regarding the Lean Production practices implementation, was Element 1 (Ethics and Organization).

In the following year, Lucato et.al [36] conducted a study to explore the implementation of lean practices in Sao Paulo Metropolitan Area, Brazil. The authors attempted to find if there were significant differences in the degree of leanness according to the firm's size (small, medium and large), types of ownership (national and multinational) and industrial sector. The survey was conducted on 51 firms and used the same conceptual model as Calarge which was SAE J4000 standard. The composition of sample firms are as follow; ownership: 27 were subsidiaries of multinational companies operating 24 were national firms; size: three were small (less than 100 employees), 20 were medium (between 101 and 499 employees) and 28 were big (more than 499); and industrial sector: 22 and 20, belong to automotive and metal-mechanical sectors respectively while the rest belong to other seven distinct industries (abrasives, printing, non-ferrous alloys, furniture, plastics, systems automation and glass manufacturing). For obtaining the survey results, statistical analyses performed included descriptive analysis for computing mean the degree of leanness (DOL), independent t-test and one-way ANOVA for mean comparisons analyses. The results obtained from the survey showed that the lean practice adoption was not at equal level between different types of ownership. The degree of leanness (DOL) demonstrated by multinational firms was higher in comparison to the national firms. Nevertheless, it was not possible to confirm any association between the degree of leanness (DOL) and the size of the firms. It was not either possible to confirm a clear and certain relationship between degree of leanness (DOL) and the industrial sector to which the sample firms belonged. In addition, the highest degree of implementation was for Element 2 (People) while the least progress was Element 4 (Client-Supplier-Organization Relation).

Study done by Gupta, Acharya and Patwardhan [37] proposed that implementing lean paradigm in an organization involves both strategic as well as operational approach. Interpretive structural model (ISM) was adapted in their study served as an important tool for strategic decisions making, within the same research they had developed an Excel-based lean self-assessment template for measuring leanness in an Indian tire manufacturing firm. ISM helped top management to understand the inter-relationship between critical factors of lean implementation in order to improve lean performance of the case firm. The ISM was formulated from the consulted opinions of a group of experts of the case firm while the Excel-based lean self-assessment was developed on the basis of feedback from the operational staff whose have been working for at least nine (9) years in the firm. ISM had enabled the top management of the case company to clearly identify the factors which are required to be controlled for making strategic decisions in developing lean environment. There were ten (10) factors that had been identified, Human Resource Management, Organizational Culture, Production Methodology, Performance, Supplier Integration, Top Management Commitment, Customer Involvement, Change Management, Macro Environment and Financial Capability. These factors were then computed and compiled using reachability matrix and transitivity matrix. ISM which suggests the use of collective experts' opinions is similar in to Delphi method adapted by Azevedo et.al [26] and Analytical Hierarchical Process (AHP) adapted by Chauhan and Singh [13] in terms of the concept. This assessment model proposed by the authors also looks quite identical to Axiomatic Design Methodology (ADM) developed by Sanati and Seyedhosseini [30] because both researches translated the lean factors into matrix formulas.

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Karim and Arif-Uz-Zaman [6] proposed a leanness evaluation metric named Continuous Performance Measure (CPM) which was developed based on five (5) lean core principles coined by Womack and Jones [4]. From authors' point of view, achieving manufacturing leanness requires continuous process improvement technique to generate optimum value from the process. Therefore, CPM is claimed to be an ideal model because it is a simplified leanness evaluation metric consists both efficiency and effectiveness attributes of manufacturing performance for evaluating continuous lean implementation. In this study, authors referred efficiency as comparing actual output value generated from a particular machine to total resource used by the same machine in a given period of time. In simpler words, efficiency is output value versus input value in terms of time frequency. In this case, the input parameters are, number of operators and total working time while output parameters are total output, time of completion. This proposed model had been validated through a case study in an Australian switchgear manufacturing company. Researchers also utilized time study method to obtain the input parameter (total working time) data and process mapping. From these two methods they were able to identify non-value added (NVA) time and value added (VA) times and wastes existence in each process of producing switchgears. From this finding, the production system efficiency was calculated and the manufacturer knew their current status. As they knew their current performance, they tried adopting various lean practices (TQM, TPM, JIT, 5S, single piece flow, cellular layout, concurrent engineering, process integration and line balancing) to reduce wastes and non-value added (NVA) activities. After several months of implementation, once again the efficiency was calculated and the implemented lean practices were proven effective.

