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Metrics for Assessment and Management of Lean Manufacturing Implementation

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by

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ABSTRACT

This research is to introduce a new concept of auditing and implementing Lean Manufacturing by translating qualitative criteria to quantitative metrics. Therefore, quantitative formulas were developed to produce a numeric score, representing the progress of three lean manufacturing tools implementation. The tools are 5S, Kaizen, and Value Stream Mapping. The scores could then be compared to an ideal state or a standard set by industrial studies (i.e. baseline). These tools were chosen based on the researcher's industrial experience and the gap seen in assessing the implementation of these three tools. Other metric formulas with the same approach could be derived for other tools and altered to better-fit different industrial requirements. For the provided metrics, a binary system (i.e. 1 or 0) is used to reduce auditing variations and discrepancies, producing a numeric score. These metrics were demonstrated through hypothetical and actual case studies to prove their industrial practicality.

The developed 5S scoring metric was compared to a followed auditing system in a machine and tool manufacturer in Windsor, ON, Canada. The Value Stream Mapping case study was adapted from the literature while the Kaizen case was a hypothetical example to prove the metrics practicality. A score was generated by each tool metric and combined in an Overall Lean Score. These scores are more relatable to current and future states in comparison to implementation checklists and questionnaires with no solid indicators (i.e. numeric, descriptive, suggestive, etc.).

The significance of this research lies in the ease to track and set goals for future progress plans compared to current states. Such plans could include upgrading to various manufacturing paradigms such as Industry 4.0 in which all information is digitized. Therefore, the lean implementation should extend from applying the lean tools to numerical values (i.e. metrics).

DEDICATION

By completing this thesis, I dedicate this accomplishment to:

My mother, father, and sister for supporting me and believing in me through this journey

My friends, who always encouraged me through their good words

My peers and colleagues for always providing me with the help I needed

My supervisor for his patience and understanding

ACKNOWLEDGMENT

The author expresses his deepest gratitude and acknowledgment to his supervisor; Prof. Waguih ElMaraghy for the guidance he provided, patience and understanding of this hard journey. This Masters thesis would not have been completed and presented if it was not for his willingness to accept my effort and guidance to produce a research with the best quality I could produce. His mentorship is characterized by eliminating any form of pressure or hardships so that his students would bring their best into their work.

The gratitude extends to the master's committee members; Dr. Hoda ElMaraghy and Dr. Asfour. Their valuable feedback and guidance were no less important. Their knowledge in the academic field was a determining factor in the value of this research came to meet. Even at the end of this journey, they did not save any effort to help get this thesis finished in a good fashion of quality.

It is also important to remember all the researchers at the Intelligent Manufacturing System Center (IMSC) lab at the University of Windsor. In particular, Mr. Mostafa Moussa, Ms. Jessica Olivares Aguila, and Mr. Ahmed Marzouk for their continuous help and support. I am honored to have been a member of such a powerful, full of academic knowledge and scientific research.

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LIST OF ABBREVIATIONS

TPS	Toyota Production System
LM	Lean Manufacturing
V.S.M.	Value Stream Mapping
LI	Lean Indicator
OLS	Overall Lean Score
KPI	Key Performance Indicators
JIT	Just In Time
PM	Preventative Maintenance
TQM	Total Quality Management
OA	Operational Availability
AR	Actual Run Tim
SR	Scheduled Run Time
LESAT	Lean Enterprise Self-Assessment Tool
RPA	Rapid Plan Assessment
GMS	General Motors Supplier
MoSCoW	Must-Should-Could-Would rules
SAE	Society of Automotive Engineers
DSS	Decision Support System

Chapter 1 : INTRODUCTION

1.1   Research Motivation

In the early 20th century, industries have experienced a revolutionary shift which led to shorter cycle times, hence meeting takt times with reduction in production costs. The shift started by Henry Ford and his first-of-a-kind Model-T production line in Rouge production complex. His new production system was broken into 30-seconds processes which eventually were repeated thousands of times daily through the production of Model-T. However, as explained by Khadem was taken from Womack, Ford did not abide by the lean principles and focused on raising the production rate as high as possible. Through which, the production line would get out of balance; pushing work-in-progress stock towards the next station whether or not the next station was ready to receive or not. It also created an overstock produced of Model Ts. (Khadem, Ali, & Seifoddini, 2008)

Through the century, different industries adapted the new production philosophy; production lines were set up of different processes, from processing raw material all the way to assembly and shipping final products. In the 1950s, Eiji Toyoda and Taiichi Ohno combined their knowledge and skills in a standardized and efficient manner in the field of automotive production and thus the TPS (Toyota Production System) was born. (Wan & Frank Chen, 2008) The system was the first cornerstone of a new philosophy; the Lean Manufacturing philosophy.

The philosophy was built on the basis of reducing wastes, which could be in the form of inventory, production cycle time, cost, etc. while increasing the positive attributes of the system such as quality, production system flexibility, customer satisfaction, etc. (Wan & Frank Chen, 2008) It was further developed in the 1940s by Eiji Toyoda, along with Taiichi Ohno; an

industrial engineer working in Toyota invented the Toyota Production System (TPS). This resulted in an increase in production and lowering of wastes level. (Gardner, 2017) From there, the philosophy was adopted by different industries and was implemented in different production systems. The philosophy was proven to be flexible with regards to its application fields. However, over the literature survey, no confined bases for metrics were set to track the progress of the system in the adopting firms. Hence, this research work on developing a framework of metrics that could be used as a guideline for enterprises to assess their progress by assigning scores to the progress level and competing against their competitors in the fields of cost reduction and improved quality brought by the application of the system. Figure 1.1 represents the lean manufacturing tools that concentrate on three different subjects of improvements:

- Waste Elimination

- Simplification of processes and management

- Workflow
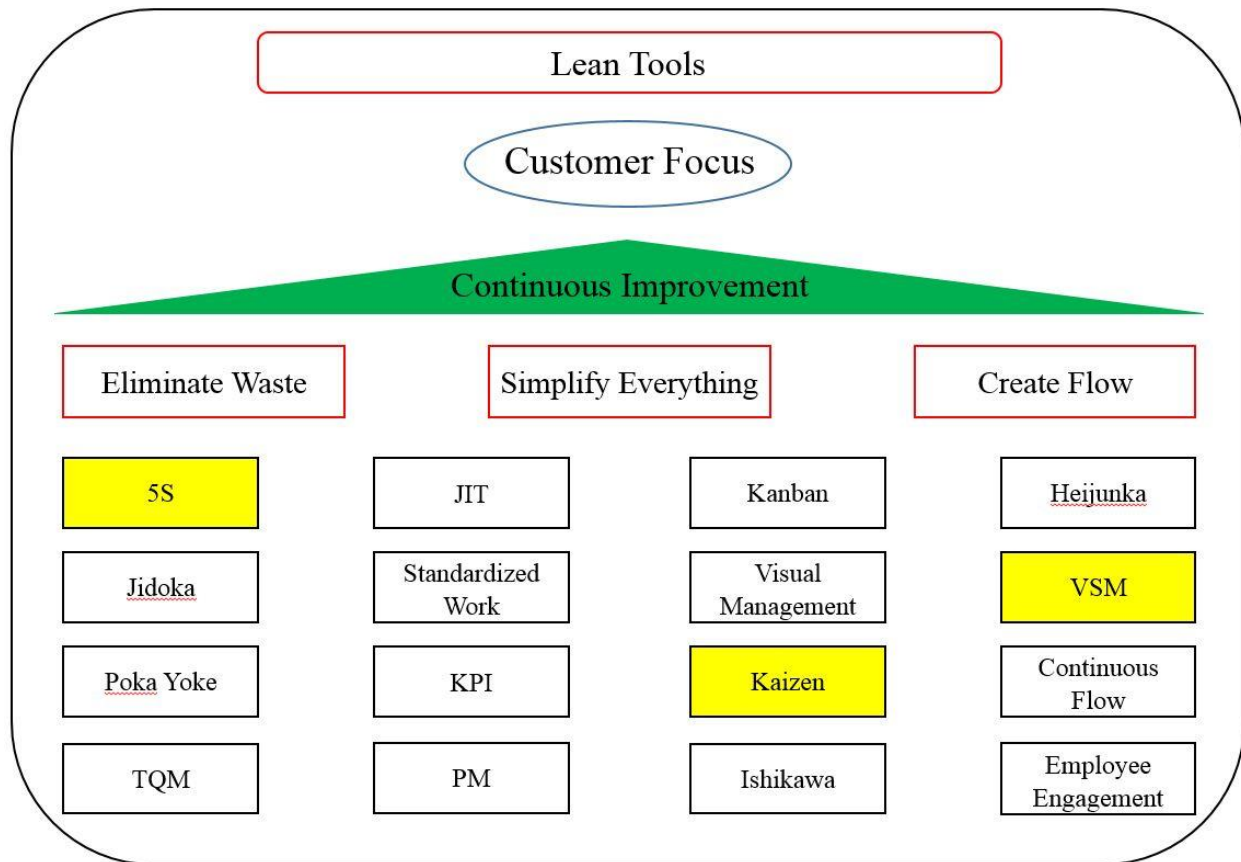
Figure 1.1 - Lean Manufacturing Tools

These tools shown in Figure 1.1 could be considered the major tools used in the enterprises. There are more tools that are used or developed to better suit the use depending on the needs and the industry requirements. Internal departments in some business enterprises are set up with the sole purpose to track and ensure that the tools are applied.

In this research, three metrics were developed for the three highlighted tools to produce a numerical score. While different studies where focused on defining the overall effects of lean manufacturing implementation, this study focuses on the translation of the qualitative measures of specific lean manufacturing tools quantitatively. Hence, this research works to fill this gap, in

which by return reproach between the academic work and industrial application, implementing these metrics in industries to ease the targeted tool implementation.

1.2   Engineering Problem Statement

The primary problem being targeted in this research is the translation of the lean manufacturing qualitative measures into a quantitative system, assessing the implementation of lean philosophy. This will involve representation and projection of the lean implementation in the metrics system.

1.3   Objectives

As stated in the engineering problem statement, the objectives of this research are:

- To translate the qualitative parameters to quantitative measures

- To demonstrate the translation in a specific but not limited, and expandable system

- To develop metrics which demonstrate progress in implementing Lean Manufacturing in the form of a numeric scoring system

  - The developed metrics are designed to project the current state through a numeric score to use in comparing with a target score of future state

- To attain a level of waste reduction in the system which could be applied to different industries

1.4   Research Scope

The current research concentrates on working on three out of the lean manufacturing tools presented in Figure1.1. Each of the chosen tools would deal with one of those areas lean manufacturing targets. These are:

- 5S from the Waste Elimination category

- Kaizen from Simplification of Processes category

- Value Stream Mapping from the Work Flow category

The concept of translating qualitative measures quantitatively on which this research is proposing is not limited to those three tools but could be applied to the rest of the tools depending on the progress tracking and assessment goals. The main purpose is to develop a measure to formulate these qualitative tools into quantitative metrics with scores and measures. This will play an important role to standardize a system to assess the Lean Manufacturing approach an enterprise is following and would establish in planning the enterprise future plans.

1.5   Research Hypothesis

Better assessment of lean implementation resulting in increasing quality levels, production cost reduction and adaptation to frequent market and manufacturing processes changes could be achieved by developing numeric metrics/formulas for lean manufacturing tools.

