UiT – The Arctic University of Norway

New Practical Exercise in Lean Six Sigma for Masters Students in UiT – The Arctic University of Norway

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PREFACE

This thesis is written as part of the Master course in Industrial Engineering at UiT-The Arctic University of Norway, Narvik. The duration of the project is approximately eight months. My keen interest on Lean Six Sigma has allow me to choose the thesis topic on ʺNew Practical Exercise in Lean Six Sigma for Masters Students in UiT – The Arctic University". This thesis work can be divided to three section:

Part I (A)	Literature Review on Lean Six Sigma
Part I (B)	Review on Some Existing Practical Training exercise on Lean Six Sigma
Part II	New Lean Six Sigma Training Exercise
APPENDIX	Supporting Materials

Hope you enjoy reading.

ACKNOWLEDGEMENTS

Foremost, I'd like to express my earnest gratitude to my supervisor Espen Henrik Johannessen for his continuous support, guidance and motivation throughout the time period without which this thesis work would not have been achievable.

Secondly, I'd like to our Department of Industrial Engineering for providing me with a financial support and allowing me to use the lab equipment, tools and resources that let me to complete the design and construction of the training kit. In connection, I'm also very grateful to Dmitri Plotnikov and Lazar Sibul for their profound assistance in the workshop lab and helping me for the 3 D printing of the parts which, without doubt, was very crucial to my thesis work. My sincere thanks to Tore H. Johansen for providing me the measuring equipment from the chemistry lab.

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At last, special thanks to all our teacher and staff who have shown so much dedication during the two year, appearing in every status meeting and giving their valuable comments so that we do not lack on anything. Also, thanks to my classmates who have been a helping hand in many ways.

Sujan Maharjan

ABSTRACT

Lean Six Sigma has proven to be a valuable tool for improving flow and quality in any business activities. It is being implemented by almost all business forms globally. It is now an important curriculum for engineering and management students. UiT- The Arctic University of Norway, Narvik is one of the fine institutions which provide training course on Lean Six Sigma for Master's students studying Industrial Engineering. For the past years, UiT-Narvik has been adopting this training exercise from external sources. Now, UiT aims to develop its own training exercise. This project is all about proposing a new training exercise for UiT.

The new training exercise is a project based problem-solving exercise where the students (group of ca. 6) will run a simulation of a mini- beverage factory for at least two times, first run is for documenting current situation of the factory and next run is for improved process. The training activity follows DMAIC (Define Measure Analyze Improve Control) methodology and has been designed such that some of its contents are linked with other Industrial Engineering courses.

The entire training kit has been built inside the UiT workshop lab. To facilitate the exercise, a separate student manual and an excel model have been constructed. As for now the exercise has been design only for engineering students but it has a full potential to be used for people with different professions.

Keywords – Lean; Six Sigma; Lean Six Sigma; DMAIC (Define Measure Analyze Improve Control); SIPOC (Suppliers Input Process Output Customer)

LIST OF ABBREVIATIONS

Table of Contents

LIST OF FIGURES

LIST OF TABLES

PART I (A): LITERATURE REVIEW

"Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it".

-H. James Harrington

1 INTRODUCTION

The application of new technologies has benefited all sort of business firms significantly. The costumers are also enjoying high level of services and products. If they want something, they can easily get them from the market. There are so many options available which facilitate the costumers not just to rely solely on their old seller or single seller but many. But from the seller point of view, this has been a major concern. In order to keep the hold of their client and to flourish their business activities in the market, they have to either improve or maintain their service standard. Globalization of market have made even difficult to the companies who cannot maintain their quality level and cost, directly reflecting only champions can rule the market.

Every business firms have some flaws and there is always room for improvements. Sometimes the problems are direct which can be easily identified and controlled. Most of the time, even though everything seems to be working well, the organization keep losing their service quality and customers or failed to keep their clients satisfied. Therefore, every business must discover the problems and issues which is holding them from being successful. Lean Six Sigma (LSS) is one the most powerful methodology, by implementing it, one can solve all the problems mentioned above.

LSS is a data-driven management concept which is used to improve business processes based on the combined principle of lean and six sigma principles. It is directly involved in consistently increase in the speed of the processes, improve the quality of the products/services and decreasing the cost of the products as well. [1, p. 39]. This approach is a slow process but is a game changer which eventually leads to reduce cost of product, increase its efficiency and effectiveness thus increasing profit as well as customer satisfaction. It uplifts the team spirit and encourages in team work.

It cut out fat, not muscle i.e. reduce costs without destroying the ability to meet customer needs and demands [2]

Many organization and institutions have perceived the importance of LSS strategy. Thus, started to train their employee about it. There are many practical exercises on LSS, on completion of it, one will be able to develop techniques in making decisions, problem solving and so on.

UiT-The Arctic University of Norway is one of the institutions which provide training courses on Lean Six Sigma (LSS) to the students studying Master's degree in Industrial Engineering under the course STE6207: *Quality Management & Improvement* with an objective to provide some practical experience on using Lean Six Sigma methodologies and its tools. Currently the students are using Statapult for carrying out their experiment. Statapult is a registered trademark of Air Academy Associates [3] which was released by Lockheed Martin for educational use at UiT-Narvik.

UiT aims to develop their own training exercise in the field of LSS and built an exercise which can also facilitate the Industrial Department by linking the task to some of its Industrial Engineering courses. The training exercise is target to have a competence of LSS Green Belt Level. However, to be eligible to hold a green belt certificate, the student must pass the course STE6207: *Quality Management & Improvement* or have a proof of similar level of knowledge.