Aurelio, Grilo and Cruz-Machado [38] suggested a framework to determine whether lean strategies are appropriate to be implemented or not, considering both strategic and operational factors. The framework consisted of five (5) key aspects which are strategic needs and capabilities, commercial model, ability to extent in the future and influence of external as well as internal factors. The first three (3) factors are classified as strategic level dimension while the other two (2) are within operational level dimension. This paper also highlighted on Lean practices Penetration Ability based on extensive literature analysis done by the authors. They had classified the ability into three (3) stages, Low, Medium and High Penetration. Accounting Methods, Management by Value Stream, JIT delivery by suppliers, Pull and Flow production, Total Productive Maintenance and Relationship with Customers were staged as *Low Penetration Ability*. Continuous Improvement, Cellular Manufacturing, Reducing Suppliers and follow up activities of some *Low Penetration* activities like Target Costing, Value Stream Performance measurement and Control Methods were identified as lean practices with *Medium Penetration Ability*. Meanwhile, *High Penetration Ability* included practices such as Total Quality Management, Employee Empowerment, 5S, Single Minute Exchange of Die and Work Standardization. Authors claimed that this framework would guide any decision maker to evaluate whether an organization suit or not to implement Lean Management practices and they had validated it in a case study. However, authors recommended a further research based on empirical data to determine the weights of each key aspect consisted within the framework, for example Analytical Hierarchical Process (AHP).

Switching to local (Malaysia) scope, lean manufacturing research based on quantitative survey and statistical analyses method can be said as not widespread compare to other countries since accessed papers from literature survey are mostly from USA and India. Earliest local quantitative survey publication found dated in 2009 by Wong, Wong and Ali [39]. In addition, the research trend demonstrates that SME, supply chain and automotive industries are the usual interest of local lean researchers. Wong et.al investigated the lean manufacturing implementation by electrical and electronics industry in Malaysia. Using a questionnaire set contained 52 items adapted from Shah and Ward [19] as the research instrument, researchers explored the level of lean manufacturing implementation in fourteen (14) key areas namely, Scheduling, Inventory, Material Handling, Equipment, Process, Quality, Employees, Layout, Product Design, Tools and Techniques, Management and Culture, Safety and Ergonomics, Suppliers and Customers. From the survey, researchers had validated that most of respondent companies were committed in implementing lean manufacturing and they were rated as *moderate* to *extensive* implementer. Besides implementation status, this paper also revealed the extent of understanding, perceived benefits and obstacles faced by respondent companies regarding lean manufacturing adoption. Researchers considered the respondents as highly understood of what is lean manufacturing since majority chose *waste reduction* and *continuous improvement* out of other six (6) choices as criteria which closely associated with lean manufacturing. As for perceived benefits, majority agreed *Cost Reduction* as the benefit they clearly gained besides seven (7) other benefits (Flexibility, Quality, Productivity and Response Time Improvement, Waste and Inventory Reduction and Profit Increment). Meanwhile, the biggest obstacle identified was *Backsliding to the Old Ways of Working* and followed by *Employee Resistance* with other six (6) obstacles. The survey results also highlighted *5S, Kaizen, Work Standardization* and *PDCA* as most implemented tools and techniques regardless of the company maturity in adopting lean manufacturing into its system.

Rashid, Hani, Shaari, Basri and Fazliana [40] had validated the application of value stream mapping (VSM) through a case study in a food processing company categorized as SME. Researchers' findings revealed the case company had almost 40% lead time reduction which subsequently reduces operating hours as well as number of operators which also can be interpreted into operating cost. However this study is not an empirical research based on quantitative survey and only focusing on single lean practice which is VSM. In a different study related to lean implementation among SMEs was done by Rahman, Sharif and Esa [41]. They had identified five (5) factors which hindering SME companies from implementing Kanban production system from their literature survey. The five (5) barriers were then validated by interviewing three (3) managers of a local automotive manufacturer and authors also declared their study as a qualitative research. Rose, Deros, Rahman and Nordin [42] proposed seventeen (17) lean practices which claimed to be appropriate to be applied in SMEs due to three (3) relevant support factors. The support factors were least investment, feasible for adoption and based on researchers' recommendations. Capability of the enterprise to implement lean with existing resources defined feasible for adoption in more specific manner. This study declared *5S*, *Visual Control, Operation Standardization, Statistical Process Control (SPC)* and *Quality Circle* as lean practices which required less investment and authors suggest SMEs to start adopting lean strategy into their system using these practices before continue with other practices such as *Kanban* and *Small Lot Size*. Other ten (10) practices considered as feasible for SMEs adoption and supported by several highly cited literatures are Cellular Layout, Continuous Flow, Uniform Workload, Total Quality Control, Continuous Improvement, Supplier Management, Preventive Maintenance, Training, Teamwork and Multifunction Workers. Authors concluded that even SMEs might not able to gain full benefit from implementing only few lean practices but these adoptions still could improve their enterprise performance gradually.

