A systematic approach to evaluate the process improvement in Lean Manufacturing Organizations

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Abstract

Numerous tools and techniques have been developed to eliminate or reduce waste and carry out Lean concepts in the manufacturing environment. However, in practice, manufacturers encounter difficulties to clearly identify the weaknesses of the existing processes in order to address them by implementing Lean tools. Moreover, selection and implementation of appropriate Lean strategies to address the problems identified is a challenging task. According best of authors' knowledge, there is no method available to quantitatively evaluate the cost and benefits of implementing a Lean strategy to address the weaknesses in the manufacturing process. Therefore, benefits of Lean approaches cannot be clearly established. The authors developed a methodology to quantitatively measure the performances of a manufacturing system in detecting the causes of inefficiencies and to select appropriate Lean strategies to address the problems identified. The proposed methodology demonstrates that the Lean strategies should be implemented based on the contexts of the organization and identified problem in order to achieve maximum cost benefits. Finally, a case study has been presented to demonstrate how the procedure developed works in practical situation.

Keywords

Performance improvements; Waste; Lean Manufacturing; Mathematical model

1 INTRODUCTION

The goal of implementing new tools and techniques in a manufacturing system is to increase the performances of new or existing manufacturing processes. The tools and techniques that are effective for organizational performance improvements are different in new and old organizations. Evidence shows that some of these tools are more effective in some organizations than others. Lander [1] suggests that while the concepts are the same from organization to organization, the actual tools used to accomplish lean are different. Some tools may not be applicable or need to be modified in order to be useful in a specific organization [2]. Liker and Morgan [3] showed that there is a need to determine how to adapt lean tools for individual organizational contexts. Therefore, systematic methods are crucial to successful lean implementation, or the successful implementation of any world class manufacturing principles, as these have roadmaps which illustrate the company's current status along with its most important performance parameters. Moreover, it is well known says that 'we can't improve what we can't measure'. One important issue is to be able to easily assess the current level of achieved performances and to ensure which factors are to be considered as critical for achieving further improvement. In this regard, some needs still exist for an easier implementation of the improvement procedure in companies, i.e. how to clearly identify the existing weak points of a given or new manufacturing system. A very common way used by many of the researchers to find the current state of the system is using the lean assessment tool with surveys. The surveys are used to help the manufacturers evaluate the degree of adoption of the lean principles. Results of the surveys are often provided the scores and shown the differences between the current state of the system and the ideal conditions predefined in the surveys. However, the predefined lean indicators may not be appropriate for every system. Besides, the responses are inevitably subjective. The results of the surveys may be biased. Lean metrics are the performance measures that are used to track the effectiveness of lean implementation or continuous improvement. Allen et al. [4] categorized lean metrics into four major groups, i.e., Productivity, Quality, Cost, and Safety. Several lean metrics are suggested in each group, such as "changeover time" in Productivity, "yield and "scrap" in Quality, "material" and "Labour" in Cost, and "injuries" in Safety. Each metric is developed to evaluate the progress of improvement in a specific area. However, these metrics do not provide the way of identifying the problems and selecting appropriate tools according to the problem. Another way of measuring the performance of a lean manufacturing system is Value Stream Mapping (VSM). This tool was developed by Rother and Shook [5] and published in the book *Learning to See*. VSM graphically depicts the current level of leanness of the system, and the future VSM, serving as a target of improvement. Weakness of the VSM is that "cost" is not shown explicitly, since it is created strictly based on the time frames of the processes. It has been found that evaluation of a lean manufacturing system is done in three different ways such as qualitative, quantitative, and graphical. However, consideration of organizational contexts such as new or mature organization as well as detecting the causes of inefficiencies and selecting lean strategy accordingly lacks in the current literature.