2 BACKGROUND

Lean and Six sigma both have separate initiatives however they both complement each other and furnish dovetailing in cost reduction and continuous quality improvement activities. [4]

2.1 Lean Concept

The concept of lean date back during 1890s when an American mechanical engineer Frederick Taylor introduced science in management through time study and standardized work. Henry Ford, an American industrialist during 1910s, developed a new strategy in manufacturing of automobiles through flow production. The result was much faster production time and higher production output. In 1960s, Japanese industrialist, Taichii Ohno started to incorporate flow production into a new approach known as Toyota Production System which in today commonly known as lean manufacturing [5]. His idea was to eliminate waste in order to gain productivity and increase the speed and flow in working process. He put forward some practical methods to implement his two concepts:

- Just in time
  It is a philosophy which deal about producing right parts at the right time and in the right amount which eventually eliminates all unnecessary wastes thus leading to high productivity
- Jidoka
  It is also termed as autonomation which refer to an intelligent operation of the automatic machines under human supervision i.e. if any abnormalities occur in the process, the machine stops automatically, the whole production will stop until the problem get solved.

The implementation of these concepts were proved to be high successful. Since then, the concept of lean and lean thinking continues to spread throughout the world. Lean principles are being adapted beyond manufacturing to logistics, healthcare, maintenance, and even government. [6]

2.2 Six Sigma Concept

The first concept of Six Sigma traced back in 1924s when Walter Shewhart introduced control charts and statistical quality control for the processes requiring correction. However, in 1986, Bill Smith, an engineer at Motorola, coined the term "Six Sigma" for quality improvement process. Later in 1989, Motorola established the Six Sigma Research Institute which was soon followed by

Jack Welch of General Electric Company and Larry Bossidy of Allied Signal (now Honeywell). Motorola through the application of this new methodology and making some needed cultural changes granted themselves with the amount of $ 16 Billion in savings. Since then, Six Sigma has evolved all over the world and have been adopted as a means of doing business. [7]

2.3 Lean Six Sigma Concept

The integrated use of Lean and Six Sigma was first published in a book <<Leaning into Six Sigma>> where LSS was implemented using “Five S” programs; Sifting, Sorting, Sweeping & Washing, Standardizing and Self-Discipline. [8]. When it comes to LSS, Michael George is the upmost mention who gave an emphatic overview on why combining lean and Six Sigma are essential. Since Lean cannot maintain process under statistical control and Six Sigma alone cannot improve speed of process and reduce cost, thus blending of LSS together is very important [9]. Now this methodology has been adopted by thousands of companies for improving their product and quality control.

3 LEAN

Lean is a relentless pursuit of the perfect process through elimination of all forms of non-value-added work (which is also known as waste) to increase the speed and flow in any business processes and transactions. National Institute of Science and Technology [NIST] defined Lean as a systematic approach to identify and eliminate waste through continuous improvement in flow of the process. Lean thinking is a way to do more with less effort. There are three type of processes; value added, non-value added (waste) and business value add (waste but absolutely necessary). Value added is a process of changing some sort of form, fit or function to your product. These value-added are the only things that the customers are willing to pay.

Mostly everyone prefers to spend their time on value added time but if we look through value stream map, we would notice that a significant amount of time have been spent on non-value-added process. Typically, people don’t realize these wastes rather they thrive to improve value added time. Whilst Lean focus on those waste first before moving forward to improve the value-added time.

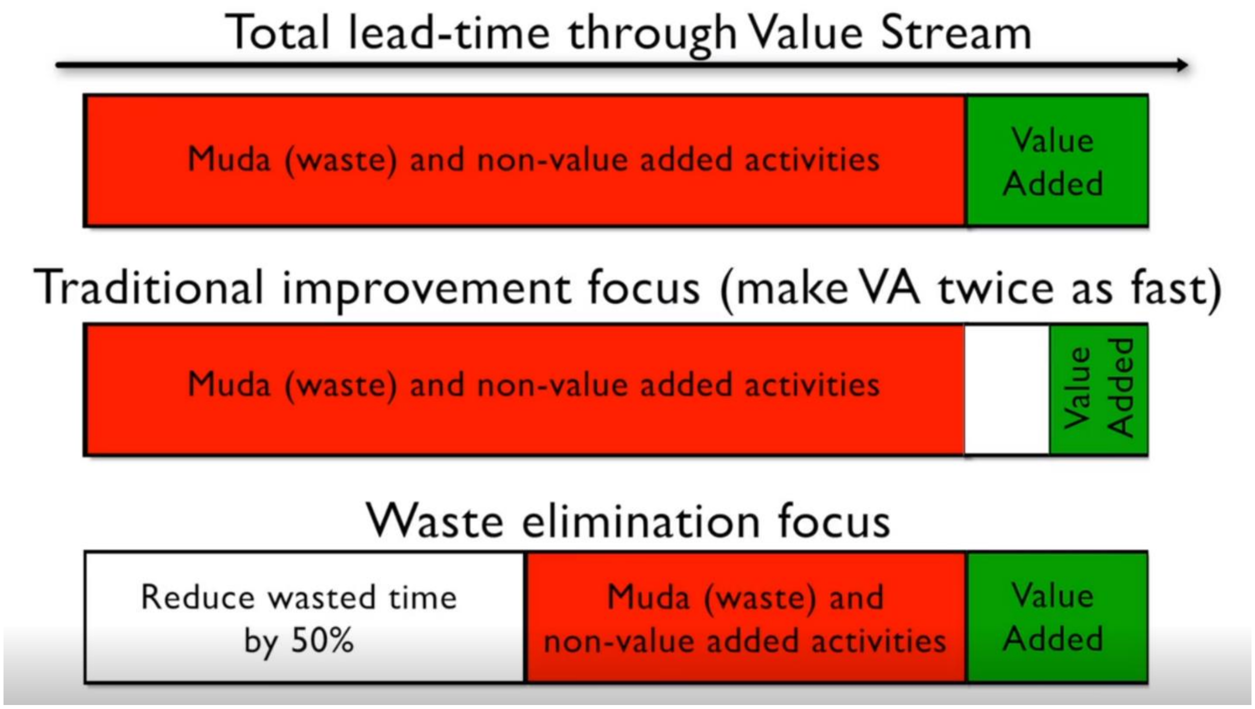

Figure 1: Value Added and Non-Value-Added Activities [10]