Study on lean supply chain management done by Daud and Zailani [43] did not specifically mentioned what are the lean practices had been analyzed. Authors listed Demand Management and Waste Management as their independent variables and Lean Performance as dependent variable. Demand Management comprised of four (4) facets which are demand signal, demand collaboration, sales and operating planning and inventory management practices while Waste Management was simply defined as eliminating non-value added activities in the manufacturing processes. The population of the study samples are 551 electrical and electronics manufacturing including electronic manufacturing service (EMS) and original equipment manufacturer (OEM) companies from both multi-national company (MNC) and small-medium enterprise (SME) sectors. Researchers did analyzed causal association between independent variables constructs and dependent variables constructs (Better Quality, Faster Throughput and Cheaper Cost) and the results implied 15% of Better Quality variation, 27% of Faster Throughput variation and 44% of Cheaper Cost were explained by Demand Management constructs while Waste Management explained 27% variation for overall Lean Performance constructs (Better Quality, Faster Throughput and Cheaper Cost).

Another lean research concerning local supply chain industry was conducted by AbRahman, Saibani & Zain [44]. Authors' purposes were to evaluate the possibility of lean supply chain (LSC) implementation within Halal food industry besides identifying barriers hindering the implementation. Similar to study done by Daud and Zailani, no specific lean practices were mentioned and this study focused more on barriers of the implementation rather than leanness level of the target sample companies. The results of this study showed that 70.5% of responded companies had not implemented LSC and the most dominant factor which hindered its implementation is market competition and uncertainty. Poor understanding of lean concept is what contributed to uncertainty to implement LSC since the companies did not know how they can become more competitive in business through LSC. Authors also concluded companies suffer from external issues more compare to internal issues which correspond to common sense of thinking, managing internal issues are easier than dealing with external issues (customers and suppliers). The findings also highlighted that majority of barriers interfered companies in implementing lean manufacturing also impeded LSC implementation.

More study in lean area related to supply chain by local researchers was contributed by Agus and Hajinoor [45]. Different from two (2) publications previously discussed, this paper had clearly state specific lean practices as their independent variables. Five (5) lean practices analyzed in this research are Setup time reduction, Continuous improvement, Pull production, Shorter lead time and Small lot size. Researchers aim were to gain better understanding on to what extent of lean production has been diffused into Malaysian manufacturing company and its effect upon level of performance in the industry. Two (2) main constructs of performance studied by researchers were Product Quality Performance (PQP) and Business Performance (BPERF). Authors had highlighted three (3) important findings from their results; the first one was lean practices particularly Setup time reduction, Pull production system and Shorter lead time had strong positive effect upon PQP. Secondly, there was significant relation between independent constructs (lean practices) and BPERF constructs but relatively moderate association. However, the third finding demonstrated that PQP constructs had positive and direct effect on BPERF of Malaysian manufacturing industry. Authors also suggest that, even there was only moderate link between lean practices and BPERF but due to strong relation with PQP constructs, it can be said lean practices had positive but indirect effect on BPERF through PQP.

Turn to local lean study within automotive scope, Nordin, Deros and Wahab [46] had explored the extent of lean manufacturing (LM) implementation and several barriers which hindered its implementation in manufacturing firms related to automotive industry. The respondent firms comprised of electrical, electronic, metal, plastic, rubber and other automotive components suppliers. The results from statistical descriptive analyses revealed that most of the respondent

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firms had been implemented LM system up to a certain level. Therefore, cluster analysis was performed to categorize the responded firms in detail according to their implementation status on twenty six (26) lean practices which were grouped into five (5) categories namely Process and Equipment, Manufacturing Planning & Control, Human Resources, Supplier Relationships and Customer Relationships. Authors had outlined three (3) categories which are Non-lean, In-transition and Lean and most respondent firms were categorized as In-transition due to moderate mean scores. Authors also concluded that the lack of understanding on lean manufacturing concept and workers' attitude as the major barriers towards lean implementation among these firms.