Therefore, this research proposed a systematic methodology to evaluate the process improvement considering the maturity stage of an organization. The proposed methodology: firstly, define the maturity stage of the organization, secondly, identify the causes of wastes, thirdly, select appropriate Lean strategies based on the contexts of the organization and problems identified, finally, implement and evaluate the implemented lean strategy. In this research, Organizational Life Cycle (OLC-5) scale is used to identify the maturity stage of an organization. Value Stream Mapping (VSM), Quantitative analysis of a process related parameters such as Lead Time, Quality, OEE and cost of goods sold of producing a product are used to measure the performance of a specific process, then criticality analysis by lean implementation team finalize the causes of specific problems. Then a set of tools are suggested for this organization based on their maturity stage and removing the causes of low productivity. Finally, a case study has been presented to demonstrate how the procedure developed works in practical situation.

The rest of the paper is structured as follows: Section 2 provides the systematic approach to evaluate the process improvement, a case example of proposed method is presented in Section 3. Research findings are discussed in Section 4. Limitations and extensions of this work round out the paper.

2 A SYSTEMATIC APPROACH FOR LEAN IMPLEMENTATION AND EVALUATION

In this section, a systematic methodology has been proposed for selecting appropriate lean strategies based on the contexts of an organization and identified problems. Figure 1 shows the process flow of the proposed methodology.

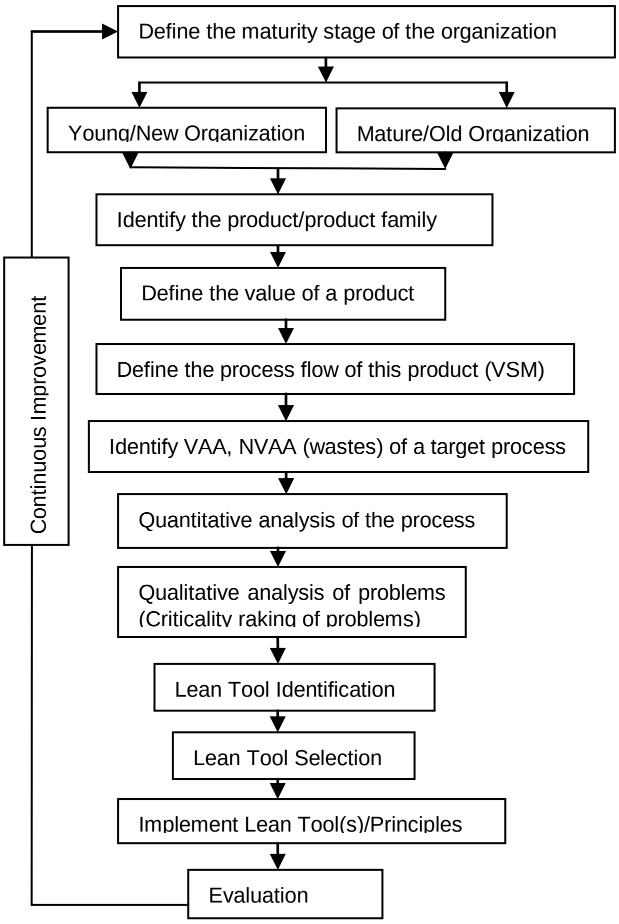

Figure 1: A systematic lean implementation and evaluation process (LIEM)

2.1 Define the maturity stage of an organization

In this research, the identification of maturity stage (new or old) of an organization is considered as the first step of selecting appropriate lean tools. A study by Pavanskar, Gershenson, and Jambekar [6] also suggests that there is no empirical evidence that shows which tools are useful in a specific situation. Liker and Morgan [3] showed that it is necessary to determine how to adapt lean tools for individual organizational contexts. Organizations that are in the early stages of the organizational life cycle have little research or practice upon which to build their own lean systems. New organizations are lack of resources. Therefore, choosing the most effective tools is imperative for young organizations. In this research, the Organizational Life Cycle (OLC-5) scale developed by Lester et al. [7] is used to determine the organization's life cycle stage. The categorization was based upon self-reported answers to survey questions regarding the prevailing characteristics of the subject organization. Information collected from the survey used to categorize the organizations into two groups; young and mature.