1.6   Thesis Structure

This research thesis consists of five chapters, among which this Introduction chapter. Chapter 2 summarizes the covered literature surveyed for the work in the research. Certain topics and keywords were used to discover the research done by other researches in the area of lean manufacturing such as Framework for Lean Manufacturing, Scoring System for Lean Manufacturing assessment, Standardizing Lean Manufacturing, and alteration in wording for better search.

Chapter 3 showcase the different approaches that were taken to formularize the considered lean tools in this research. These formulas will be applied to case studies in Chapter 4. Chapter 5 will cover a detailed discussion on the case study and further applications that could be considered for the proposed auditing system formalization. It will also include a conclusion for the research, a highlight for the novelty of the research and proposed future work.

Chapter 2 : LITERATURE REVIEW

2.1 Overview

In this chapter of the research thesis, a good number of presentations, articles, and studies on lean manufacturing are reviewed. Since the principles of lean are more of a practice rather than scientific concepts, some definitions have been gathered from articles and technical presentations by engineers and other professional presenters in the area of Lean. The first section covers some the definition of Lean and some of the tools being used in different industries.

2.2 Lean Philosophy Background and Definitions

Lean Manufacturing could be defined as a philosophy, intended to systematically eliminate different forms of wastes and reduce non-value added steps in processes; aiming for continuous improvement in an organization, resulting in higher level of customer satisfaction. (Susilawati, Tan, Bell, & Sarwar, 2015) Initiated by Toyota Automotive in Japan in the 1960s, its main concentration was a waste reduction as well as cost while improving product quality. However, as explained by Koren in The Global Manufacturing Revolution book (Koren, 2010), the first step of implementing lean is Value Stream Mapping of production. He introduces the term Operational Availability (OA) which is defined by Equation 2-1 as the ratio between Actual Run-time (AR) and Scheduled Run-time (SR) by the formula:

$$OA = \frac{AR}{SR}$$
Equation 2-1

where:

OA = Operational Availability

AR = Shift time – Scheduled Downtime; in minutes

SR = AR – Unscheduled Downtime; in minutes

Scheduled downtime is defined as break time, scheduled maintenance, etc. while the unscheduled or undermined downtime is defined as any other downtime that was not scheduled such as shortage of people or material, the breakdown of machines before or after scheduled maintenance, changeover and set-up time, etc. While takt time is theoretically pre-determined based on scheduled demand; defined as the ratio between production time in minutes or seconds available and demand, OA directly effects cycle time which is basically the realistic version of takt time. Hence, OA determines how close the cycle time is to takt time. In other words, if the Unscheduled Downtime is eliminated, the cycle time will meet the required takt time, satisfying the required demand. Koren explains that this could be achieved through the following lean principles:

1. Value Stream mapping the whole production processes, eliminating all possible non-value added steps such as waiting time, internal transportation, etc., reaching a continuous leveled stable production flow.

2. Integrating quality into production, making it one of the production team's responsibilities; reducing as much of waste, defects, and errors as possible. This could also include stopping production to resolve quality problems rather than jeopardizing reproduction for defectiveness (i.e. Jidoka).

3. Ensuring Just In Time arrivals of resources, eliminating any kind of unavailability in an exact amount as needed, utilizing a Kanban (Pull) system both inside the company as

well as the supply chain, meeting the customer demand. In other words, ordering and producing what, when and as needed.

4. The dedicated and motivated workforce of people willing to adopt the lean philosophy principles through the feeling of responsibility continuously improving the system (i.e. Kaizen).

5. Multitasking manpower utilization, specifically for presaging and delivering for production procedure while running an unmanned operation.

Koren then summarized the implementation of these lean principles in a diagram shown in Figure 2.1. (Koren, 2010)
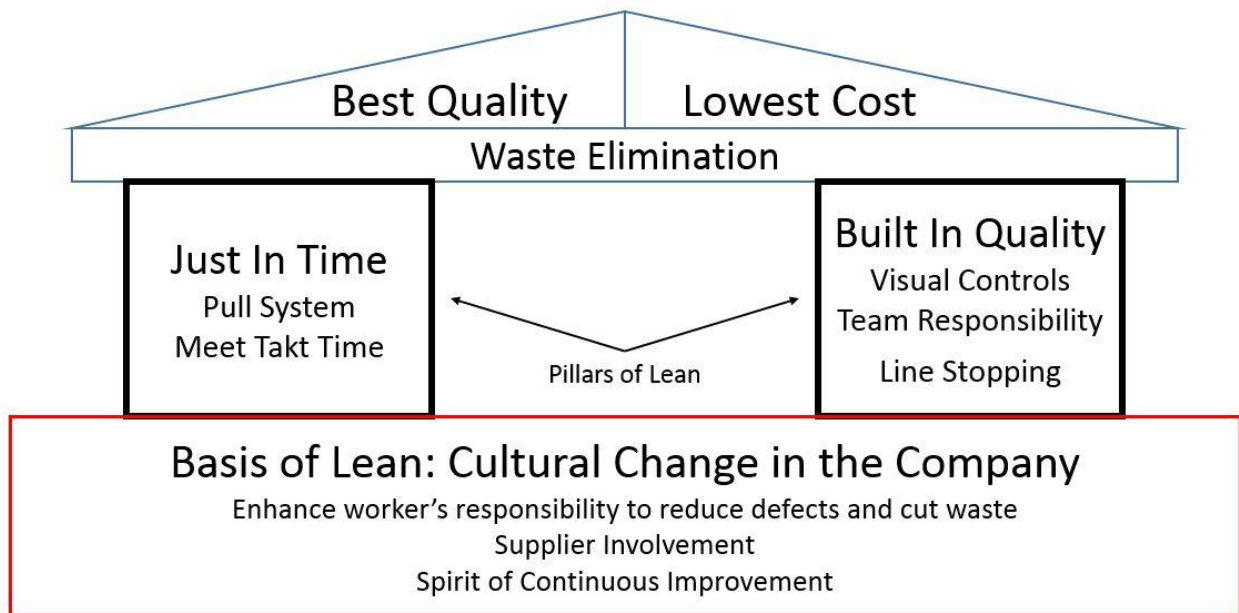
Figure 2.1 - Lean Principles implementation strategy and goals (Koren, 2010)

As per the literature reviewed, the lean manufacturing could be studied through a number of variables listed:

- Elimination of waste

- Continuous Improvement

- Zero defect (i.e. quality level)

- JIT (i.e. Just In Time delivery)

- Pull Material system; rather than Push

- Multi-functional teams (i.e. training level)

- Decentralization (i.e. supply chain network)

- Integration of functions

- Vertical Information System and time to market (i.e. supply and demand)

- Value Added Operation (Susilawati *et al.*, 2015)

Lean implementation aims to eliminate waste in the workplace. As simple as it sounds, these include but are not limited to unusable content. As explained by many researchers and presenters, the 7 types of Muda (i.e. Waste in Japanese, as based on the TPS) are:

- Overproduction: waste through the producing too many goods or producing too early

- Defects: waste through excess "cost" added to products because of rework or scrap

- Transportation: waste through moving material throughout the facility or double and triple handling material

- Waiting: waste from workers waiting for material or machines

- Inventory: waste through excess "costs" of managing space, materials

- Motion: waste through unnecessary worker movements

- Over-processing: waste through unnecessary processing steps (Khadem *et al.*, 2008)

Each of the lean tools mentioned earlier or other hybrid tools aim in tackling at least one type of Muda.

Taking the variables into consideration, studies have shown implementing lean philosophy and tools and has attributed to performance gains. An experiment was conducted with the intention to study the effect of implementing lean manufacturing principles in a textile industry organization. The study concluded that the implementation resulted in 50% fewer set-ups, 10 minutes less on set-ups, 30% higher in production efficiency (i.e. production time utilization) and 40% cost reduction. (Mourtzis, Papathanasiou, & Fotia, 2016) Other studies have related to the following gains:

- Defects reduction by 20% per year, with the possibility of zero defects performance.
- Delivery lead times reduction by at least 75%.
- On time delivery improvement by at least 99%.
- Productivity (sales per employee) increase in the range of 15 - 35% per year.
- Inventory reductions by at least 75%.
- Return on assets improvement of more than 100%.
- Improvements in direct labor utilization by at least 10%.
- Improvements in indirect labor utilization by up to 50%.
- Increase in the capacity of current facilities by at least 50%.
- Reduction in floor space by 80%.
- Improvement in quality of 50%.
- Machine availability improvement by 95%.
- Reduction in changeover time in the range of 80 - 90%.

- Reduction in cycle times by 60%. (Khadem *et al.*, 2008)

As stated earlier, there are a number of lean manufacturing tools that are widely used in industry. The most common tools as per surveys are defined below as per literature:

- **5S**, which stands for the names of the 5 processes the tool is involved in applying. Their application aims to reduce any inefficiency within the workspace due to the organization. In order, these are:

  1- Sort – The process of elimination of waste and unneeded material from the area

  2- Straighten – The process of organizing the remaining (i.e. needed) material area

  3- Shine – The process of cleaning the working area

  4- Standardize – The process of scheduling cleaning and maintenance for the working area

  5- Sustain – This involves a scheduled repetition of the previous steps to maintain the 5S standards

- **Heijunka:** the smooth flow of material through the production cycle. (Prasad, 2013)

- **Jidoka:** Stopping/disregarding in case of defectiveness.

- **JIT:** It stands for Just In Time, which is related to production based on demand, but also it should count for the delay in supply for raw material and avoidance of overstocking, overproduction, etc.

- **Kaizen:** 3 to 5 days (DMAIC) continuous improvement projects. This should display how the enterprise is working on continuously improving their procedures. However, some Kaizen projects are expanded, and their lengths and phases are extended or

- **Poka-Yoke:** error proofing; ensuring zero defects. This includes creating and updating SOPs (Standard Operation Procedures). These will act as the "lessons learned" rule book formed from the mistakes previously made in production.

- **VSM:** Value Stream Mapping, intended to map whole processes, identifying value-added and non-value-added procedures, along with cycle times, wait times, takt times, etc. It intends on reducing, if not eliminating non-value-added procedures such as waiting-for-inspection and transfer, in-house transportation, etc. The value is defined as "what is included in the customer pricing". In other words, "what would the customer pay for". However, it must be noted that some non-value added procedures are unavoidable such as packaging, labeling, etc.

- **KPI:** Key Performance Indicators. These act as the variables which represent a process, such number or products produced, number of defected products, etc.

- **Visual Management:** Display of KPIs. The main aim of this tool is to highlight and summarize the performance of the processes system to the employees and management. It acts as an employee empowerment to bring them into the picture and encourage commitment for improvement. (Prasad, 2013)

- **Kanban:** Trigger to replace as consumed in processes. It is usually associated with JIT along with Kaizen to identify need, capacity, and signals to resupply essential needs.