Another research on lean related to automotive industry conducted by local researchers was concerning critical success factors (CSFs) of lean six sigma (LSS) implementation in Malaysian automotive suppliers. Habidin and Yusof [47] analyzed seven (7) factors namely Leadership, Structured improvement procedure, Quality information Analysis, Supplier relationship, Just in time, Customer focus and Focus in metric. Researchers then validated and verified these factors via Exploratory factor analysis (EFA), Confirmatory analysis (CFA) and reliability analysis. From the total of 252 respondents the results of the survey highlighted two (2) factors which are Leadership and Customer focus. Authors also concluded, there was positive progress in LSS adoption since overall responded companies had been classified as *slightly high* and *high* regarded to CSFs level of LSS from computed mean scores.

Pioneer study on CSFs of LSS in local context was published by Jeyaraman and Teo [48] in 2010 (before Habidin and Yusof's study). They analyzed impacts of critical success factors (CSFs) of lean six sigma (LSS) towards company performance involving six (6) multi-sites electronic manufacturing service (EMS) companies in Malaysia. The conceptual model consists of nine (9) CSFs as independent variables (management commitment, reward system, staff's competency, financial capability, project prioritization, track records and training program) and both organizational and operational performance as dependent variables with organizational belief and culture as moderating variable. Unlike lean practices, CSFs of lean seem more into policies and strategic planning related, which involve authority at top managerial level rather than operational level which directly related to products production and processing. The results from the study were not yet reveal in this paper as authors declared the study still in progress.

From these discussed models, studies on lean practices in manufacturing industries are often associated with performance which empirically validated through structured survey [11, 15-17, 21, 22, 45] or via case study [5, 6, 12, 26, 29, 34, 40]. Operational performance, financial performance and business performance are typical researchers' interest and relevant performance measure within manufacturing scope. Meanwhile, most of quantitative model reviewed [6, 26, 29, 30] were using waste elimination or the concept of value added and non-value added activities as their aim to achieve leanness rather than lean practices implementation level used in most hypotheses testing studies. As for local context, study on lean manufacturing mostly still focusing on drivers, barriers and possibilities of its implementation [44, 46-48] unlike foreign studies which focus on effect and impact of lean implementation especially on firm performance. The reason might be because lean production system are not widely spread and infuse in Malaysian manufacturing industry and only limited to multi-national companies (MNC) and joint-venture (JV) companies.

## 4.0 PERFORMANCE MEASURES

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Performance dimensions from financial perspective are usually related to sales and assets as in Table 2 while operational performance basically involved the measure of cost, time and quality. Table III exhibits literature supports for operational performances' dimensions.

**Table 2**: Dimension of Financial Performance

| Sources | Financial performance |
|---|---|
| Soriano-Meier & Forrester (2002) | Sales per employee ratio<br>Asset turnover ratio |
| Olsen (2004) | Sales growth<br>Asset productivity |
| Humbert | Sales |
| Fullerton & Wempe (2009) | Return on sales |
| Yang, Hong & Modi (2011) | Return on sales |
| Hofer, Eroglu and Hofer (2012) | Return on sales<br>Return on assets |
| Agus & Hajinoor (2012) | Return on sales<br>Return on assets |
| Dora et.al (2013) | Sales improvement |
| Nawanir, Teong & Othman (2013) | Sales (profit) |

Cost, time and quality are the frequent constructs included in performance measures. However for time measures, different researchers might have their respective focus, but most emphasized on on-time delivery [19, 22, 46, 49-55]. Other time measures studied are lead time [15, 56, 57], cycle time [15, 22, 58, 59] or throughput time [55, 60]. Flexibility in terms of product-mix and production volume also included as one of the performance indicator studied by few researchers [16, 49, 52, 53, 56] besides cost, time and quality. In a larger scope, business performance usually encompassed market share performance as addition to financial performance [45, 61]. Unlike financial performance measures, operational measures usually used perceptual source of data rather than archival source since there is no such public database which enclose data regarding cost, quality and manufacturing time of every manufacturing firm due to confidential issues.

Back to the discussion on causal relationship between lean practices and performance measures, all literature supports presented in Table 2 and Table 3 had validated the empirical positive impact of lean practices upon operational and financial performance except mixed responses upon business performance. Olsen [58] found that firms which practicing lean had significant better ROE compared to non-lean firms and consistent with results demonstrated by Nawanir, Teong and Othman [54]. Lean practices explained 36% variance of profitability (return on sales) measure while Agus and Hajinoor [45] found that lean practices had significant but indirect (mediating) effect on business performance through product quality performance. As many researchers had investigated and validated causal relation of lean practices towards performance measures, none study found demonstrating the causal relation of lean practices upon the original objective of lean production system. The original objective of lean production system meant here is elimination of waste.