2.2 Define a product/product family

Once organization is identified as a young or mature organization then it is important to identify the product or product family for lean process improvement. As Abdulmalek and Rajgopal [8] stated that the first step of implementing VSM is to define a particular product or product family as the target for improvement. Characteristically, a product family consists of a group of product variants that pass along comparable processing procedures and use ordinary appliances in the workshop.

2.3 Define the Value of a product

Value can only be defined by the ultimate customer, and it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time [9]. In our research, product value is defined below by Browning [10].

Product Value = f (Product Performance, Product Affordability, Product Availability)

Therefore, the aim of lean implementation in an organization is to enhance the product quality, at a low price, as well as make it available in the market at a short time.

2.4 Identify the process steps (VSM)

Once value is clearly defined, then value streams can be clearly identified. Value stream mapping (VSM) is a lean manufacturing technical methodology that helps to interpret the flow of materials and information currently needed to transfer goods or services to the end consumer. To produce a product, manufacturing process activities are classified into three categories; namely: Value-added activities, Non-Value-added activities, Necessary but non-value-added activities. This step identifies the all activities related to producing the defined product.

2.5 Measuring Value of a Product

The measurements are used to create facts for manufacturers to find improvement suggestions. Together with the process maps and define parameters, these will make the basis of building improvement suggestions.

Manufacturing Lead Time

The lead-time can be expressed as a function of the throughput time, the activity cycle time, and the total number of units waiting to be produced. The total number of units can be further subdivided into those units in queue to enter production (N_q) and those that have been ordered and are going to enter the queue (N_0). The lead-time is thus defined in Equation 1 as

$$T_L = T_t + T_{ca}.(N_q + N_0) \quad (1)$$

$$T_t = (T_{ca})(N_a) = (T_{ca})(VA + NVA + NNVA) \quad (2)$$

This equation of throughput time can be expressed by a discrete event case by considering the m value-added activities and the n non-value added activities and z necessary but non-value added activities.

$$T_t = \sum_{i=1}^{m} T_{cai}.VA_i + \sum_{j=1}^{n} T_{caj}.NVA_j + \sum_{k=1}^{z} T_{cak}.NNVA_k \quad (3)$$

As the number of non-value added activities are reduced in making the system leaner, the throughput time reduces, while all else remains the same. Thus from a customer satisfaction perspective any removal of non-value added activities (waste) from the production system will result in better product lead time, and therefore increase their satisfaction with the company.

$$\frac{T_{Lf}}{T_{Li}} < 1 \quad (4)$$

This result impacts both the lead-time for the product and the productivity of the process which will ultimately influence the process throughput rate, processing time, material handling time, set up time, equipment and personnel waiting time, material waiting time, and information waiting time.

Other parameters related to Lead-Time;

- Processing time ratio: it is the ratio of value-added processing time to the total manufacturing lead time.

$$P_{tr} = \frac{VA_{pt}}{T_L} \quad (5)$$

- Material handling time ratio: it is the ratio of material handing time for creating a specific product to the total manufacturing lead time.

$$MH_{tr} = \frac{MH_t}{T_L} \quad (6)$$

- Change over time ratio: C/O is period required to prepare a device, machine, process, or system for it to change from producing the last good piece of the last batch to producing the first good piece of the new batch.' It is the ratio of set up time to the total manufacturing lead time.

$$CO_{tr} = \frac{S_t}{T_L} \quad (7)$$

- Equipment and personnel waiting time ratio: it is the ratio of personnel waiting time for equipment to the total manufacturing lead time.

$$EP_{tr} = \frac{W_{EPT}}{T_L} \quad (8)$$

- Material waiting time: it is the amount of time of waiting for materials to the total manufacturing lead time.