- **Continuous Flow:** 1 Piece Flow which in essence is the "Production Line" method, where the product is assembled along the path of production. The idea has expanded to structure the placement of station where production is not a process along a straight line of travel. In other words, the service should only move forward. (Prasad, 2013)

- **Ishikawa:** 5 Whys, a systemic root-cause analysis used to identify flaws across the system. (Roy, 2017)

- **Standardized Work:** documentation of processes, which ensures the reduction of times consumed by decision making, error proofing through systemic repetition. (Vidyut, 2013)

- **PM:** Predictive Maintenance, which is a set of procedure determined to ensure a consistent non-disturbed process operation capacity of machines. It might include Kanbans, Kaizens, Visual Management (i.e. inspection stickers), etc. (Earley, 2017)

- **TQM:** Total Quality Management; PDCA (Plan, Do, Check, Act), which are mainly followed to ensure the reduction of defects. (Brand, 2017)

- **Employee Engagement:** Ownership for Kaizen, and hence the employees are motivated to join the journey of continuous improvement.

An important resource to cover while studying would be the book Lean Thinking by Womack and Jones. Most of the researches covered in the literature survey were aided by the definitions given in this book, in particular the five lean principles defined and explained in the first part of the book. These are later explained as used in different researches. While the part two, three, and four of the book explained tests and cases on lean implementation and after plans, the book did not an emphasis on assessments for neither the lean implementation nor its progress. (Womack & Jones, 1997)

2.3   Assessment of Lean Implementation

Researchers have been studying ways to assess the implementation of Lean in enterprises. However, this was not the focus of researchers only but the enterprises as well. They wanted to

know how far and well are they implementing lean. For this reason, different auditing systems were set-up with the sole purpose of assessing the lean implementation. Some of these systems are used and employed by external consultants who are contracted to audit enterprises accordingly or develop strategies to embed these systems into the lean implementation plans for assessment.

Among the researchers was Sushil Kumar Shetty who researched different lean assessment systems in his Ph.D. dissertation titled "A Proposed New Model to Understand Lean Implementation Using Employee Perception". He started by studying the lean implementation model in general as explained by James Womack and Daniel Jones in the 1996 book "Lean Thinking: Banish Waste and Create Wealth in your Corporation" (Shetty, 2011). Like Koren, Shetty explained that according to Womack and Jones, there 5 principles on which lean implementation is successful. These are:

1. Value Definition in accordance to the customer

2. Value Stream Identification across the essential activities of a business while eliminating waste. The activities should cover the Product/Service definition, Management of Information, and Physical Transformation to products/services.

3. The flow of value through processing without interruptions or waste.

4. A pull strategy rather than push, initiated by the customer and communicated forward through processing, ensuring delivery with not "leftovers" which translates to an overproduction category of waste.

5. Aiming for the perfection of an ideal state, which is looked at as a continuous endless journey for enterprises. (Shetty, 2011).

These principles are what Shetty saw in the different assessment systems he researched and looked for. Most of the systems he researched are summarized in Table 2.1. It is important to note that all assessment systems are composed of questionnaires, with the metrics built on the answers submitted by the auditors. Most of the systems he researched required training to be used with no validated or published data results. Some of which are designed to be used by external consultants as auditors. Shetty aimed to develop a new system based on Womack and Jones principles. His new system would still consider the studied systems but would be designed primarily to be used by the enterprise's employees being the auditors rather than external consultants. It would have to require less training and easier adaptability to industries. The new system would be also composed of questionnaires, where the questions are directed towards the employees, discussing the implementation of the lean principals. The system would assess the answers on a five points scale. The scale acts as a source for reliability analysis using statistical measure, particularly using variance for this purpose. (Shetty, 2011)

Table 2.1 - Different Assessment Models; adopted from (Shetty, 2011)

Assessment System Model	Notes and Description
Shingo Prize	This is a form of an award given for implementing the lean principles. Its auditing process requires training (i.e. assessed by trained auditors), resources and time consuming without reliable published results. The weights of lean principles, systems, or tools implemented are unknown.
Lean Enterprise Self-Assessment Tool (LESAT)	The model was developed in Massachusetts Institute of Technology (MIT). It is composed of the assessment of 54 enterprise activities under the 3 sections of Leadership & Transformation, Lifecycle Process and Enabling Infrastructure. It covers the whole organization; it cannot be concerned with a particular department of the process. However, the assessment is in-depth consisting of 68 pages of questions. This length makes it resources and time consuming, but it doesn't have reliable

	published results. It requires training in order to be used.
Rapid Plan Assessment (RPA)	An assessment model consisting of visual information (graphs, diagrams, etc.) without metrics. Using 20 questions with a "Yes" or "No" answers in 11 categories, the RPA model helps in strategic planning for an enterprise. The published results show no validation quantitatively but there are data that proves that the model is a success. However, it requires a team to do the assessment, which has to be trained on it.
Hung-da Wan	A chart resulting based on the mathematical model, setting a pathway for improvement bases hypothetical quantitate measures. However, due to the rapidly changing nature of the decision of the factors considered in the model, the model hardly adapt. Its cases provide no validated data.
Mahalanobis Distance	A theoretical model serves to benchmark the performance data. It guides the direction of progress through positive and negative signs based on the reference data, which are based on the same 5 principles as the LESAT. The data fall under various categories, however, it is recommended to take 8 samples of 4 data points. There are no results published or validated.
General Motors Supplier (GMS)	The model is not detailed, focusing on 5 principles implementation through GM's supplier enterprises, to ensure mutual understanding and goal orientation towards lean and reducing waste. The principles are Lean implementation; People involvement, Standardization, Built-in Quality, Short Lead Time, and Continuous Improvement. Consisting of 71 questions, the responses are assessed on a 3 level response scale. However, the model is specific to GM standards. It is also a resource and time consuming with no published or validated data.
Strategos	A simple model consisting of 3 to 6 questions. The results are summed and/or averaged to produce the Lean Index. These are based on personal judgment of the auditor. Hence, it is a resource and time consuming with no published or validated data.

Similar to Shetty, Degirmenci (Degirmenci, 2008) based lean implementation on the principles presented by Womack and Jones. However, his approach was different from Shetty, in which he

researched whether the standardizing of lean would further help the implementation process of lean. The research contained a case study to test the hypothesis of lean implementation improvement through standardization. The review included an analysis of the pros and cons of standardization as a form of implementation guide. The literature of the studies of the benefits of implementing lean was covered in the literature review as well as well as a background in certification and standardization. Degirmenci used the ISO 9000 standard and its development to ISO 9001, Woodmark Quality System (WQS), Certified Production and Inventory Management (CPIM) certification offered by The Association for Operations Management (APICS), and Project Management Professional (PMP) certifications for Project Management Institute (PMI) as examples for different standardization and management certification used and abided by in today's enterprises.

(Degirmenci, 2008) later explained that a similar standard exists for the implementation of lean. Developed and published by SAE (Society of Automotive Engineers), SAE J4000 and J4001 which serve as a guide of best practices and user manual respectively for lean implementation. J4000 lists 52 components, rated on a level scale under six elements, with different percentage weights as measuring points for lean implementation. The elements and their weight percentage are shown in Figure 2.2. The level scale indicates the implementation level, where level 0 represents and non-existing implementation while level 3 represent a full implementation with progress over the last 12 months. The research also mentioned that individual certification for resources within the enterprises improve the level of lean implementation. (Degirmenci, 2008)
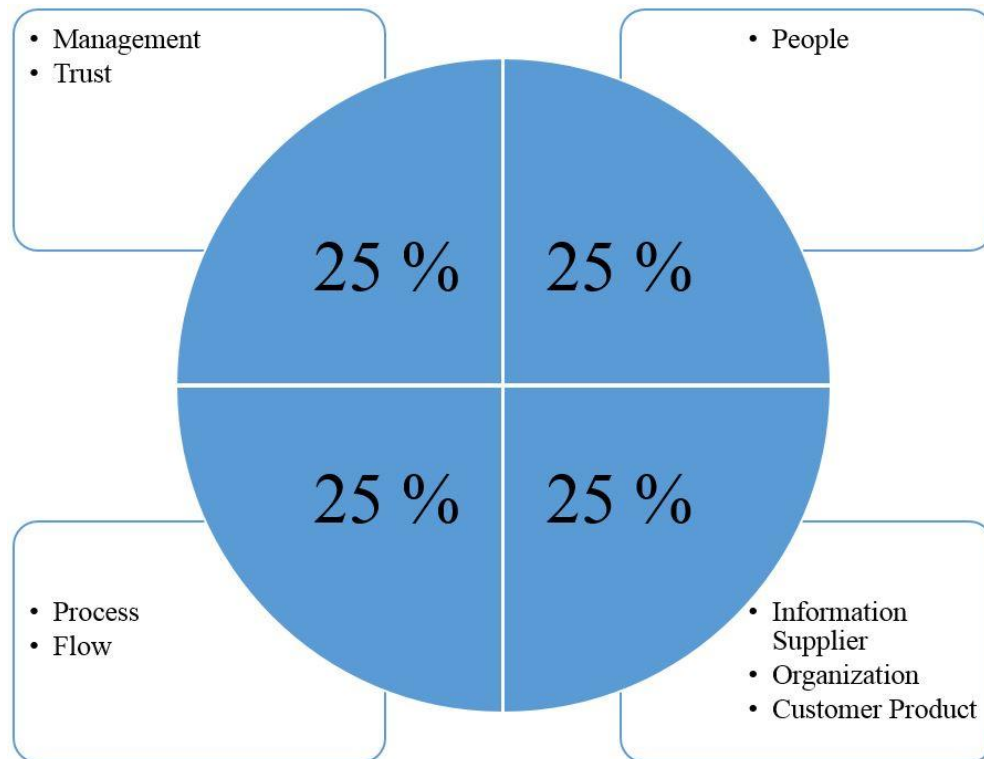
Figure 2.2 - J4000 Implementation areas and their percentages (Degirmenci,2008)

The researcher later on was involved in a research that studied the standardiziation of lean implementation (Degirmenci, Yegul, Erenay, Striepe, & Yavuz, 2013). He observed the lack of implementing the standards mentioned earlier (i.e. SAE J4000 and J4001). This, according to the research, is due to different reasons including stemming from the automotive industry to fit other industries, lack of publicity, and other resourcefulness other than SAE such as consultants. However, the research mentioned that a standard for lean implementation is important to set a common definition of lean implementation and its effects. It would also communicate the knowledge of best practices for implementing lean through guiding the management team of the organization in lean implementation decision making for long term benefits rather than short term ones. This would also serve as building a lean culture in the organization, rather than enforcing the implementation on employees.