**Table 3**: Dimension of Operational Performance

| Quality | Cost | Time |
|---|---|---|

| | | |
|---|---|---|
| 1. Sanchez & Perez (2001)<br>2. DalPont, Furlan & Dinelli (2008)<br>3. Rahman, Laosirihongthong & Sohal (2010)<br>4. Taj & Morosan (2011)<br>5. Balaguer (2011)<br>6. Ghosh (2012)<br>7. Dora, VanGoubergen, Kumar, Molnar & Gellynck (2013)<br>8. Nawanir, Teong & Othman (2013)<br>9. Kull, Yan, Liu & Wacker (2013) | 1. Sanchez & Perez (2001)<br>2. DalPont, Furlan & Dinelli (2008)<br>3. Rahman, Laosirihongthong & Sohal (2010)<br>4. Dora, VanGoubergen, Kumar, Molnar & Gellynck (2013)<br>5. Nawanir, Teong & Othman (2013)<br>6. Todorova (2013)<br>7. Kull, Yan, Liu & Wacker (2013) | 1. Sanchez & Perez (2001)<br>2. DalPont, Furlan & Dinelli (2008)<br>3. Rahman, Laosirihongthong & Sohal (2010)<br>4. Taggart (2010)<br>5. Taj & Morosan (2011)<br>6. Balaguer (2011)<br>7. Ghosh (2012)<br>8. Dora, VanGoubergen, Kumar, Molnar & Gellynck (2013)<br>9. Nawanir, Teong & Othman (2013)<br>10. Todorova (2013)<br>11. Kull, Yan, Liu & Wacker (2013) |

## 5.0 PROPOSED FRAMEWORK

The birth of Toyota Production System (TPS) was due to survive with minimum amount of resources after the Second World War. The limited availability of resources made all wasting intolerable and unaffordable. Hence, reducing wastes in the production system became the mission of survival for Toyota [29]. This TPS concept is then lead to the foundation of lean philosophy or principles. Ono [2] the founder of TPS, pointed out that the basis of TPS is eliminating waste, besides JIT and Autonomation as the supporting practices in the system. This is to prove that the main objective of lean production system is also eliminating waste since the concept is inherited from TPS.

Consistent to other researchers' point of view, Simons and Zokaie [62] considered lean production philosophy based on waste elimination in searching for perfection and continuous improvement. Shah and Ward [19] described lean production as an integrated socio-technical system with the main objective of eliminating waste by concurrently reducing or minimizing supplier, customer, and internal variability. Some more descriptions of lean from different researchers and authors, lean is a paradigm which focuses on the elimination of waste and non-value added activities to achieve higher levels of efficiency, profitability and flexibility [63] and lean operations are characterized by the elimination of apparent wastes reside within the manufacturing processes, thereby facilitating cost reduction [64]. From these descriptions written in previous studies, it is clear that the main objective of implementing lean production system is eliminating waste and it works as the bridge or medium to other success such as cost reduction, high efficiency and profitability increment. Therefore, it is concrete to justify that a firm must achieve minimal waste first before able to achieve other performance measures and proved waste elimination as the dependent variable. Some more evidences to strengthen the justification, in supply chain industry, Qi et.al [65] and Parveen and Rao [66] mentioned that lean strategy is focused on eliminating waste to reduce cost, enhance efficiency, profitability and obtain manufacturing flexibility.

Quantitative models for evaluating leanness developed by Chen [29], Azevedo et.al [26] and Karim and Arif-Uz-Zaman [6] also emphasized on waste elimination. They considered waste reduction efforts would result in better performances, which subsequently include lower cost, shorter lead time, more stable quality, lower work-in-process (WIP) and inventory level, and increased product variety. Their proposed models also for the purpose of giving manufacturers insights onto firm's leanness level in order to become more competitive through waste minimization, and also quick response to unpredicted changes. Study done by Chauhan and Singh [13] showed contradicting finding on eliminating waste (EW) between AHP weighting rated by experts and mean of the survey. Experts' rated eliminating waste as the most important lean practice should be implemented while the level of implementation according to the industrial survey is below than 'good' rank. This opposite finding between experts' opinion and survey validation might be because waste elimination is more befitting as an outcome to be measured (dependent variable) rather than a practice which manipulated the outcome (independent variable).