Lean identifies three different kind of wastes (3M);

- Muda (wastefulness, uselessness, futility)
- Mura (unevenness, irregularity, non-uniformity)
- Muri (overburden, excessiveness, unreasonableness)

Figure 2: Three Different Types of Waste [11]

3.1 Seven Types of Waste (7 Mudas)

There are commonly seven forms of waste (non-value added) defined by Lean principles which are listed below:

Table 1: Seven Types of Waste (7 Mudas) [12]

S.N.	Seven forms of waste (TimWood)	Description
1.	**T**ransport	Unwanted and undesirable movement of people or product
2.	**I**nventory	Raw materials, work in process and products being stocked
3.	**M**otion	Unnecessary movement of people and product within a process
4.	**W**aiting	People or parts waiting for work cycle to be completed
5.	**O**ver-processing	Processing time beyond the specification limit
6.	**O**ver-production	Excess production than required
7.	**D**efects	Process and products that doesn't meet the standards

3.2 Five Lean Principles

There are five core lean principles: value, value stream, flow, pull and perfection [13].

1. Specify value from customer point of view.
2. Map the value stream for the product.
3. Create product flow in the value stream without interruption.
4. Create pull system approach in the value stream.
5. Strive for perfection through continuous improvement.

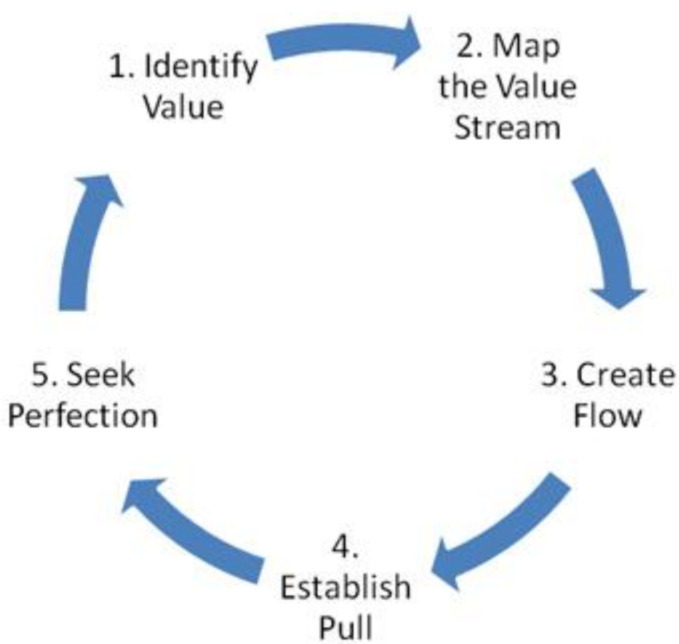

Figure 3: Five Lean Principles [13]

3.3 Lean Tools

There are a lot of lean tools to explore in lean manufacturing. Here is some list of the lean tools along with a brief description of each.

3.3.1 Value Stream Mapping

Value stream Mapping is a representation of the flow of materials and information from supplier to the customer throughout the organization. It enables you to identify each necessary (value added) and unnecessary steps (Non value added) of the process allowing you to directly locate the wastes/delays that are occurring in the process.

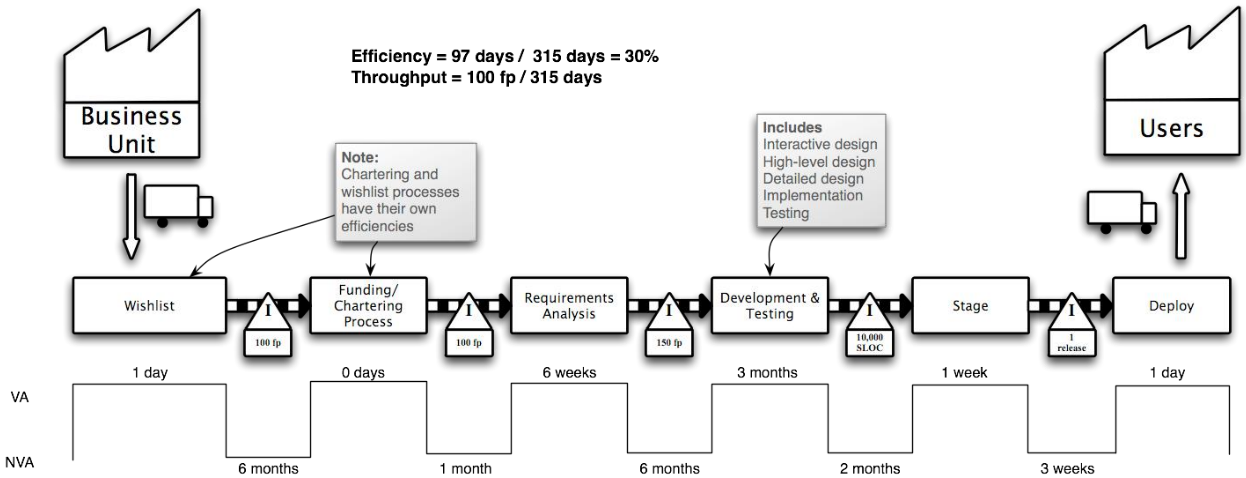

Figure 4: A Typical Example of Value Stream Mapping [14]

3.3.2 Takt Time

Takt time is the rate at which a product is produced in order to meet the customer demand. It is usually the between the start of production of a first unit of product until the start of the second unit. Mathematically, takt time is:

$$Takt\ Time = \frac{Available\ time\ for\ production}{Required\ units\ of\ production}$$

3.3.3 Just-in-Time (JIT)

JIT is a management strategy that are based on customer demand. It is the system to produce and deliver the product at right quantity and at the right time. The raw materials are ordered from the suppliers only according to production schedules thus reducing waste and inventory cost.