While the previous researches were more concerned with the assessment of lean implementation, primarily qualitatively, a different approach was taken Cai who looked into assessing the value created over Product Development Processes (PDP) while implementing the lean principle of waste elimination. (Cai, 2011) This would be done quantitatively as well as qualitatively through a framework that would define the value and its adding processes while fitting the lean principles and hence enhancing the PDP system. Through the literature review, in addition, to reviewing PDP, the following formula in Equation 2-2 was found to quantitatively define value:

$$V = \frac{B}{C}$$
<div style="text-align:right">Equation 2-2</div>

where

V = Value

B = Benefit (i.e. profit); in monetary units

C = Cost; in monetary units

He explained, that according to lean, waste (i.e. Overproduction, defects, etc.) would be endured more towards the costs, bringing the value of the product lower. So he tried to investigate the effect of implementing the lean principles in a PDP framework and its formularization to define, better enhance and utilize the value addition while eliminating waste. (Cai, 2011)

The concept of defining a framework for implementing lean into enterprises, rather than just PDP has been researched. Jirapat researched this area, particularly for small and medium-sized enterprises. He explained this process through a methodological process, starting with a Lean Enterprise Transformation (LET) initiative; integrating lean into enterprises' activities while collecting data (i.e., lead time, VSM, etc.) through the process, then using these data and fuzzy

logic analysis for decision-making purposes. In this study, Jirapat considered a Job Shop case as an enterprise and supplier selection as a decision-making process, which makes this methodology a metaheuristic approach. (Wanitwattanakosol & Sopadang, 2012) Similarly done by other researchers in the same topic, where Belhadi, Touriki, and Fezazi researched a similar framework. However, they implemented an existing framework in 4 different small/medium enterprises, studying the implementation process as 4 different case studies. Then they explicitly studied the effect factors and implemented tools in each case. By doing so, they were able to build a newly modified lean implementation framework that would suit small and medium enterprises. (Belhadi & Touriki, 2016) Researchers even expanded the methodology of a framework, building a mathematical model for the framework. (Mostafa, Dumrak, & Soltan, 2013)

These frameworks let researchers study the effects of implementing lean manufacturing on an organization. Researchers went on to study cases of the implementation effects as done by Motwani. However, the study overall was qualitative and did not investigate any progress done through the implementation journey of lean manufacturing. In other words, it described the before and after lean status in an organization. (Motwani, 2003)

Similar to the different approaches presented earlier, Hutchins tried to assess the effect of implementing and integrating the 5S tool into the workspace on employees' commitment and engagement. It also looked into the effect on productivity as a measuring factor, along with safety, quality, and utilization of floor space. The research consisted of multiple hypothesizes, each with different surveying scenarios. The research then collected the qualitative data and analyzed it using the ANOVA statistical package. The analysis highlighted the effect of the above-mentioned factors before and after implementing and integrating 5S. (Hutchins, 2007)

2.4 Assessment Score of Lean Implementation Progress Using Lean Metrics

Using a lean metrics for assessment and improvement of lean implementation had been looked into by many researchers. This method effectiveness has been researched as well and was proven to be successful and has many benefits when used. Oleghe and Salonitis were among those researchers who looked into these areas and researched how to further improve the effectiveness of this method. They researched the different assessment model, such as the ones summarized in Table 2.1 and then they defined fuzzy logic relationship metrics to quantitatively measure the qualitative measures the assessment models measured. (Oleghe & Salonitis, 2015)

(Oleghe & Salonitis, 2016) later on they researched the variation of the lean implementation using those fuzzy logic definitions Equation 2-3:

$$\mu_A(x) = \begin{cases} 1, & \text{if } x_i \leq a \\ 1 - \frac{x_i - a}{b - a}, & \text{if } a < x_i < b \\ 0 & \text{if } x_i \geq b \end{cases} \qquad \text{Equation 2-3}$$

where

μ: "assigned value" of score of performance variable A

x: measured value of performance valuable A

a: "baseline" or minimum threshold value of performance variable A

b: "target" value of performance value A

This definition was used to assign and values to different lean performance variables, and LI (Lean Indicator), which is the average of all the assigned values. The LI was then calculated through different time intervals and used to study the variation of lean performance level over time. However, this definition would scale the performance between the values of "a" and "b"

only. This would mean that a performance level defined by a value above point "b", no further assessment would be required.

The benefits vary from improved safety and quality, higher manufacturing utilization of machines and processes to employees and customer satisfaction. This was thoroughly looked into by Khadem through his research. His research highlights the benefits of lean through the studies the research covered. However, the research was concerned with the effects of what the researcher called "Management Metrics". These were dived into primary and secondary metrics as follows:

- Primary Metrics
    - Dock-to-Dock Time (DTD) time:
    - First Time Through (FTT) Capability
    - Overall Equipment Efficiency (OEE)
    - Build to Schedule (BTS) Ratio
- Secondary Metrics
    - Days on Hand Inventory
    - Value Adding Ratio
    - Manufacturing Cycle Time
    - Five S Diagnostic Rating
    - Square Footage Required (Per)

The research provided some formulas to calculate the primary metrics and derivative metrics from the secondary ones. The researchers then explored the ways through which these metrics are used to equip management in decision making and other management scopes such as

production planning, investment management, etc. (Khadem *et al.*, 2008) Other researchers have used the lean assessment to align current and future goals with business plans. The researcher explained that this would aid managers in different ways when conducting a value stream analysis. The researcher, however, emphasized that this method is a based-on-the-case situation, where the result of value stream map analysis couldn't be compared to another. The results covered by the researched could include monetary terms. (Gündüz, 2015)

A similar approach was represented in a different research paper. It, however, was directed mainly towards the wood products industry in particular. The metrics that the research came examined were only concerned with the enterprise inventory and management (i.e. energy, labor, etc.). The lean approach was followed in the sense of reducing waste in these categories, working with these metrics to reach a certain standard or goal. (Ray, Zuo, Michael, & Wiedenbeck, 2007)

While the researches covered earlier were more concerned with a management system to track the progress of lean implementation, this section covers researches that look into assigning a quantitative score to for a clearer demonstration of lean progress in enterprises. It also helps management and employees work towards improving overall productivity; meeting production goals, enhancing safety standards while empowering employees with engagement and ownership in the work environment.

The research paper published by Wan and Chen on leanness measures was detailed and as intended highlighted the lean implementation impaction quantitatively. They have done so proposing a methodology using data envelopment analysis (DEA) of data gathered from the manufacturing system intended to study. Using cost, production time and product value and Decision-Making Units (DMU) variables as well as the analysis, a leanness measure was

determined. The analysis and measure formulation was based on previous work made by other researchers. It, however, was not defined as a lean tool or any governing factors. (Wan & Frank Chen, 2008)

However, concerns arose that the score might include a prejuidce factor, which in turn would inaccurately scale the lean implementation; its progress and impacts. Some researchers had taken the initiative to try to deal with biases, whether looking into the scoring audits that are made to the applications of the lean principles and tools or the initiative of applying new lean principles and tools. This biasness might be developed due to the major belief of an organization of the priority scale and how to keep the improvement gained. One of the researchers concluded that using MoSCoW (Must/Should/Could/Would rules) management method to prioritize the lean implementation tools and its tasks would help in managing the application of lean and its development in an organization. (Mourtzis *et al.*, 2016)

Other researches went further and used fuzzy logic modeling to assess the leanness of an organization. They used the fuzzy logic to manipulate a certain chosen Key Performance Indicators (KPIs) measured quantitatively, resulting in a scored assessment. The fuzzy logic they used was fairly simple and would work with scores to produce a Lean Index (LI). They even applied to their system on a hypothetical case and LI was calculated for different tasks where different lean tools were applied. (Oleghe & Salonitis, 2016) The same concept was further investigated but using triangular and trapezoidal fuzzy logic correlation and graph to correct any vagueness and biasness the auditors might subject into their auditing score (Susilawati *et al.*, 2015). Another research dove deeper into the theory and produced a DSS (Decision Support System) and assess in applying and managing the implementation of lean (Vinodh & Balaji, 2011). Warehouse performance measurement was as well an application for combining the fuzzy

logic manipulation with lean manufacturing scoring method. (Buonamico, Muller, & Camargo, 2017)

A new approach was presented by Al-Janfawi - a new lean assessment metrics call EVF metric. This metric assessed the lean level of an organization based on 3 criteria; Efficiencies of Process, Variability of the overall system, and Flow type of goods: Continuous Pull and Push. He used this metric on a steel production enterprise as a case study. He broke down this metric to different sub-metrics to further assess the lean level of the organization and set a target for the overall metrics based on the improvement opportunities that could be found. The metric was then calculated based on the study case data and its conclusions were discussed. (Al-Janfawi, 2011)

While these metrics were concerned with the assessment of lean progression and the improvement impacted by its implementation, other researches were concerned with the implementation strategies. The decisiveness comes from the limitation of resources. The researcher developed metrics based on Method-Time Measurement (MTM) to create a Decision Support Tool (DST) using different programming languages, impeding a mathematical model in the tool. The mathematical model includes using fuzzy logic similarity as used by Olehe and Salonitis in their research paper. (Oleghe & Salonitis, 2016) With these, the researcher claims they should aid in designing a lean implementation strategy and plan it according to the available strategy. After applying the appropriate strategy, the implementation will be assessed using the same process and a future strategy would be designed. (Amin, 2013)

2.5   Industrial Implementations Review

Figures A.1 and A.2 in the appendix provide examples of two 5S assessment sheet from an industrial floor of an enterprise in Windsor, ON. These are examples of generic forms used by

industries calling the process 5S audit. However, many auditors and area leaders in different industries have complained that the scoring sheet does not fairly represent the area and the scoring categories are sometimes hard to recognize or apply to the area being audited. However, such checklist sheets cannot track the increase or decrease in compliment to the 5S standard set. In other words, it will not assign a score as an assessment to the achievement level to comply with the 5S standard. Industries since then have come up with other different scoring sheets, each enterprise in every industry on its own. However, it was noticed that it was very general which led to bias assessment depending on the auditor and losing the consistency of the assessment tracking.

As that review was concerned with 5S only, other reviews included VSM and Kaizen. The highlights of these reviews include the following:

- For the VSM, a map would be constructed for the production of a product or of a process. Each step would be included on the map, with notes of its cycle time and delays. Mapping the processes aims to reduce the production time by a factor or to a pre-calculate another takt or cycle time.

- With regards to Kaizen, which are mainly concerned with small improvement projects, enterprises used these as assessment for employee engagement and criteria in employees' evaluation. The organization evaluates the implementation of Kaizen by the number of projects suggested, implemented and any other measured improvements.

2.6   Research Gaps

As the Lean Manufacturing has been adopted by different industries and fields, the philosophy failed to comply and follow a standardized procedure. The philosophy is composed of multiple

qualitative tools such as the ones mentioned earlier in the literature review. More tools are introduced based on the needs and application of the specific industry. These tools would be used in the current systems of production and would assess improvement measures. However, since there was no foundation of a standard concluding the assessment, every industry would use these tools to the best of their knowledge and judgment. Each company would try to incorporate these tools into their own standards, measures, and targets. The application has no definite assessment with an incomprehensive objective of result measurement. Thus companies in different industries proceed to call the philosophy Continuous Improvement rather than Lean Manufacturing and other names. For example, the FCA group would call this waste reduction philosophy World Class Manufacturing which again is based on the TPS. The conventional way of assessing the implementation of these tools are usually through questionnaires as demonstrated through the literature survey earlier.

Researchers have been on the path of assessing and correcting the assessment data of the lean manufacturing to compare the implementation and improvement levels and measure its effect on the industrial economy. However, as mentioned earlier, the philosophy variables are qualitative variables which made it harder to measure and assess them and their effects. While some researches depended on Triangulation data gathering from different sources to ensure unbiased data gathering and analysis, others used mathematical and rational calculations to produce a quantitative figure to measure the system. This was done through average weight ratio, categorization of data or other quantitative approaches, including decision-making models and tools, assessment systems and other examination methods. The research gap identified through the literature review is summarized in Table 2.2.