$$MW_{tr} = \frac{MW_t}{T_L} \quad (9)$$

- Information waiting time ratio: it is the amount of time waiting for specific information without that a production process cannot be started to the total manufacturing lead time.

$$IW_{tr} = \frac{IW_t}{T_L} \quad (10)$$

Overall Equipment Efficiency (OEE)

OEE is a quantitative metric used primarily to identify and measure the productivity of individual equipment. It improves equipment performance by identifying and measuring the losses of potential sources namely yields, motion, operational effectiveness, availability. According to Federico et al., [11] OEE can be expressed as:

$$OEE = \frac{t_{qn}}{t_{np}}.\frac{t_{np}}{t_{ap}}.\frac{t_{ap}}{t_{available}}.\frac{t_{available}}{t_{effective}} = Y.v.OE.A \quad (11)$$

These above expressions are time-based only, thus being applicable to any production system.

Measuring Quality of a lean production process

In this research, a measure of the quality of the system is defined as the ratio of the number of defect-free units produced (# of good units =N_g) to the total number of units produced. This ratio is called the quality factor (Q_f), the value of quality factor between zero (no good units produced) and one (no defects produced). The defects can be generated from the process or machine. The number of bad units produced (N_b) will thus be defined as;

$$Q_f = \frac{N_g}{N_u} \quad (12)$$

$$N_b = N_u.(1 - Q_f) \quad (13)$$

A certain number will be repairable (N_r) to meet specification from the bad units and a certain number will be unrepairable and will have to be scrapped *(Ns)*. The scrap ratio (S_r) is a number between 0 and 1, defines the percentage of bad units that cannot be repaired. So the total number of units to rework is thus defined as [12];

$$N_r = N_u.(1 - Q_f).(1 - S_r) \quad (14)$$

The number of rework activities (A_r) will rise in proportion (constant =α) to the number of units that can be reworked. Since rework only exists because the product was not built right the first time, it is all non-value added. So, the total number of non-value added activities in the production system (NVA) will be the sum of the existing non-value added activities (NVA_e) and the rework activities as follows [12];

$$NVA = NVA_e + A_r \quad (15)$$

The expansion of Equation 15 by substituting Equation 14 yields

$$NVA = NVA_e + \alpha.N_u.(1 - Q_f).(1 - S_r) \quad (16)$$

The result of Equation 16 is that any increase in quality will cause the quality factor to rise, thus reducing the number of non-value added steps in the process.

Measuring Value of a Product: Integrated cost equation for a lean product

In this research, value of a product is defined by calculating the cost of goods sold of a product. Cost of goods sold will determine the affordability of buying a product by a customer. Figure 2 shows the components of Cost of Goods sold of a product. The costs of goods sold ($COGS$) is comprised of labour costs (L_C), overhead costs (OH_C), Material costs (M_C) and lean implementation cost (LI_C).

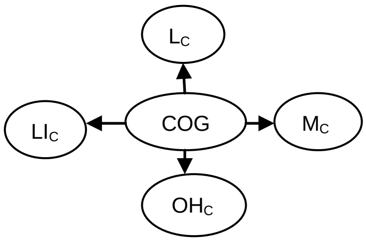

Figure 2: Cost components of a lean product.

The total cost can be expressed as;

$$COGS = OH_C + L_C + M_C + LI_C = (OH_{Cu} + L_{Cu} + M_{Cu} + LI_{Cu}).N_u + C_{ovf} \tag{17}$$

The labour cost per unit (L_{Cu}) can be represented as the product of the Labour rate (L_r), the Labour time per activity (T_{la}), and the number of activities in the process. Equation 17 can thus be expanded to create Equation 18.

$$COGS = \big((OH_{Ca} + T_{la}.L_r).(VA + NVA) + M_{Cu} + LI_{Cu}\big).N_u + OH_{Cf} \tag{18}$$

The cost of goods associated with improved quality is a slightly more complex relation. First, Equation 18 must be modified to include the cost of scrap material (OH_{Cs}), which is a part of the total overhead cost.