Figure 5: Just in Time [15]

3.3.4 Heijunka (Production Leveling)

Heijunka is form of production scheduling that intentionally produces the sequence of different products within the same process. The products are manufactured in small batches at constant rate such that the further processing of the goods may also be carried out at constant and predictable rate. There is an inventory of product proportional to the variability in demand. This concept has a predictable, flexible and stable working schedule which meets the customer demand over a long period of time regardless of Bullwhip demand from the customers.

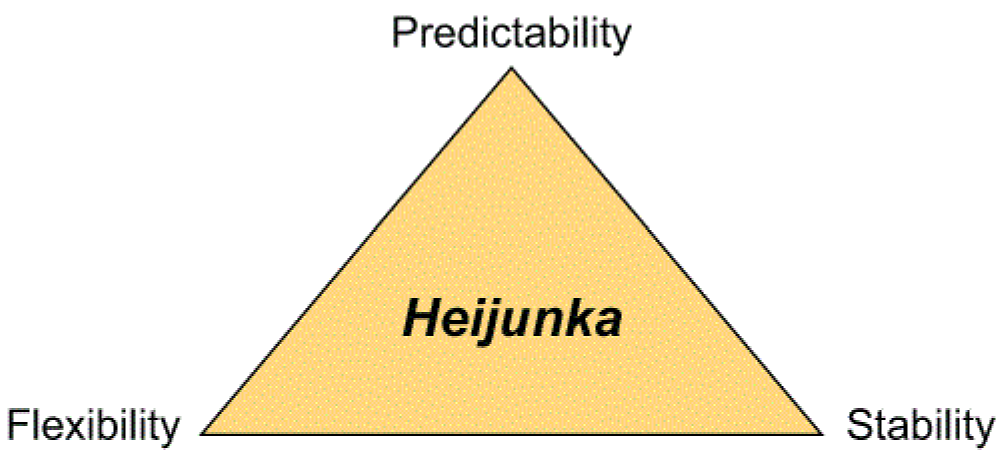

Figure 6: Heijunka [16]

3.3.5 Kaizen (continuous Improving)

Kaizen is continuous improving process involving everyone – from manager to employees. It believes in strong team work of collective talents such that a regular, incremental improvements in the process can be achieved.

Figure 7: Kaizen Principles [17]

3.3.6 Mistake Proofing (Poka Yoke)

Mistake Proofing is the activity of awareness, detection and prevention of mistake into the production flow with the goal of achieving zero defects. Since the detection of error though inspection is not always reliable approach, it is wise to design or develop a process in advance such that it is free of error.

3.3.7 5 S

The term 5S stands for Sort, Set, Shine, Standardize and Sustain. It is a system to organize the work flow in a systematic way to eliminate all sorts of unnecessary wastes. It improves the quality of the process through regular clean up.

Figure 8: 5S [18]

3.3.8 Plan, Do, Check and Act (PDCA)

PDCA is a scientific approach in making continuous improvement in any business process. It is loop which starts with the plan of the process (P) followed by implementation of the plan (Do) and then verification of the results achieved (Check) after that reviewing and making an adjustment (Act). It is a never-ending improvement process which lead towards perfection.

Figure 9: PDCA [19]

3.3.9 Single-digit Minute Exchange of Dies (SMED)

SMED is a way to design a setup time and changeover time in any process for a machine in less than 10 minutes. It removes unnecessary operation by creating standardized work. It allows manufacturing of variety of product within a short time and reduces inventory.

3.3.10 Kanban (Pull System)

Kanban Pull System is a visual communication method of controlling the flow of work by automatic replenishment of raw materials or products only when the demands are made. The Kanban signal cards are used to indicate the necessities of replenishment.

3.3.11 Standardized Work

Standardized Work is one of the key components of Just-in-Time production system. With the application of standardized work, unnecessary adjustments, searching for tools and parts, excess movement, mishandling of parts and awkward ergonomics could be eliminated [20]. Every work should be standardized in order to achieve a balancing work flow and adequate takt time. It is a never-ending continuous improving process. As soon as the standard of the work are improved, a new-standards are set to facilitate further improvements [21].

4 SIX SIGMA (6σ)

Sigma (σ) is the 18th letter of the Greek alphabet. In statistic, σ is the representation of standard deviation for measuring variation of process performance. 6σ concept can be explained using Normal Distribution Curve also known as Gaussian distribution. One of the characteristics of this distribution is 68.2%, 95.4% and 99.7% of its area fall within the area of ±1σ, ±2σ and ±3σ respectively. A peak curved bell shape signifies lower variation in process whereas flatter curve indicates vise-versa. [22]