Table 2.2 - Research Gaps Summary

| | Defining Lean | Lean Implementation Platform | | Lean Metrics | | | |
| | | Transformation | Assessment | Data Correction | Assessment Metrics | | |
					Categorized Lean Assessment	Overall Lean Assessment	Lean Tool Specific Metrics
(Al-Janfawi, 2011)	✓				✓	✓	
(Amin, 2013)		✓	✓	✓		✓	
(Belhadi & Touriki, 2016)	✓	✓					
(Degirmenci, 2008)	✓		✓				
(Gündüz, 2015)		✓	✓		✓		
(Hutchins, 2007)	✓	✓	✓	✓			
(Khadem *et al.*, 2008)	✓				✓	✓	
(Mostafa *et al.*, 2013)	✓	✓	✓			✓	
(Oleghe & Salonitis, 2016)				✓	✓	✓	
(Oleghe & Salonitis, 2015)	✓			✓	✓		
(Ray *et al.*, 2007)	✓		✓		✓		
(Susilawati *et al.*, 2015)	✓			✓		✓	
(Wan & Frank Chen, 2008)	✓			✓		✓	
(Wanitwattanakosol & Sopadang, 2012)	✓	✓	✓				

However, these were seen as theoretical to the industry. Based on the industrial implementation review, the continuous improvement programs in companies have been associated with goals such as scores and rankings, a number of applied continuous improvement projects (Kaizens); which sometimes extends more than the supposed length, reduction of cycle time to a certain goal, monetary gains, and savings, etc. Some, however, have adopted the triangulation correction to the assessment through multi-level audits. Through these, the auidotrs' prejeduiceness were not avoided which would base the results on the auditor's judgment, or by the generic questionnaires of the auditing systems which would mislead or be misinterpreted in some auditing cases.

As identified, this research approach is to provide an example of metrics for a number of lean tools, producing numerical scores. These would then be used to directly assess and validate the lean improvement and implementation. The metric score could be corrected through mathematical models to further enhance the accuracy of the assessment procedure (i.e. counting for standard deviation and statistical analysis). As an example, the 5S, Kaizen, and the Value Stream Mapping tools will be examples for which metrics will be determined in this research. If successful, formalizing the rest of the lean tools should not be complicated. While this formulation approach is generic, it could be tailored to fit specific needs in the different industries depending on their factors, measures, and goals.

Chapter 3 : METHODOLOGY AND METRIC FORMULATION

3.1 Assessment Elements

As defined by Khadem, Lean Metrics are essential elements by which the improvement in current performance is measured quantitatively in comparison to a standard. (Khadem *et al.*, 2008) In this chapter, these elements are defined as numerical metrics. The definitions are generic and made to fit the main objective of the Lean Manufacturing tool application. These metrics are subject for further specific alteration or adjustment based on the industry they are being used in and any other affecting factors as judged by the assessing committee of an organization.

3.2 Approaches and Tools

To better illustrate the intent of the research, an IDEF0 representation in Figure 3.1 has been developed for a Lean Manufacturing Tool metric assessment process. The IDEF diagram indicates that the KPI, the manufacturing system performance and assessment parameters are input into the assessment process done by of the lean manufacturing tool metric such as downtime in the V.S. M. metric. The market demand would be associated with the performance target goals (i.e. cycle time, takt time, etc.). Hence, in order for the production to meet the market demand, these goals must be attained and would act as constraints.

While the inputs and constraints are qualitatively linked, the formularization of the metric would numerically link them depending on the tool implementation. The formalization of the implementation in the metric would act as parameters (i.e. scoring parameters). The activity of that the IDEF0 approach is mapping would be the assessment of lean manufacturing implementation. Hence, combining all of those in Lean Manufacturing Tool metric will produce

a score. This score is entered into the weighing average formula assessing the leanness of the organization as a whole based on the scores of the different Lean Manufacturing tools' implementation metrics.
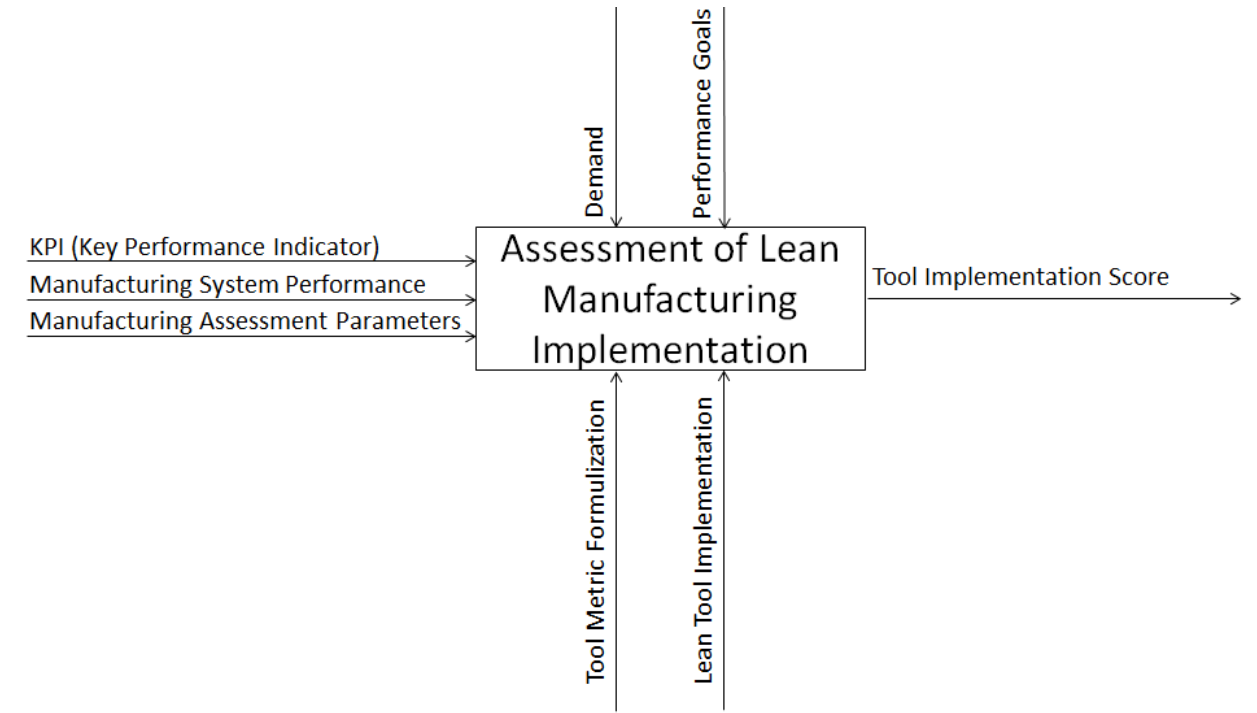
Figure 3.1 - IDEF0 for a Lean Manufacturing System Metric

3.3 Mathematical Model of Metric Formulation

The mathematical model used to calculate the score is different for every lean manufacturing tool. As mentioned earlier, the 3 tools considered for the research are the 5S, Kaizen, and V.S.M.

3.3.1 5S Assessment Score

For the 5S, major points of scope in the areas are considered for the audit such as sorting of parts, availability of tools and its placement in assigned places, etc. derived from a generic 5S checklist items. These items are unidentified under the relevant category of the 5S principle.

Table 3.1 summarizes those items in every 5S category. These items could be modified, added to and/or updated per organization as needed.

Table 3.1 - Categorized 5S Items

5S Category	Item
Sort	• Disposal of and/or relocating of broken items, products, tools, unneeded furniture, equipment, etc. • The only required material, work-in-progress products, and components, needed tools, needed furniture, etc. are present in the area
Straighten	• Designated drop-in, pick-up, the storage location for all required items • All pathways, aisles, shelves, designated locations etc. are marked, clear
Shine	• All working surfaces, aisles, shelves, labels, etc. are clean and clear and adequately lit • Cleaning material is available in the area
Standardize	• Documentation for area structure, information architecture, guiding material for the area are present • Documented standardized working procedure for the area
Sustain	• Are the rules set being followed and regularly applied • Are all the 5S standards derived from the categories earlier being maintained

Auditing points are then generated to target those items and evaluate while considering those items of importance to complete the job in the workplace. The philosophy behinds setting these

points represent how vital those items at that point to complete the same task by the same person faster or even by different people, that it becomes visual for the person how and where are the essentials to complete the job tasks. In addition to these points; a number of general rules are to be followed. The rules are as well derived from generic regulations that could have an effect on the areas of the 5S principles such as the cleanness of the area, removing obstacle blockage of pathways of sight or movements, etc. A good practice would show these points in the picture of the area at the perfect state and have this picture in the area and on the area's audit sheet.

Many of the generic 5S audit sheets or checklists use a scale system (ex.: 1 to 5; 1 being the worst and 5 being the best). This scale scoring system would have big variations determined by the auditor's judgment. In the new proposed system, each point is represented for a 1-grade point score on a scoring sheet (i.e. 1 for compliant and 0 for noncompliance), which follows the basic binary system (i.e. 1s and 0s). With this one point scoring system, along with visual verification of the point on the picture, those should reduce the variation in auditing significantly.

This serves as a general guideline for calculating the score with respect to the 5S tool. The scores and points of scope are area and organization dependent but stem to derivation from the generic categorized items. The compliance ratio represented in 5S score relative to the overall lean score of the organization is also subjective to the organization's views and goals. The following diagrams show an example of highlighted points of scope before and after applying the 5S principles. To equate all areas, a number of points should be set for every 5S category for all area in an organization. This will unify all the scoring weights of all areas in the organization. For example, specifying 10 points for all audited locations/areas within an organization facility. Thus, an auditing score would be a mark made out of 10 total grading points for each location.

Figure 3.2 - 6 points of scope before applying the 5S principle in a working area (5S Training & Research, 2016)
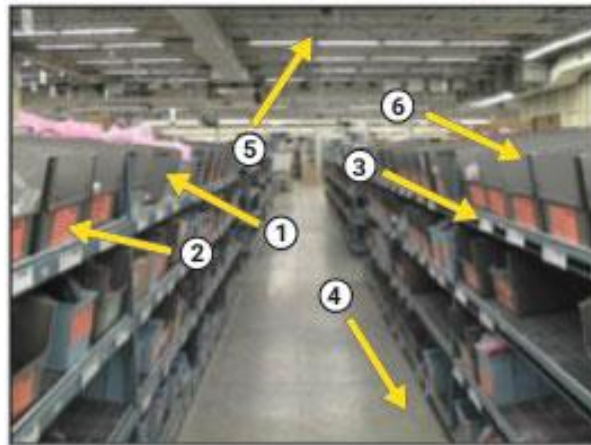

Figure 3.3 - 6 points of scope after applying the 5S principle in a working area (5S Training & Research, 2016)

It could be noted that the application of 5S involved strategically changing the environment of a working area such as using plastic containers. It also involved labeling the containers and placing on the shelves in an orderly fashion. It also could be seen that the shelves are leaning in an angle. As trivial as it may seem, this was intentionally set in this way for two reasons: is for easy retrieval and re-shelving of material as well as to ease of reading the labels on the containers. In addition to these, the lighting of the area and a clear pathway were considered as points of scope

(i.e. point 4 and 5) as it is vital in such working areas. Such an area could be assumed to be used for shipping and receiving, material storage area, etc. Hence, good lighting and clear pathways are essential. Those 2 points could be included in the generic questions or as points of scope, as well as any other additional measures based on the judgment of the lean auditing committee of the organization. All of those points could be derived from the 5S categorized items. The 5S score could be calculated using the following formula in Equation 3-1:

$$5S\ Score = \sum_{i=1}^{i=n} Xi$$

Equation 3-1

where

X: audit point grade mark (i.e. 1 for compliance and 0 for uncompliance)

i: the 5S assessment points

n: number of 5S assessment questions

3.3.2 Kaizen Assessment Score

A Kaizen project is defined as a simple small-scale project that could be completed in a short period of time, with no dedication of resources and would have relatively small improvements on the procedure of operations or process. As for assessing the Kaizen principle of lean, the small continuous improvement projects are to be broken down into different stages or phases. It is recommended that a Kaizen project number of stages should not exceed 4, making it possible to finish the projects in a week or two spans of time. If more stages or longer time span is needed, it safe to assume that the project is no longer Kaizen but a bigger scale Continuous Improvement project. The stages should be of smaller scales such as buying essentials, implementing a

system, etc. The weights of the phases should sum up to 100% or 1. Every week, the management team would meet and update the progress of the different Kaizen projects. From the weekly updates, a weekly score is to be calculated based on the number and progress of different Kaizen projects. This weekly score should be tied to meet or be higher than a minimum Kaizen progress score set by the lean auditing team as a goal. The projected weight is set based on its necessity and importance relative to the organization priorities. For example, a safety kaizen project would have a weight of 100% while a sorting kaizen project would have a weight of 40%. Any project weight should not exceed 100%. The results in Table 3.2 are for tracking reasons, to be used for management and following-up on kaizen projects in progress. It would also highlight the availability to start a new kaizen project if possible.