On the other hand, independent variables are selected on the basis of majority lean practice studied in survey based researches. Table IV demonstrates thirty five (35) lean manufacturing practices identified from thirty four (34) literatures reviewed. From these 35 practices, some practices are excluded from being selected due to minority reason and some are combined into single item in independent variable constructs. The selected LM practices are then grouped into five (5) main constructs following Nordin et.al [46] and Wahab et.al [67] namely Workforce Engagement (WFE), Process and Equipment Enhancement (PEE), Production Rule and Discipline (PRD), Supplier Integration (SPI) and Customer Focus (CUF). The rational for following local researchers in grouping these distinct individual LM practices is these five (5) categories they were suggested seems not overlapping with the concepts and principles of other manufacturing programs such as TQM, TPM, JIT and PPC since any manufacturing technique which is used to eliminate waste is considered as a lean practice. Besides, referring predecessor local researchers seems more appropriate and suitable since the environment and context are similar. Even so, previous researchers only suggested these five (5) constructs but never use them as independent variables neither for correlational nor regression analyses. Supported by these cited literatures, a new conceptual model for evaluating leanness is proposed as in Fig. 2.

This newly developed model will be useful for lean practitioner to assess the status of lean manufacturing (LM) practices adoption in their plant and its effect upon achieving lean principle objective with respect to elimination of seven (7) wastes *(muda)* identified in TPS. Research instrument for measuring all variables within the proposed model has been developed and attached in Appendix. Thirty six (36) items under five (5) main constructs are outlined based on items used by several researchers in previous studies. Technically, evaluation or assessment is defined as comparing the result with the objective. Therefore, this proposed model seems appropriate because lean manufacturing objective posed as dependent variable which affected by selected lean practices implementation that posed as independent variables. Using this model will enable lean practitioner to evaluate whether their lean practices implementation are effective or not in achieving the objective of adopting lean production system into their manufacturing operations.

**Independent Variables** **Dependent Variable**

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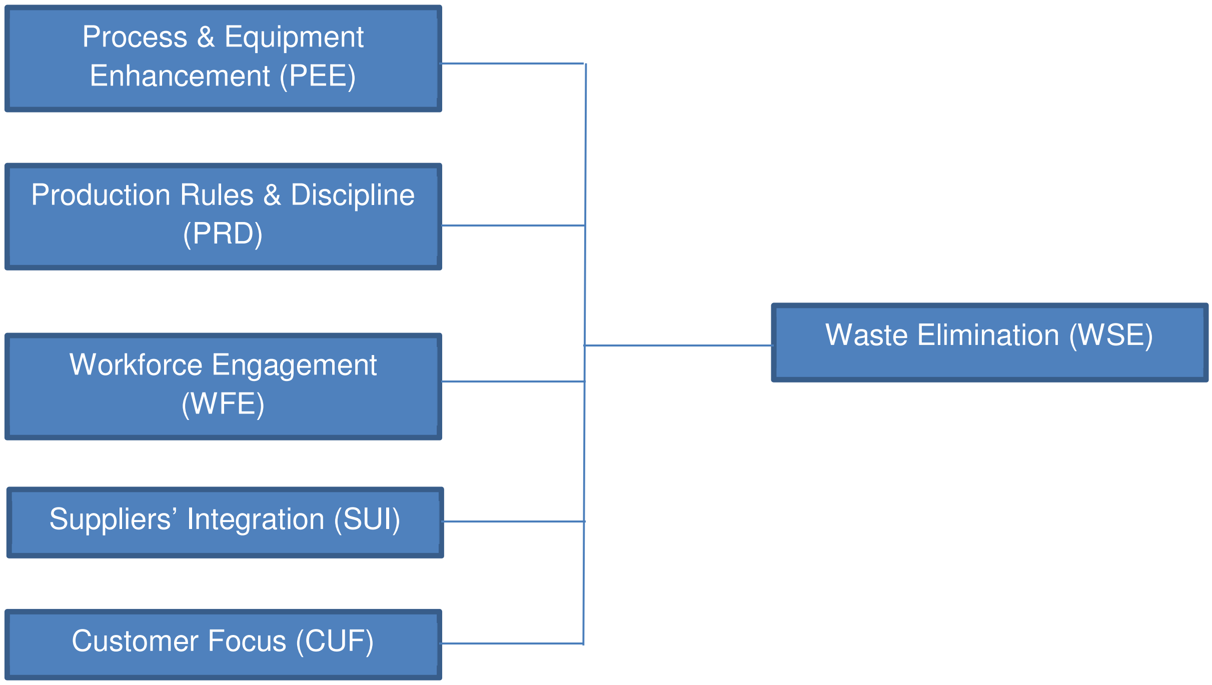