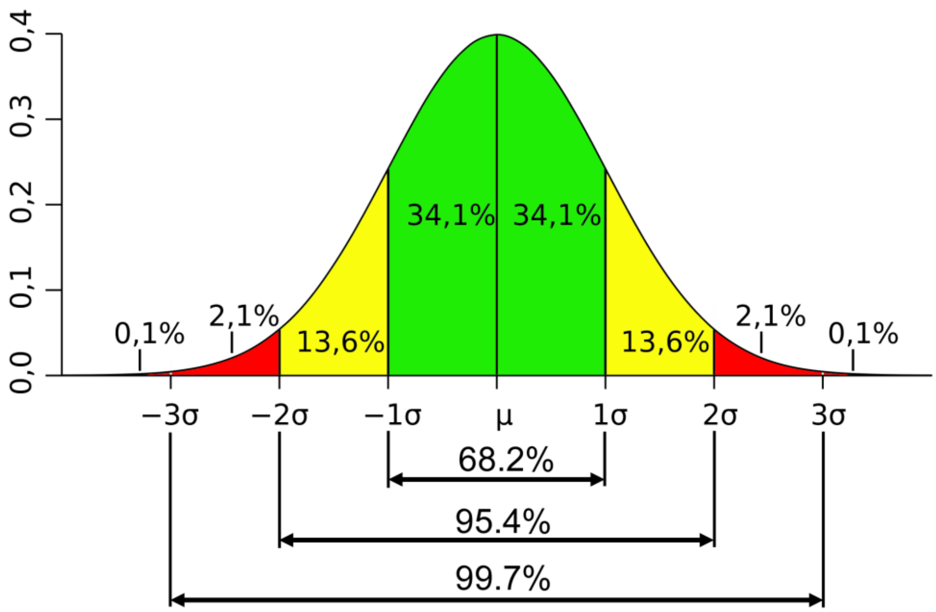

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Figure 10: Normal Distribution and Standard Deviations [23]

Six Sigma is a statistical based methodology that attempts to understand and reduce variation and eliminate defects in any process. [4]. It measures how far a given product or process can deviate from perfection. The sigma level can be measured in standard deviation from the process which corresponds to a related defects per million opportunities.

The core idea behind Six Sigma is to measure the total number of defects that exist in the process and try to eliminate them statistically in order to achieve zero defects. According to Bill Smith these defects are measured per million opportunities and in 1986, he deduces 3.4 defects per million opportunities, which correspond to Six Sigma, is the optimum level to balance quality and control.

In terms of project management statistics, 6σ corresponds to 2 defects per billion opportunities whereas 3.4 defects per million opportunities (DPMO) is equivalent of 4.5σ. It is seen that there is 1.5σ difference in σ level defined by Bill Smith of Motorola. According to him, this 1.5σ is an adjustment made considering long-term dynamic mean variation. The normal σ value only consider short-team values that contain only common cause of variation. However, it fails to consider long term common cause of variation. That is why there is 1.5σ shift in the σ level [24].

Table 2: Sigma level with/with 1.5 shift [25]

Sigma level without 1.5 σ shift	DPMO without 1.5 σ shift	Sigma level with 1.5 σ shift	DPMO with 1.5 σ shift
1.0	317,311	1.0	697,672
1.5	133,614	1.5	501,350
2.0	45,500	2.0	308,770
2.5	12,419	2.5	158,687
3.0	2,700	3.0	66,811
3.5	465.35	3.5	22,750
4.0	63.37	4.0	6,210
4.5	6.80	4.5	1,350
5.0	0.574	5.0	232.67
5.5	0.038	5.5	31.69
6.0	**0.002**	**6.0**	**3.40**

Six sigma level corresponds to 99.9997 % defect free but sometimes it is not enough. According to Jeff Dewar, OCI International, Red Bluff, CA, in USA if things were done 99.9% right would result in the followings:

- 20000 wrong drug prescriptions every year
- 1 hour of unsafe drinking in every month
- 2100 incorrect surgical operation each month
- 2 unsafe plane landings per day at O'Hare Airport
- 16000 pieces of mishandled mail by the Postal Service every hour

4.1 Six Sigma Tools

Here are some lists of the Six Sigma tools which are very important in analyzing and improving processes and reducing the defects.

4.1.1 M's of Variation

There are six elements that contribute to variation in any process. The variation caused by these elements are predictable but unavoidable. It can be controlled and improved through the change in the process.

- Man (e.g. error in measuring)
- Machine (e.g. Use of incorrect tool)
- Method (e.g. Inappropriate method)
- Material (e.g. Physical properties of material)
- Mother Nature (e.g. Temperature, humidity affecting quality)
- Measurement (egg, different measuring techniques)

4.1.2 Cause & Effect Diagram

Cause & Effect Diagram is also known as Fish Bone Diagram as it resembles a sketch of a skeleton of a fish. It is a tool where all the potential causes of the problem are identified and listed in a fishbone chart. The head of the fish defines the main problem statement, the big bones are the possible source of the cause whereas the small bones are the most specific types of causes which contribute to the larger bones [1, p. 68]. This diagram doesn't answer which one is the root cause of the problem but shows all the possible way that can lead to the problem. All these problems are further investigated through brainstorming or some other Six Sigma tools.

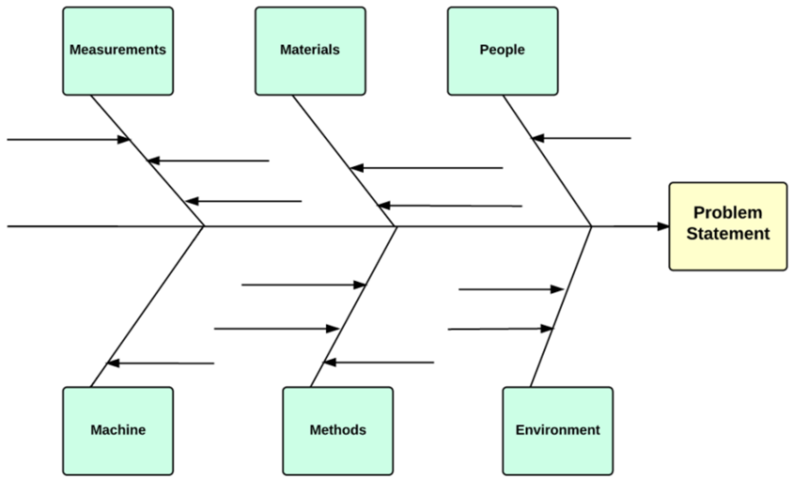


Figure 11: Example of a Fish Bone Diagram [26]

4.1.3 5 Whys?