Table 3.2 - Kaizen Chart/Matrix Table

Project Number	Weight	Phase 1	Phase 2	Phase 3	Phase 4
Project 1					
Project 2					
Project 3					
Project 4					
Project 5					
Project 6					

At periodic audit at T, the Kaizen score is calculated using Equation 3-2:

$$K = \sum_{f=1}^{f=d} P_f * s_f$$

Equation 3-2

where

f: Kaizen Project being implemented

d: maximum number of Kaizen projects that could be implemented in T

s: individual phase weight of the project "f", expressed as fraction or decimal

P: Weight of Kaizen Project "f", expressed as fraction or decimal

The phase points may differ based on the importance of the phase, expressed as a fraction or decimals. Also, the weights of the projects are assessed based on the judgment of the management team. An example of the implementation of this scoring system will be explained in the next chapter.

3.3.3 V.S.M. Assessment Score

Lastly, with regards to the Value Stream Mapping (VSM) assessment score, the progress of eliminating waste should be tracked and the percentage of reduction is translated into a score. Hence, the assessment score will be calculated at the beginning of the mapping of processes and after improving the procedures of processes in the proposed improvement through the mapping project. As most of the VSM projects, the cycle time of processes are intended to be reduced, and so improving the takt time of processes. As there will be always room for improvement, a map should not attain a full score. The score could be calculated using the following formula in Equation 3-3:

$$V.S.M.Score = 1 - \sum_{q=1}^{q=r}\left(\frac{Non\ Value\ Added\ time}{Total\ Cycle\ Time} * W_q\right)$$ Equation 3-3

where

r: number of non-added value processes

q: Non-Value added time process time

W_q: Weight of corresponding Non-Value Added time "q", expressed as fraction or decimal

The weight represents the importance of the non-value added procedure to the process being mapped in an inverse proportional relationship (i.e. the higher importance of the non-added process, the lower its weight). The non-value added steps are considered in the equation to distinguish and rank their importance in the mapped operations. The lower the weight, the smaller the deduction value, maintaining a score for the map closer to 1 (i.e. a map with a score of 1 has no non-value added processes). Non-value added operations with higher weight are the first subject for elimination to reduce waste through the mapped processes. The weights are dictated after the assessment by the mapping team; discussing them in accordance with the executors of the operations and management. Hence, when working on improving the value stream map score (i.e. reducing cycle time by minimizing non-value added), the team will work on eliminating the non-value added time starting with ones with the highest weight through to the ones with the smallest weight. This will establish consistency and a systemic approach when working on a V.S.M., rather than randomly reducing the cycle time of different processes on the map to meet a target cycle time.

3.3.4 Overall Lean Score (OLS)

Like the individual lean tools, the overall lean score is calculated based on the weight of the different lean tools being implemented and included in OLS. As a standard, all implemented lean tools should be assessed and the scores should be included in the OLS. The importance of each tool will be subjective to an auditing or management team setting the standards for the Lean Implementation. Thus, OLS could be defined by the following Equation 3-4:

$$OLS = \sum_{a=1}^{a=b} LT_a * H_m$$

Equation 3-4

where

a: Lean Tool being implemented

b: number of Lean Tools being implemented

LT: Lean Tool "a" score (i.e. 5S, Kaizen, and V.S.M. assessment scores)

H: Weight of Lean Tool "a", expressed as fraction or decimal

Chapter 4 : EXAMPLES AND CASE STUDIES

4.1 Overview

In this chapter, the previously mentioned equations will be applied through different hypothetical examples for the 5S and Kaizen tools while using actual data gathered from a different research for which the V.S.M. score is calculated. The total OLS for the cases combined will be calculated, assuming 25% weights for the 5S and Kaizen tools' scores and 50% for the V.S.M. score. This weight can vary from 1% to 99% based on vision and management's judgment of the applying organization.

4.2 5S Score Example

Taking the pictures in Figure 3.3 on page 35, the six points in the picture will be used to fill the 2 industrial 5S audit sheets presented in the Appendix on pages 56 and 57. The filled audit sheets are presented in the appendix, labeled Figures A.3 and A.4, filled by the researcher. As can be seen from the first audit sheet in Figure A.3, the questions are very generic, and some questions could be seen as not applicable. The "Yes" represents the positive scores. When talking to the industrial engineers, they said they intend to use one audit sheet for all areas as a principle of standardization. As for the non-applicable questions, the decisions are to be made by the auditors. It is also important to note that some negative answers to the questions are supposed to be a positive mark such as questions 3 and 4; if there are no tools or equipment blocking the aisle ways, 2 marks will be deducted. This creates confusion when using this sheet for audits. In an overall evaluation, this could be seen as a highly inaccurate auditing system. Filling the second audit sheet which is shown in Figure A.4 in the appendix, a number of questions were again hard to answer due to their indirect correlation to the area being audited.

These were just examples of the many audit sheets being used in industries to audit their 5S compliance. However, among these was the perfect example comparison case, in which a picture of the area is shown at its perfect state, with points where a 5S standard is applied. While these are examples to follow, they are not used for auditing purposes. Hence, the new concept is proposed in this research to use these models for auditing. A newly proposed auditing sheet is prepared for the same area shown in figure 4.1 below.
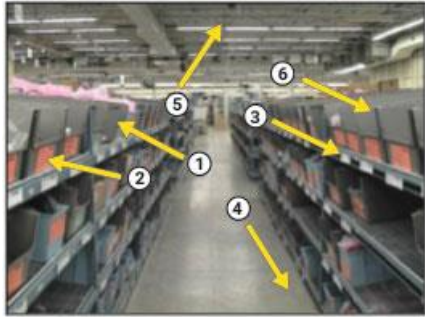
5S AUDIT CRITERIA		
Point		Yes (1)	No(0)
1	Are the bins stored properly on the designated shelves?		
2	Are the bins labeled clearly?		
3	Are the shelves labeled clearly?		
4	Are the pathways clean and clear?		
5	Is there area adequately lit?		
6	Are the bins filled with the respective parts?		
	Is it clear that there are no parts outside their designated bins?		
	Is the area leader information shown and available?		
	Is there an administration checklist available and used?		
	Overall, is it clear that there are not any conditions that would restrain work in this area?		
Total		/	

Figure 4.1 - A proposed 5S Audit Sheet for the working area in Figure 3.3 on page 35

It is the easier and more visual (i.e. which stems from the principle of visual management of lean) how to audit the area based on the points pointed at in the picture. The question clarifies what to look for at each point. Also, the general questions serve as an assurance for an overall

compliance with the 5S standards at any point that is not pointed at or included in the principle auditing process. A filled audit sheet is shown in Figure A.5 in the appendix. It is clear why the area scored 7/10 in the proposed 5S audit. To add to the clarity, the first and last of the general questions are stated in a way that positive reply would have a positive implication on the score.

4.3 Kaizen Score Example

As an example of the Kaizen scoring system, 2 Kaizen projects will be proposed to be implemented in the area previously audited using the proposed 5S audit sheet. It will be assumed that the timeline for both projects is two weeks and at the end of each week, the Kaizen score will be calculated. The two projects proposed are listed below:

- Project 1: Use printed and standardized labels for the bins. A color, along with naming standard should be used for the easier identification and faster processing.

- Project 2: Paint the floor to identify safe walking zones around the area and where it is mandatory to check for incoming traffic (i.e. forklifts, cranes, etc.).

The first project, assumed to weigh 60%, will be broken down into 3 phases as follows, along with each phase's weight:

- Phase 1: Buying labels and label printer (25%)

- Phase 2: Standardizing names and color codes for the labels (50%)

- Phase 3: Printing the labels and placing them on the bins (25%)

For project 2, it is assumed to weight 100% due to its connection to safety standards. It will be broken down into 2 phases:

- Phase 1: Buying floor paint (25%)

- Phase 2: Painting the floor in the area (75%)

Assuming phase one of both projects has been implements as well as the second phase of the first project in the first week. That week's Kaizen chart will be as follows:

Table 4.1 - Week 1 Kaizen Chart

Project Number	Weight	Phase 1	Phase 2	Phase 3	Phase 4
Project 1 (Bin Labeling)	0.6	0.25	0.5		
Project 2 (Floor Painting)	1	0.25			

The Kaizen score for the first week will be:

$$K = \big((0.6 * ((1 * 0.25) + (1 * 0.5)))\big) + ((1 * (1 * 0.25))) = 0.7 \text{ or } 70\%$$

In week two, the remaining Phases of both projects wear completed. Hence, the Kaizen chat for week two changed to as follows:

Table 4.2 - Week 2 Kaizen Chart

Project Number	Weight	Phase 1	Phase 2	Phase 3	Phase 4
Project 1 (Bin Labeling)	0.6			0.25	
Project 2 (Floor Painting)	1		0.75		

The Kaizen score for the second week will be:

$$K = \big((0.6 * (1 * 0.25))\big) + ((1 * (1 * 0.75))) = 0.9 \text{ or } 90\%$$

If the minimum Kaizen score that is to be maintained is 0.75, then in week 1, the organization didn't reach their goal but did accomplish in week 2. In order to accomplish in week 1, they

should have implemented more phases of the same or other projects. The score could be seen to have no maximum which could have some pros and cons as will be discussed in the next chapter.

4.4 V.S.M Case Study

For the V.S.M. case, the data used will are the same data collected and used by Al-Janfawi in his research (Al-Janfawi, 2011). It was hard to find similar data from a local industrial organization due to management approval. Al-Janfawi explains that the data is based on a large steel company in North America, producing pipes of different diameter sizes ranging between 30 and 60 inches. The production runs 24 hours a day, 365 days a year producing 150 – 200 pipes a day employing 55 employees. The production is broken down into 11 stages, with an additional repair stage in the case of inspection failure. These are listed below:

1. Pipe making
2. Pipe cleaning
3. Preliminary sonic inspection
4. Internal inspection (ID)
5. Outside inspection (OD)
6. X-ray inspection
7. Final finishing
8. Final visual inspection
9. Final sonic inspection
10. Scale
11. Customer inspection

In Case of inspection failure, pipes are sent to "Burn Bay and Real-Time Repair Stage".