**Figure 2**: Proposed Conceptual Framework

Within Process and Equipment Enhancement construct, lies lean practices such as statistical process control (SPC), productive maintenance, setup time reduction, 5S and kaizen program. Production Rules and Discipline construct include JIT practice, pull system, heijunka, lot size reduction and group technology. Any practice related to involvement of employees like task delegation, teamwork and training are grouped into Workforce Engagement construct. Suppliers' Integration construct comprised the effort of the manufacturing organization in developing long term relationship with suppliers, selecting qualified and certified suppliers and ability to perform JIT or at least on time delivery. The last independent construct, Customer Focus involved activities related to customers' feedback on quality of product produced by the manufacturer, design of product according to customer requirement and market demand based on customer needs and wants.

**Table 4**: Literature Supports for Independent Variables

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| No | Lean practices | Authors | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| 1 | Employee involvement | X | | X | X | X | | X | X | X | | X | X | X | | | | | | X | | | X | X | | X | | X | | X | | X | X | X | |
| 2 | Information and feedback | X | X | X | | | | | | | | | X | | | | | | | | | | X | X | | | | | | | | X | | X | |
| 3 | Group problem solving | X | | X | X | | | | X | | | | X | X | | | | X | X | X | | | X | X | X | | | | | | | X | X | X | |
| 4 | Training | X | X | X | | | | | X | | | | X | X | | | | X | X | X | | | X | X | | | | | | | | X | X | X | |
| 5 | Customer involvement | X | | | | X | | X | | | | X | | X | | | | | | | | | X | | X | X | | X | X | | | | X | X | |
| 6 | Supplier feedback | X | X | | | X | | X | | | X | X | | X | | | | X | X | | | | X | | X | X | | X | X | | | | | X | |
| 7 | Supplier development | | | | | | | | | | | | | | X | | | | X | | | | X | | | | | | X | X | | | | X | |
| 8 | JIT delivery by suppliers | X | X | | | X | | X | X | | | X | | X | | | | | X | | | | X | | | X | | X | X | X | | | X | X | X |
| 9 | JIT production & delivery | | X | X | X | | | | X | | | | X | X | X | | | | | | | | X | X | | | | | | | | X | | X | X |
| 10 | Pull system production | X | | X | X | | | X | X | | | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | | X | | X | | X | X | X | |
| 11 | Schedule adherence | X | | | X | | | | X | | | | | X | | | | | | | | | X | | | | | | X | X | | | | X | |
| 12 | Process reduction initiatives | | | | X | | | | | | X | | | X | X | | | X | | | X | | X | | | | | | | | | | | X | X |
| 13 | Set-up time reduction | X | | | X | | | X | X | X | | X | | X | X | X | | X | | X | X | | X | | X | X | | X | X | X | | | X | X | X |
| 14 | Lot size reduction | | | | X | | | | X | | | | | X | X | | | X | | X | X | | X | | | | | | X | X | | | | X | |
| 15 | Group technology | X | | | X | X | | X | X | X | | X | | X | | | | X | X | X | | X | X | | | X | | X | X | | | | X | X | X |
| 16 | Level production | | | | | | | | | | | | | X | | X | | X | | | | X | X | | | | | | | X | | | X | X | |
| 17 | Continuous improvement | | X | X | X | | | | X | | X | | X | X | | X | X | X | | | X | X | X | X | | | | | | | X | X | X | X | |
| 18 | Planned maintenance | X | | | X | | | X | | | | X | | X | X | X | | | X | | | X | X | | X | X | | X | | X | | | X | X | |
| 19 | Maintenance record | | | | | X | | X | | | | X | | | | X | | | X | | | | | | | X | | X | | | | | X | | |
| 20 | Maintenance optimization | | | | X | | | X | | | | X | | | | X | | X | | | | | | | | X | | X | | X | | | X | | |
| 21 | Proprietary equipment development | X | | | X | | | | X | | | | | | | | X | | | X | | X | | | | | | | | | | | | | |
| 22 | Safeguard device | | | | X | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | |
| 23 | Technology emphasis | X | | | X | | | | | | | | | | X | | | X | | | | | | | | | | | | | | | | | |
| 24 | Elimination of zero-value activities | | X | X | | | | | | | | | X | | X | | | | | | | | X | X | | | X | | | | X | X | X | X | X |
| 25 | Process management | X | | X | X | X | | X | X | | | X | X | | | | X | X | X | | | | X | X | X | X | | X | | X | | X | | X | X |
| 26 | Quality management programs | | | | X | | | | | X | X | | | | | | X | X | | X | | | X | | | | | | | X | | | | X | |
| 27 | Jidoka | | | X | | | | | | | | | X | | | | | X | | X | | | X | X | | | | | | | | X | X | X | |
| 28 | Visual control | | | X | | | | | | | | | X | X | | | | X | | | | | X | X | | | | | | | | X | X | X | |
| 29 | Error proofing | | | | | | | | | | | | | X | X | X | | X | | | | | X | | | | | | | | | | X | X | |
| 30 | Competitive benchmarking | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 31 | Value stream analysis | | | | | | | | | | X | | | | | | | X | | | | | X | | | | | | | | | | X | X | |
| 32 | 5S practices | | | | | | X | | X | | | | | X | | X | | X | | | | X | X | | | | | | | X | | | X | X | |
| 33 | Standardized work | | | | | | | | | | | | | | | X | | X | | | | X | X | | | | | | | | | | X | X | |
| 34 | Policy deployment | | | | | | | | | | | | | | | X | | | | | | | X | | | | | | X | | X | | | X | |
| 35 | Cultural awareness | | | | | | | | | | | | | | | X | X | | | | | | X | | | | | | | | | | | X | X |