This is one of the simplest Six Sigma tool which is can be performed easily yet delivers very efficient and convenient results. 5 Whys is repeatedly asking "why" for a problem source in order to reach into the root cause of the problem.

4.1.4 Zero Defect

According to Six Sigma Standard, the zero defect is achieved when there is 3.4 DPMO. Practical it is quite impossible to achieve. Therefore, Zero Defect is a quest for perfection by improving the quality of a product or process to the maximum extent.

4.1.5 Histogram

Histogram is a visual representation of collected data which will demonstrate on how those data are behaving and visualize the variation. It has a wide application but in terms of six sigma, it is usually used to investigate the normal distribution of the data, usually it is a bell shaped [Figure 12] (symmetrical bell shaped to achieve 6σ level [Figure 10]). If there is significant amount of variation, it has a spiked shape. If a histogram has a even shape, it is more likely that the data are collected in a wrong manner or something is wrong.

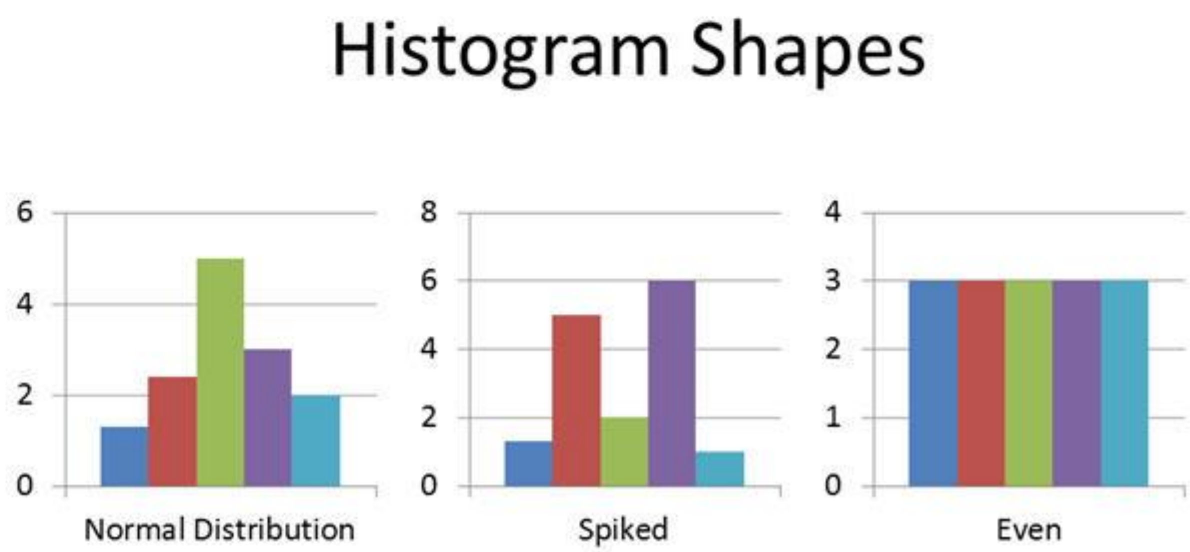


Figure 12: Different Shapes of Histogram [27]

4.1.6 Failure Mode Effects Analysis (FMEA)

FMEA is a tool to quantify and prioritize the potential failure of the process and their impact on the process or output. It prioritizes the failure mode of a process by calculating a Risk Priority Number (RPN) [28].

$$RPN = Severity\ (S) * Occurence(O) * Detect\ ability(D)$$

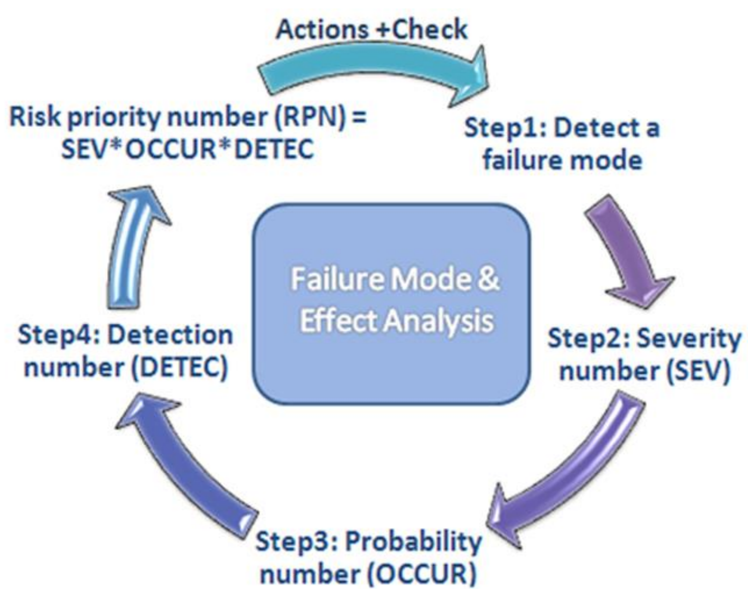


Figure 13: Failure Mode Effects Analysis [29]

4.1.7 Pareto Diagram

It is a graphical representation of a Pareto Principle which states 20 % of inputs are responsible for production 80 % of output. The diagram consists of vertical bar graph and a line graph. In general, the pattern of the graph is usually same. The use of Pareto Chart will narrow the focus on only 20 % of the input which are drastically influencing the output. In the Figure 14, the red and yellow bar are collectively influencing 80 % of output results.