The data collected by Al-Janfawi are summarized in Table 4.3.

Table 4.3 - V.S.M. Data collection (Al-Janfawi, 2011)

Stage			Cycle Time (C/T)	Changeover Time (C/O)	Uptime	Number of Operators (OP)	Production Rate
Pipe Making			5 minutes	72 hours	65%	16	150 - 200/day
Pipe Cleaning			6.5 minutes	0	100%	1	4-10/hour
Preliminary Sonic Inspection			7 - 8 minutes	4 hours	100%	1	7.5 - 8.5/hour
Internal Inspection			3 - 5 minutes	0	100%	4	12 - 20/hour
Outside Inspection			3 - 5 minutes	0	100%	3	12 - 20/hour
X-ray inspection			5 minutes	1 hour	100%	4	10 -12/hour
Final Finishing	Hydro		3 - 5 minutes	6 hours	100%	2	11 -12/hour
	Endsizer		3 - 5 minutes	2 hours	100%	2	12 -12/hour
	Beveller		3 - 5 minutes	4 hours	100%	2	13 -12/hour
Final Visual Inspection			7 - 10 minutes	0	100%	5	6 - 8.5/hour
Final Sonic Inspection			7 minutes	1 - 3 hours	100%	1	7 - 8.5/hour
Scale	Double Joint	Both ends	15 minutes	0	100%	1	4 - 6/hours
		One end	10 minutes				
	Normal Pipe	Both ends	7 minutes	0	100%	1	8.5 - 12/hour
		One end	5 minutes				
Customer Inpsection			5 minutes	0	100%	2	10 - 12/hour
In case of failing inspection							
Burn Bay and Real Time Repair	Cutting		5 minutes	0	100%	10	4 - 10/hour
	Welding		40 minutes	0	100%		
	Double Joint (DJ)		15 minutes	12 hours	100%		
	Grinding		20 minutes	0	100%		

Although these data are insufficient to draw a full map for thr process (i.e. transportation, waiting and other data are missing), a V.S.M. score will be calculated based on this data. Changeover time will not be included in the calculation, as the calculation will count for 1 cycle of cycle time. Other assumptions include:

- Inspection time will be averaged and will be considered as a non-value-added process time

- Any repair cycle time will be considered as a non-value-added process

The non-value-added weight of each process is assumed by the researcher and summarised in Table 4.4. As explained earlier, the lower the weight, the higher the importance of the process. The V.S.M. score in this state will be calculated based on the maximum cycle time.

Table 4.4 - Non-Value-Added Processes weights

Stage			Cycle Time (C/T)	Non-Value-Added Time Weight
Pipe Making			5 minutes	0
Pipe Cleaning			6.5 minutes	0
Preliminary Sonic Inspection			7.5 minutes	50%
Internal Inspection			4 minutes	30%
Outside Inspection			4 minutes	30%
X-ray inspection			5 minutes	5%
Final Finishing	Hydro		3 - 5 minutes	50%
	Endsizer		3 - 5 minutes	50%
	Beveller		3 - 5 minutes	50%
Final Visual Inspection			8.5 minutes	70%
Final Sonic Inspection			7 minutes	40%
Scale	Double Joint pipe	Both ends	15 minutes	0
		One end	10 minutes	0
	Normal Pipe	Both ends	7 minutes	0
		One end	5 minutes	0
Customer Inspection			5 minutes	0
Total Maximum Cycle time			104.5 minutes	
In case of failing inspection				
Burn Bay and Real Time Repair	Cutting		5 minutes	50%
	Welding		40 minutes	50%
	Double Joint (DJ)		15 minutes	50%
	Grinding		20 minutes	50%

The best case from these data is that the pipes will never go to the "Burn Bay and Real Time Repair". In this case, the V.S.M. score will be:

$$V.S.M.Score = 1 - \frac{\left((7.5*0.5)+\left(2*(4*0.3)\right)+(5*0.05)+(3*(5-3)*0.5)+(8.5*0.7)+(7*0.4)\right)}{104.5}$$

$$= 0.80$$

Hence, the best V.S.M. score for this state is 80%

The worst case score would depend on how many repair cycle the pipe has to go through. So, the V.S.M. score would then be calculated using the formula:

$$V.S.M.Score =$$

$$1 - \frac{\left((7.5*0.5)+\left(2*(4*0.3)\right)+(5*0.05)+(3*(5-3)*0.5)+(8.5*0.7)+(7*0.4)+\left(x*(5+40+15+20\right)*0.5)\right)}{104.5}$$

$$= 0.42$$

Where "x" is the number of times the pipe has to go through the repair cycle. If it goes through the repair cycle once, the V.S.M. score would be 0.42 or 42%.

The maximum number the pipes would go through the repair cycle is 7 (i.e. after every inspection process). This would be the worst case scenario for this V.S.M. The score for this scenario would be -1.88. Since the score came up to be negative, this means that this process of production was not profitable. In fact, it meant that the company spent close to 3 times the cycle time on 1 production cycle.

4.5 OLS

The Overall Lean Score will be calculated using the 5S score calculated in the first case (i.e. 70%), the second week Kaizen score (i.e. 90%) and the V.S.M. score with one repair cycle included (i.e. 42%). It will be assumed 25%, 25%, and 50% are the respective weight for the 5S score, Kaizen score, and V.S.M. score respectively.

Hence the Overall Lean Score would be calculated using the following formula:

$$OlS = (0.25 * 0.7) + (0.25 * 0.9) + (0.5 * 0.42) = 0.61 \text{ or } 61\%$$

Chapter 5 : DISCUSSION AND CONCLUSIONS

5.1 Results Discussion

As seen in the example and case studies, the questions and scoring procedure were intended to be easy to implement. In the case of the 5S scoring system, the questions were structured around the points being audited in the area. Even the general questions were worded in a way so that a positive answer to confirm the statement would result in a positive mark in the audit score.

As for the Kaizen score, there is no set maximum score, unlike the 5S or V.S.M. scores; which could be maximum of 100%. The pros of this are the great effect of the Kaizen projects on the OLS. This would indicate a strong improving atmosphere in the organization. However, the cons of this would result in the shift of the organization's focus from day-to-day operations to continuously implementing Kaizen projects to improve and raise the OLS. This could be avoided by setting a limit on how many Kaizen projects are being implemented in a certain time span.

While the V.S.M. case did not have the complete set of data needed to map the whole process, the scoring system was still successfully applied to indicate the quality of the operations in a certain state. It successfully reflected the results of adding an extra non-value-added process. The non-value addition was determined based on the value to the customer; the customer would not find repairing defect an added-value operation. Although this might seem a reduction of waste approach, from the customer perspective it is still a non-value added operation. The customer expectations would be that the products would have zero defects. However, since inspection is still important, using an in-line inspection would be more ideal for a more consistent and faster operations of inspection as expressed by Koren (Koren, 2010). He also proposed using automated built-in inspection for more reliability, repeatability and faster pace of production.

(Koren, 2010)   In some cases, using such an advanced system would be cost justifiable, especially in high volume production industries. However, it might be unjustifiable in custom low volume production as in the case study. Hence, such inspections procedure would hinder production and would be considered non-added value.

5.2 Conceptual Validation of the Proposed System

While through the literature review, it was established that there are not much of researches that produced numerical metrics for the different lean implementation tools, some research already used the concept demonstrated in this research to produce a lean manufacturing performance indicator; LI. Among these researchers were Oleghe and Salonitis (Oleghe & Salonitis, 2016) where they use a fuzzy relationship to define lean performance indicator. However, they used arbitrary numbers as data for lean performance criteria such as Training, cleanliness, Kaizen, etc. to produce a numerical indicator.

While this research agrees with the concept used, it works on earlier steps for obtaining a numerical "Lean Indicator", which is to define the metric for those were called in that research "Performance Criteria". In fact, it assumes that the performance criteria are associated directly with the lean implementation tools such as 5S, Kaizen and V.S.M. Thus, both concluding to integrate those values in a numerical lean measure; called "Lean Indicator" by Oleghe and Salonitis (Oleghe & Salonitis, 2016) or Overall Lean Score in this research.

5.3 Novelty of Proposed Research

The novelty of the proposed research could be summarized in the following points:

- New conceptual approach to develop a score for Lean Manufacturing Tools

- The industrial practicality of an academic approach to be implemented in daily operations

- Eliminating the personal judgment factor of the auditors through the method of calculating the score rather than assigning it by auditors.

- Ease of transition to new advanced cipher-automated manufacturing technology

5.4 Application for the Lean Manufacturing Tools Metrics

The metrics proposed in this research are of adjustable and generic structures that are thought to be uncomplicated for easy and fast applications in different industries. These metrics are different from the different Lean assessing and auditing systems researched and discussed earlier in the literature survey. These metrics usability are vast from progress tracking to auditing and insurance of lean implementation and standard compliance. It could even be used to point out different points for improvement in processes, operations or in departments of an organization as a whole.

5.5 Conclusions

With the increasing customer demands, companies are shifting to applying the Lean philosophy in their day-to-day operations in order to lower the cost of production, reduce wastes and defects, while improving the quality level. Although Lean has been around for more than multiple decades now, the philosophy's implementation has been a hit or miss in many of the industries. Many organizations had their share of trial and error to come up with their lean implementation structure and plan.

Different systems had been developed to asses and audit the lean manufacturing implementation in organizations. However, these were not really applicable to be implemented in the daily

operations of the different industries. Hence, in this research, the proposed Metric models for the 3 Lean Manufacturing tools would help in assessing and auditing lean implementation while keeping the ease to be applied in an organization daily routine of work. In the research, these metrics were implemented in hypothetical and actual examples and cases. One of those cases was the subject of an assessment of a different system. The data were used to reflect the metrics application.

The three chosen lean tools included in this research are chosen based on the researcher's industrial experience. The experience highlighted the uncertainty in the assessment of the implementation of these three lean manufacturing tools. While, as mentioned, organizations in different industries `try to assess their efforts in lean implementation, this research serves to set guidelines for consistent and reliable method for assessment, yet easy and flexible to be applied in the daily operations of different organizations and industries.

5.6 Recommendations

In this research, three Lean manufacturing tools were included and three different metrics were developed for each. A fourth was developed to combine those metrics in one (i.e. OLS). While the development was based on the binary system (i.e. 1 and 0), further development could be used to further improve the usability, efficiency, and accuracy of the metrics. Further work would also include implementing the similar development of metrics for other different lean manufacturing tools used in organizations. It would also be beneficial if these simple metrics were implemented in an independent industry and comparing the results.

Moreover, studying and exploring the factors that would have an effect on the metrics and its scoring would be required. These include determining the combination of the organization and customer perspectives in developing and their effects on the metrics, and by sequence the metrics' scores. Also, acquiring more real data and applying the metrics model on this data would further improve and expose the limitations and undetermined factors of the metrics.

Another field of expansion for this research would be building up a bank for the 5S categorized items to better define mass customized 5S checklists for different areas in organizations. Those items could be related to the seven types of wastes (i.e. Mudas) in a form of a matrix. This way a checklist would cover the five main principles of 5S, eliminating the seven types of wastes.