$$COGS = \big((OH_{Ca} + T_{la}.L_r).(VA + NVA) + M_{Cu}\big).N_u + OH_{Cf} + OH_{Cs} \tag{19}$$

The scrap cost is defined as

$$OH_{Cs} = N_u.(1 - Q_f).S_r \tag{20}$$

Therefore, cost of goods sold can be expressed as;

$$COGS = \left((OH_{Ca} + T_{la}.L_r).\left(VA + NVA_e + \alpha.\frac{N_g}{Q_f}.(1 - Q_f).(1 - S_r)\right) + M_{Cu}\right).\frac{N_g}{Q_f} + OH_{Cf} + \frac{N_g}{Q_f}.(1 - Q_f).S_r + LI_{Cu}.\frac{N_g}{Q_f}.\frac{1}{n} \tag{21}$$

Lean implementation cost consists of engineering cost, investment cost, variable cost, and risk cost.

For 1 lean tool,

$$LI_{Cu} = \left(LI_{Cueng} + LI_{Cuinv} + LI_{Cuvar} + LI_{Curisk}\right) \tag{22}$$

For multiple tool,

$$LI_{Cu} = \sum_{i=1}^{m}\left(L_i LI_{Cuengi} + L_i LI_{Cuinvi} + L_i LI_{Cuvari} + L_i LI_{Curiski}\right) \tag{23}$$

All measurements should be documented in the database to compare the improvement. This step forces the manufacturers to be involved in the processes for a long time and gives them in-depth understanding of the processes and the production system. Further, the results from this activity should be analyzed to find additional improvement suggestions.

2.6 Criticality analysis of a problem

The previous steps provide the initial assessment of problem by using VSM and measuring process related performance parameters. As for example, analyse the process maps, find process steps, which can be removed, moved or simplified for an improved flow. Analyse the measured lead times, find long lead times with high variation. When the measurement data has been analyzed, it is time to decide in which order the improvement suggestions should be accomplished. This choice should be made in several ways. In this research, each suggestion should be sorted according to the most of the causes that determine the highest losses will occupy the highest places in the ranking. The purpose of this activity is to bring order and structure to the suggestions. The expected result is a lean implementation plan, which clearly states that what is the problem, which tool is applicable for identified problem, what is the deadline, and who is responsible for completing this task?

2.7 Tool identification and selection

Having identified the maturity stage of the organization and constraining parameters that limit the performances of the production system, appropriate lean tools and techniques should be selected from the toolbox provided in Figure 3. For this study, the tools are categorized into groups suggested by a study performed by Abdulmalek and Rajgopal [8]. The lean tools are grouped into three different categories for comparison based on purpose and each category represents tools that all have similar uses and purposes. Categories are: (a) lean quality/continuous improvement tools, (b) lean process tools and techniques, and (c) support system tools and techniques [8]. The first category includes all tools that detect problems or opportunities in the environment, analyse them for the purpose of continuous improvement, and prevent quality problems in the future. The second category includes those tools that enhance efficiency and reduce process variability. The third category contains those tools and techniques that reduce waste outside the value stream. Then, these lean tools are also categorized into 9 broad areas specific provided in Figure 3.

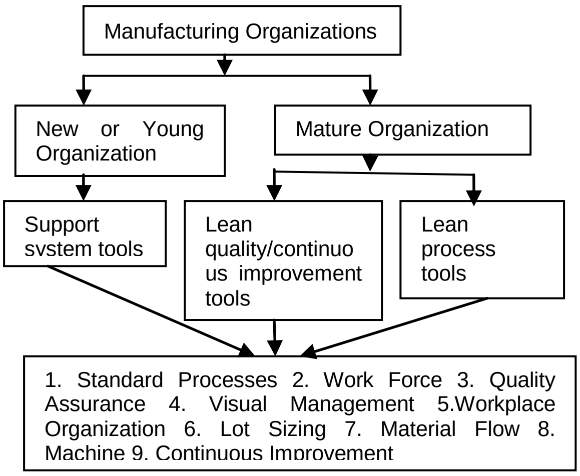

Figure 3: Selection of lean tools based on organizational context

List of lean tools and techniques

Standard Processes: SOPs, Standardized Work/Planning, Commodity Grouping, Common Processes & Best Practices, Trailer Loading & Unloading, Routing &Travel Paths