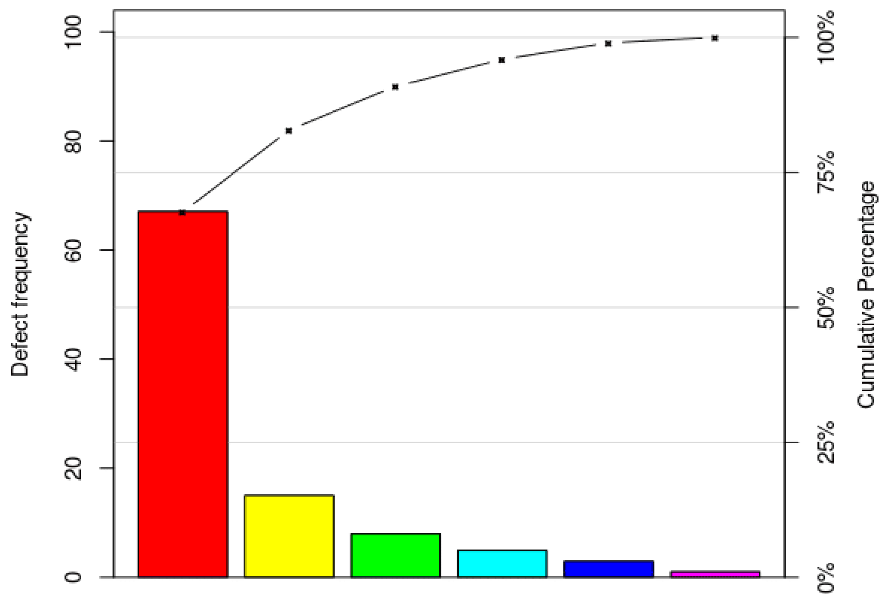


Figure 14: Pareto Chart [30]

4.1.8 Correlation Chart

Correlation Chart is a simple tool that shows the relation between two indicators. It is often obtained from scatter plot. A normal slope line is drawn on the plot to determine the correlation of the indicators. If there is no correlation, a linear line cannot be drawn. The Figure 15 below shows the positive correlation between distance covered and time taken. This is a simple example that shows if more distance is covered, more time is needed. In order to alter this relation, one should take some promising decisions.

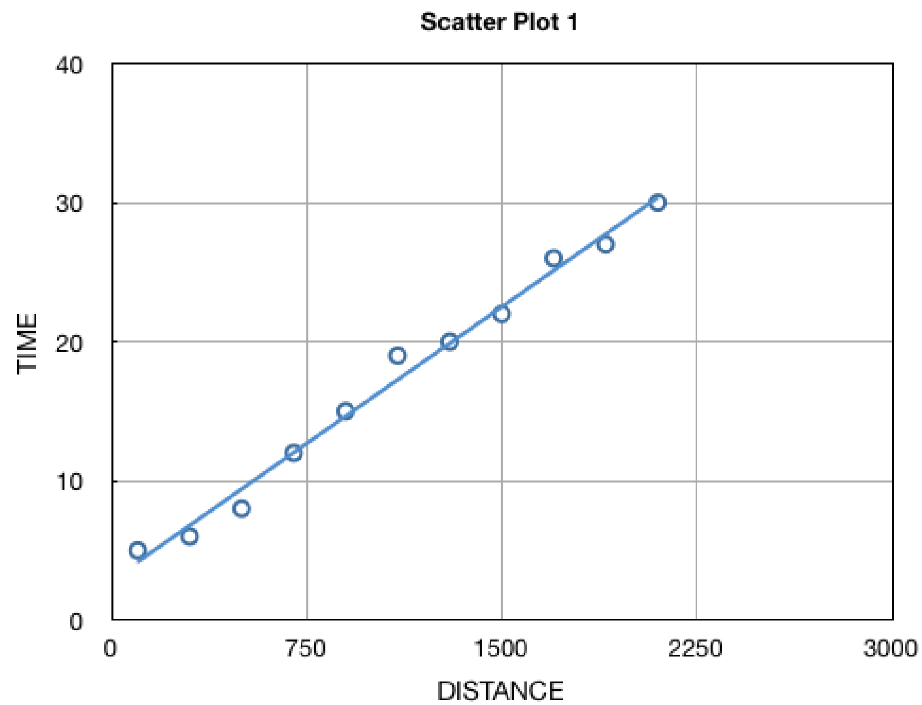


Figure 15: Positive Correlation Chart [31]

4.1.9 Control Chart

Control Chart is a statistical tool used to monitor and improve quality. Its main components are center line (mean line), upper control limit and lower control limit line. It is the time-ordered plot of the collected data which shows the process which is being monitored is whether under control or not. Usually, the Upper control limit is the sum of average value and three times of its Standard variation and Lower control limit is the difference of average and three times of Standard variation.

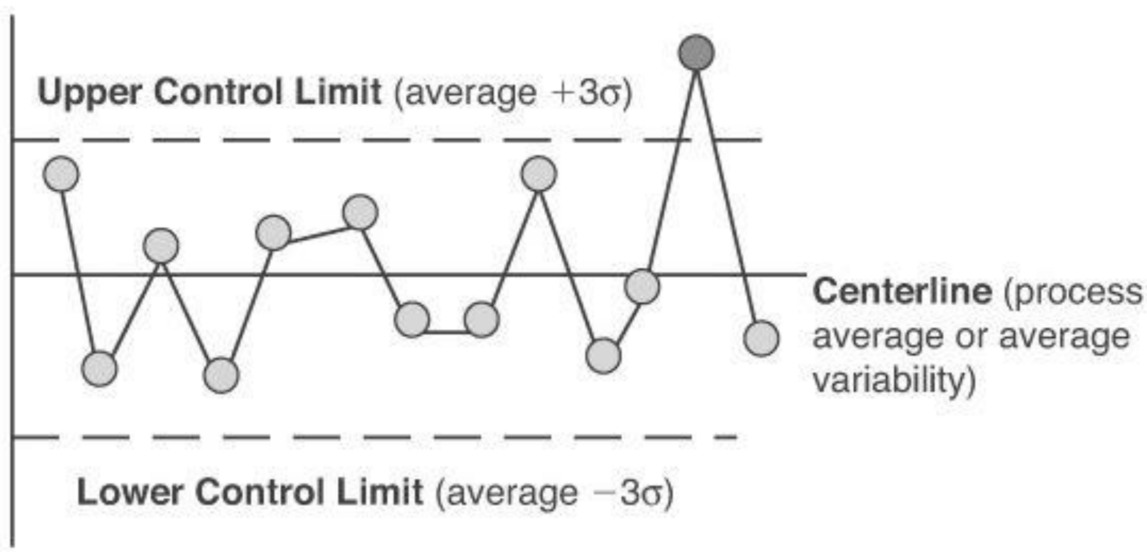


Figure 16: Control Chart [32]