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APPENDIX

5S AUDIT CRITERIA

Overall Look of The Work Area (Normal / Abnormal)	Score Look		/3	
1) Are the walls partitions, railings, signage clean, painted & undamaged?		Yes ⬭	No ⬭	
2) Are the floors clean, undamaged, and safe for use & are walkways clearly marked?		Yes ⬭	No ⬭	
3) Are work surfaces & tables clean, organized & maintained?		Yes ⬭	No ⬭	
Verify That Only the Required Items are Stored in the Area	**Score Readiness**		**/3**	
4) Only the items that belong in the area are present, parts, materials, tools, containers, equipment, furniture.... & no items, that do not belong in area were found during the audit?		Yes ⬭	No ⬭	
5) Are the tools & aids required to complete work, available & organized in the work station?		Yes ⬭	No ⬭	
6) Only valid and current paperwork, work orders, job instructions, prints required are in area and present? Obsolete items found would result in a NO!		Yes ⬭	No ⬭	
Are All Items Stored in the Area, in a Designated Location & Either Labeled or Marked?	**Score Labeling/Control**		**/4**	
7) Are customer parts, work in process, components, materials stored properly & identified?		Yes ⬭	No ⬭	
8) Are the trays, totes, boxes, bins or pallets utilized to organize materials in the work station. And are they stored in designated locations?		Yes ⬭	No ⬭	
9) Is there designated locations for paperwork, work orders, prints & manuals?		Yes ⬭	No ⬭	
10) Is there designated, labeled, or clearly understood locations for all equipment tools, furniture and is everything in it's designated location?		Yes ⬭	No ⬭	
Is There Evidence That Audit Area and Items in Area, Are Maintained & Cleaning Scheduled?	**Score Sustaining**		**/2**	
11) Is there evidence of a cleaning/ maintenance schedule posted for the area and evidence it is being followed?		Yes ⬭	No ⬭	
12) Is there evidence that cleaning equipment is available to adequately maintain the work station, and if cleaning stations are present, do they have the required equipment available?		Yes ⬭	No ⬭	
Summary of Score 12/12 = 100%, 11/12 = 92%, 10/12 = 83%, 9/12=75%, 8/12=67%, 7/12 = 58%, 6/12=50%, 5/12 = 42%. 4/12 = 33%. 3/12 = 25%			**/ 100%**	

Figure A.1 - 5S assessment Sheet 1

5S AUDIT CHECKLIST GARAGE

Area:			Date:	
Area Leader Signature:			Auditor:	

Verify that only required items are stored in the area?	Score	/	↓↓Comments↓↓	Person Responsible
1) Are there location to store customer parts /materials /components?	Yes ◯ No ◯ NA ◯			
2) Are there locations to store packaging materials/pallets/containers/ temporary storage items in area.	Yes ◯ No ◯ NA ◯			
3) Are there tools blocking aisle ways & exits?	Yes ◯ No ◯ NA ◯			
4) Is there equipment blocking aisle ways and emergency exit?	Yes ◯ No ◯ NA ◯			
5) Is the furniture in area required ?	Yes ◯ No ◯ NA ◯			
6) Is the paper work/ prints/manuals required in area.	Yes ◯ No ◯ NA ◯			

Are all items stored in the area, in a designated location & either labeled or marked?	Score	/	↓↓Comments↓↓	Person Responsible
7) Are Customer parts/ Work in process /components/materials stored properly?	Yes ◯ No ◯ NA ◯			
8) Are packaging materials/ containers/ boxes/ bins/ pallets stored in and organized?	Yes ◯ No ◯ NA ◯			
9) Are all tools/tooling/ stored in an organized & safe manner?	Yes ◯ No ◯ NA ◯			
10) Is equipment stored in an organized fashion?	Yes ◯ No ◯ NA ◯			
11) Is furniture stored in organized fashion?	Yes ◯ No ◯ NA ◯			
12) Is there locations for paperwork/work orders/prints/ manuals?	Yes ◯ No ◯ NA ◯			
13) Are walkways clear and racks accessible?	Yes ◯ No ◯ NA ◯			
14) Are all locations for tubing/fasteners/filters organized and accessible?	Yes ◯ No ◯ NA ◯			

Is there evidence that audit area and items in area, are maintained & is cleaning scheduled.	Score	/	↓↓Comments↓↓	Person Responsible
15) Is there a cleaning schedule?	Yes ◯ No ◯ NA ◯			
16) Are containers, boxes, bins, clean, functional and ready to use?	Yes ◯ No ◯ NA ◯			
17) Are tools & tooling, clean, functional & ready to use?	Yes ◯ No ◯ NA ◯			
18) Are prints/work orders/labels clean, clear and functional?	Yes ◯ No ◯ NA ◯			
19) Are Work Surfaces and Tables clean, organized, maintained?	Yes ◯ No ◯ NA ◯			
20) Are the floors clean, undamaged, and safe for use?	Yes ◯ No ◯ NA ◯			
21) Are the walls, partitions, railings, clean, painted and undamaged?	Yes ◯ No ◯ NA ◯			
22) Is the cleaning equipment present, and are there cleaning stations?	Yes ◯ No ◯ NA ◯			
Summary of Score	/	=	%	

Item #	Comments & Details of Deficiencies
Kaizen Projects Ideas	
1	
2	
3	

Figure A.2 - 5S assessment Sheet 2

5S AUDIT CHECKLIST GARAGE

Area:	Components Isle			Date:		
Area Leader Signature:				**Auditor:**		

Verify that only required items are stored in the area?	Score	2/5	↓↓Comments↓↓	Person Responsible
1) Are there location to store customer parts /materials /components?	Yes ● No ○ NA ○			
2) Are there locations to store packaging materials/pallets/containers/ temporary storage items in area.	Yes ○ No ● NA ○			
3) Are there tools blocking aisle ways & exits?	Yes ○ No ● NA ○			
4) Is there equipment blocking aisle ways and emergency exit?	Yes ○ No ○ NA ●			
5) Is the furniture in area required ?	Yes ○ No ○ NA ●			
6) Is the paper work/ prints/manuals required in area.	Yes ● No ○ NA ○			

Are all items stored in the area, in a designated location & either labeled or marked?	Score	2/2	↓↓Comments↓↓	Person Responsible
7) Are Customer parts/ Work in process /components/materials stored properly?	Yes ● No ○ NA ○			
8) Are packaging materials/ containers/ boxes/ bins/ pallets stored in and organized?	Yes ● No ○ NA ○			
9) Are all tools/tooling/ stored in an organized & safe manner?	Yes ○ No ○ NA ●			
10) Is equipment stored in an organized fashion?	Yes ○ No ○ NA ●			
11) Is furniture stored in organized fashion?	Yes ○ No ○ NA ●			
12) Is there locations for paperwork/work orders/prints/ manuals?	Yes ○ No ○ NA ●			
13) Are walkways clear and racks accessible?	Yes ○ No ○ NA ●			
14) Are all locations for tubing/fasteners/filters organized and accessible?	Yes ○ No ○ NA ●			

Is there evidence that audit area and items in area, are maintained & is cleaning scheduled.	Score	3/4	↓↓Comments↓↓	Person Responsible
15) Is there a cleaning schedule?	Yes ● No ○ NA ○			
16) Are containers, boxes, bins, clean, functional and ready to use?	Yes ● No ○ NA ○			
17) Are tools & tooling, clean, functional & ready to use?	Yes ○ No ○ NA ●			
18) Are prints/work orders/labels clean, clear and functional?	Yes ○ No ○ NA ●			
19) Are Work Surfaces and Tables clean, organized, maintained?	Yes ○ No ○ NA ●			
20) Are the floors clean, undamaged, and safe for use?	Yes ○ No ○ NA ●			
21) Are the walls, partitions, railings, clean, painted and undamaged?	Yes ● No ○ NA ○			
22) Is the cleaning equipment present, and are there cleaning stations?	Yes ○ No ● NA ○			

Summary of Score	**7/11**	=		%

Item #	Comments & Details of Deficiencies

	Blue Card Ideas
1	
2	
3	

Figure A.3 - 5S assessment Sheet 1 filled for the area in Figure 3.3 on page 35

5S AUDIT CRITERIA		
Overall Look of The Work Area (Normal / Abnormal)	**Score Look**	**1 / 3**
1) Are the walls partitions, railings, signage clean, painted & undamaged?	Yes ⬭ No ⬭	
2) Are the floors clean, undamaged, and safe for use & are walkways clearly marked?	Yes ⬤ No ⬭	
3) Are work surfaces & tables clean, organized & maintained?	Yes ⬭ No ⬭	
Verify That Only the Required Items are Stored in the Area	**Score Readiness**	**2 / 3**
4) Only the items that belong in the area are present, parts, materials, tools, containers, equipment, furniture…. & no items, that do not belong in area were found during the audit?	Yes ⬤ No ⬭	
5) Are the tools & aids required to complete work, available & organized in the work station?	Yes ⬤ No ⬭	
6) Only valid and current paperwork, work orders, job instructions, prints required are in area and present? Obsolete items found would result in a NO!	Yes ⬭ No ⬭	
Are All Items Stored in the Area, in a Designated Location & Either Labeled or Marked?	**Score Labeling/Control**	**3 / 4**
7) Are customer parts, work in process, components, materials stored properly & identified?	Yes ⬤ No ⬭	
8) Are the trays, totes, boxes, bins or pallets utilized to organize materials in the work station. And are they stored in designated locations?	Yes ⬤ No ⬭	
9) Is there designated locations for paperwork, work orders, prints & manuals?	Yes ⬭ No ⬭	
10) Is there designated, labeled, or clearly understood locations for all equipment tools, furniture and is everything in it's designated location?	Yes ⬤ No ⬭	
Is There Evidence That Audit Area and Items in Area, Are Maintained & Cleaning Scheduled?	**Score Sustaining**	**2 / 2**
11) Is there evidence of a cleaning/ maintenance schedule posted for the area and evidence it is being followed?	Yes ⬤ No ⬭	
12) Is there evidence that cleaning equipment is available to adequately maintain the work station, and if cleaning stations are present, do they have the required equipment available?	Yes ⬤ No ⬭	
Summary of Score 12/12 = 100%, 11/12 = 92%, 10/12 = 83%, 9/12=75%, 8/12=67%, 7/12 = 58%, 6/12=50%, 5/12 = 42%. 4/12 = 33%. 3/12 = 25%		**/ 100%**

Figure A.4 - 5S assessment Sheet 2 filled for the area in Figure 3.3 on page 35

5S AUDIT CRITERIA			
Point		Yes (1)	No(0)
1	Are the bins stored properly on the designated shelves?	1	
2	Are the bins labeled clearly?	1	
3	Are the shelves labeled clearly?	1	
4	Are the pathways clean and clear?	1	
5	Is there area adequately lit?	1	
6	Are the bins filled with the respective parts?		0
	Is it clear that there are no parts outside their designated bins?	1	
	Is the area leader information shown and available?		0
	Is there an administration checklist available and used?		0
	Overall, is it clear that there are not any conditions that would restrain work in this area?	1	
Total		7/10	

Figure A.5 - Proposed 5S Audit Sheet filled for the area in Figure 3.3 on page 35

VITA AUCTORIS

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