Work Force: Safety & Ergonomics, Leadership Direction/Roles Management Style, Cross-Training, Teamwork & Empowerment, Power Distance & Daily Involvement, Recognition & Compensation, Communication Strategy, Absenteeism & Turnover

Visual management: Value Stream Mapping, Process Control Boards, Metrics & KPI Boards, Lean Tracking, Visual Control, Andon Systems, (A3) One Page Reports

Quality Assurance: 5 Whys, Root Cause & Pareto, Inspection & Autonomation, Error Proofing Methodology, Inventory Integrity, Product & Process Quality, Data Mining

Workplace Organization: 5S, Signage & Shadow Boards, Cleanliness, Supply & Material MGMT, Point of Use Storage (POUS), ID Problem, Parts Areas

Material Flow: Pull Systems, Levelled Flow & Work, FIFO, Layout & Zones, Velocity & Slotting, Travel Distance, Cellular Structure, Demand Stabilization, Re-engineered production process, Cross-Docking, MTM analysis

Lot Sizing: Batch Sizes, WIP, Kanban Systems, Quick Changeover, Lead Time Tracking, Inventory Turns, Order Frequency

Continuous Improvement: PDCA, Kaizen Events, Employee Suggestions, Understand Systems View, Preventative Maintenance, Supplier Integration, SPC, Technology & Equipment

2.8 Solution implementation and follow-up

The lean tools/principles selected for the manufacturing process in the previous step are put in practice and evaluated for a period of time to evaluate the effectiveness of the lean tools. Once the improvement procedure works, a new iteration should be performed in order to continuously set new improvement targets.

3 DEMONSTRATION OF THE PROPOSED METHODOLOGY BY A CASE EXAMPLE

The case organisation, Power Pty Ltd. (PPL) has been chosen because of its highly competitive environment that would have been more challenging for the methodology. The demonstration of proposed methodology is provided here.

3.1 Define the maturity stage of the case organization

By using OLC-5 scale developed by Lester et al. [7], the case organization is identified as a new organization. Therefore, the only lean tool category that has the potential to create value for young organizations is the third: support system tools and techniques (Figure 3).

3.2 Define the product and product value

This case organization manufactures low, medium and high voltage switchgear products. The Company is specializing in medium and high voltage auto reclosers for both pole mounted and substation applications from 10kV to 38kV. The challenge for the manufacturer is to deliver the product to the customer on time, at a low cost, and higher quality. Therefore, the value of product is defined in the eyes of a customer as a function of availability, affordability, and product performance.

3.3 Define and observe the manufacturing system

Currently, the company has four main manufacturing lines which are electrical control and communication cubicle assembly line, OSM automatic circuit reclosers' assembly line, cable making line and switchgear assembly line. Although research has been carried out in all four manufacturing lines, this paper mainly focuses on electrical control and communication cubicle assembly.

VSM and Time study are used to help the manager to understand entire work processes, identify wastes, highlight problems and imply appropriate solutions. The following steps were used for the time study: **Process recording:** these steps will video record the operator's work process while working on this product. **Categorize the process:** after the time recording, the project team needs to discuss the work process with the manufacturing manager, and skilled operator to determine whether the process value added or non-value added category. **Break down and recording step time:** project time will review the recorded video and break it into time segments that represent each of the details of work process. **Sketch Non-value added and value added time spread:** after estimating the time segments an excel spread sheet is used to generate a bar chart to identify the total processing time.