| | | | |
|---|---|---|---|
| 1 | Cua, McKone & Schroeder (2001) | 18 | Taj & Morosan (2011) |
| 2 | Sanchez & Perez (2001) | 19 | Yang, Hong & Modi (2011) |
| 3 | Soriano-Meier & Forrester (2002) | 20 | Agus & Hajinoor (2012) |
| 4 | Shah & Ward (2003) | 21 | Balaguer (2012) |
| 5 | Olsen (2004) | 22 | Calarge, Pereira, Satolo & Diaz (2012) |
| 6 | Lynch (2005) | 23 | Chauhan & Singh (2012) |
| 7 | Shah & Ward (2007) | 24 | Ghosh (2012) |
| 8 | DalPont, Furlan & Dinelli (2008) | 25 | Hofer, Eroglu & Hofer (2012) |
| 9 | Fullerton & Wempe (2009) | 26 | AbRahman, Saibani & Zain (2013) |
| 10 | Humbert (2009) | 27 | Dora, VanGoubergen, Kumar, Molnar & Gellynck (2013) |
| 11 | McLeod (2009) | 28 | Habidin & Yusof (2013) |
| 12 | Puvanasvaran, Megat, Tang, Rosnah, Muhamad & Hamouda (2009) | 29 | Nawanir, Teong & Othman (2013) |
| 13 | Nordin, MdDeros & AbdWahab (2010) | 30 | Shamah (2013) |
| 14 | Rahman, Laosirihongthong & Sohal (2010) | 31 | Subashini & Kumar (2013) |
| 15 | Taggart (2010) | 32 | Todorova (2013) |
| 16 | Demeter & Matyusz (2011) | 33 | Kull, Yan, Liu & Wacker (2013) |
| 17 | Eswaramoorthi, Kathiresan, Prasad & Mohanram (2011) | 34 | Lucato, Calarge, Junior & Calado (2014) |

## 6.0 CONCLUSION

This paper compiled various reported lean assessment models which are classified into three (3) categories namely, hypotheses testing, fuzzy logic and qualitative. Authors' focus is on survey-based study which used hypotheses testing method and statistical analyses to evaluate leanness level of manufacturing firms. There are thirty four (34) publications related to survey-based study out of sixty eight (68) publications found and twenty three (23) publications associate lean manufacturing adoption with performance measures. From the literature analyses, thirty five (35) lean manufacturing practices which are commonly discussed or at

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least mentioned by the authors have been identified. These thirty five (35) lean manufacturing practices are then refined and most studied practices are selected to form a new conceptual model for assessing lean adoption status in manufacturing organization. Five (5) independent constructs (*PEE, PRD, WFE, SUI* and *CUF*) are coined based on selected lean practices while *Waste Elimination (WSE)* is proposed as the dependent construct instead of performance measures. Impact of lean adoption on performance measures have been a usual topic studied by previous researchers therefore it is something new to discover causal association between lean adoption and seven (7) wastes in TPS. This model will be useful for investigating lean practices effectiveness in eliminating seven (7) wastes.

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