3.4 Quantitative analysis

The data is collected to calculate the different parameters described in the previous section such as; throughput time, average cycle time, value-added processing time, material handling time, equipment and personnel waiting time, change over time, material waiting time, information waiting time, actual production time, breakdown time, amount of good parts produced in each process; lean implementation cost, amount of bad parts produced, amount of rework products, standard time associated to the operations performed in each step. In this organization, Industrial Engineering helped in the definition of the standard time for each process step. Finally, cost of goods sold of a product has been calculated from collected data and results are presented in Table 1.

3.5 Criticality analysis of a problem

Critical analysis was performed after completing the data collection in the previous step. From the VSM and time study result, following main problems during assemble process have been identified: **Walk distance:** operators need to walk to get assembly parts and tools all the time which some of the walking time can be treated as non-value added and are considered waste. **Handling:** some double handling problems have been identified, which mainly caused by operator's working experience. **Part replenishment:** most of the assembled parts are loaded on the work bench within single different size of bins and there is a miscommunication between operator and the person responsible for replenishment. **Waiting and sharing tools:** currently operators are sharing one set of tools, which may cause increasing waiting time and can be treated as waste. The lean implementation team finalize the problem that the operators are lack of knowledge about standard operating procedure of assembly process (handling materials) which is the reason of increasing lead time of producing a product and ultimately increase the price of a product. It was found out that there was no mention of the way the parts had to arrive to the process for processing.

3.6 Tool Identification and selection

A lean implantation team is selected for solving the defined problem in a limited amount of time. In this case, organization is a new and the problem was related to the material handling activities of assembly process. Therefore, from Figure 3 (support system tools), an analysis of working procedures (SOP) was decided to implement. The selected tool is quite simple, because it is merely a revision of the standard operating procedures that are used to train and to evaluate the performances of the workers of processes assembly of the product. A further improvement would be to redefine the layout of the factory and to review all the standard operating procedures, including the analysis of flowing parts, people and information.

3.7 Tool Implementation and Evaluation

This stage was the most critical activity where the proposal will be implemented into the system. The implementation of the selected lean tool i.e. standard operating procedure for material handling is implemented in the assembly process. The system is evaluated by calculating the different performance parameters provided in the section 2 and result is presented in Table 1. This system will be monitored everyday to record the progress and improvement made by the new system.

Table 1: Comparison of before and after lean

Performance Analysis	Pres-Condition	After Lean	Improve [%]
Implemented lean Tool	No	Yes	-
Quality factor [%]	0.6	0.8	20
Lead Time [hours]	5	3	2
VA processing time [%]	70	81	11
NNVA material handling time [%]	10	7	3
Necessary changeover time [%]	5	3	2
NVA waiting time for sharing tools [%]	5	3	2
NVA waiting time for materials [%]	5	2	3
NVA information waiting [%]	5	4	1
Scrap rate [%]	7	5	2
Rework rate [%]	12	10	2
Material cost [AUD$]	8	5	3
Fixed overhead cost [AUD$]	5	3	2
Lean Cost	0	2	-
Product Cost [AUD$]	10	7	3

4 CONCLUSION

A systematic methodology has been developed to support lean manufacturers to effectively select lean strategies for their organization and evaluate the process improvement. Initially, maturity stage of an organization has been identified. Then, several performance parameters have been calculated to identify the specific process related problems such as lead time, value-added processing time, material handling time, equipment waiting time, cost of product derived in the previous section. Based on the organizational context and the specific problems identified, lean tools are selected for improvement of the process. Results show that improved quality has positive effect on the cost of goods sold. The increase in quality reduces the rework and scrap rate, labour cost, material cost and overhead cost which ultimately decrease the product cost and increase the revenue. It is expected that the proposed methodology would make a significant contribution to evaluate the process improvement of any manufacturing organization. Future research will look for further improvement of the proposed methodology.

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