The process can be termed as ‘‘in control’’ process if the variation exhibit in a random pattern and falls under the control limits. These variations also called as common variation are normal and predictable. It has usually a Normal distribution curve (bell-shaped curved) as shown in Figure 10. Anything that occur outside of the control limit are the special occurrence which need prompt action in order to bring the process back to control.

4.1.10 Process Capability and performance

The process capability and performance can be statically measured using the following four indexes.

Process Index	Formulae
Process Capability Index (C_p)	$C_p = \frac{USL - LSL}{6\sigma}$
Process Centered Capability Index (C_{pk})	$C_{pk} = min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$
Process Performance Index (P_p)	$P_p = \frac{USL - LSL}{6s}$
Process Centered Performance Index (P_{pk})	$P_{pk} = min\left(\frac{USL - \mu}{3s}, \frac{\mu - LSL}{3s}\right)$

Process Capability Index (C_p) is the measure of the process capability to determine whether the process is capable to create products that meet customer specification whereas Process Centered Capability Index (C_{pk}) measure how far the centered of the process is skewed from the targeted centered value [33].

Relation between C_p and C_{pk}:

- If both C_p and C_{pk} are high, variations are small and process is centered
- If both C_p is high and C_{pk} is low, variations are small and process is not centered
- If both C_p and C_{pk} are low, variations are high and process is not centered

Capability Index and Performance Index differ each other on how the standard deviation is determined. The formal uses the true standard deviation value whereas the later uses the sample standard deviation [34].

5 LEAN SIX SIGMA

The term LSS came into existence due to the fact that Lean cannot bring process under statistical control and Six Sigma cannot dramatically improve process speed and reduce cost. Therefore, it is a quality improvement process along with enhancing internal business processes and activities in order to improve customer satisfaction. LSS uses all the different lean and Six Sigma tools by using collective efforts from all the employees to achieve the targeted goals of the organization.

There are four key elements to LSS: Speed, Quality, Variation & Defects and Process Flow (Figure 17). All these key elements should work together to identify a solution to a problem. For example: The only way to make any customers happy is by delivering products or services of high quality within deadline. This can only be achieved if the flow of the business process is working smoothly. Smooth process flow reflects that the products and services are within the specification limits i.e. without defects. All of these things are known only if data and facts are collected and inspected. These jobs are done by the workers and these workers are same people who produces those products. When they work as a team, they can produce flawless products which will later delight the customers.

The same approach can be implemented if the company is losing its customers. There could be many factors but one of them is due to lack of quality in their services. It happened because of slow or uneven process. If the company wants to solve this issue, the whole team should collectively work to understand the process. Through brainstorming and collaborative decision making, they can come with a solution to solve the issue.

This is a LSS technique which will increase the speed of the process, improve the quality of the products and thus, reduce the cost. There is always a misconception that if the process is slow, there is less mistake. But in reality, the process being slow is the outcome of the mistakes made during the flow by human or machines. This is costly as non-value waste are being added into it.

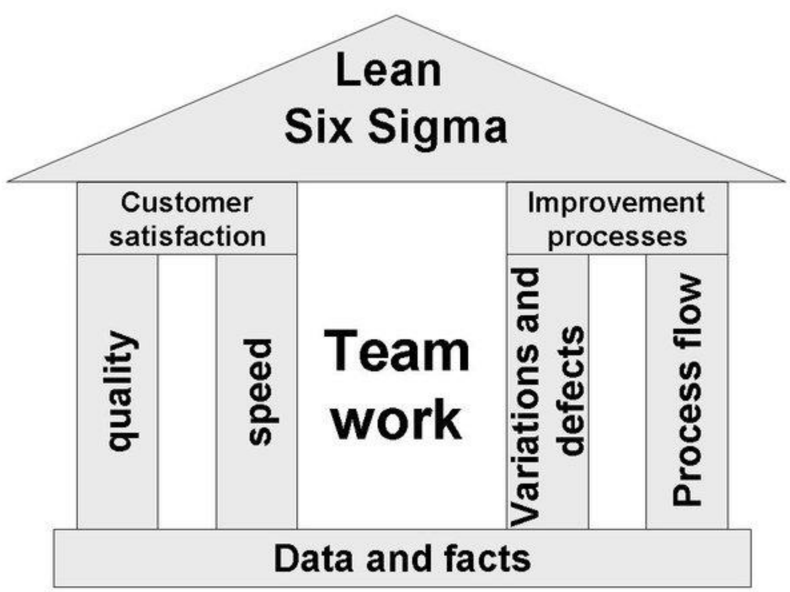


Figure 17: The Keys to Lean Six Sigma [1]

Typically, when it comes to Quality, Speed and Expense, the customers always have to make hard choice or compromise on one thing i.e. if a customer wants high quality and speed, it will be costly likewise if they want cheap product, it could be delivered late or of less quality and so forth. However, with the use of methodology and implementing problem-solving tools of LSS, the customers no longer need to make that choice, they can have it all. Implementation of LSS is win-win situation for everyone [35].

To summarized up, the benefits obtained by implementing LSS in your business are as follows:

- Faster process
- High quality of product and services
- Delighted customers
- Increase in sales and low cost
- Decisions are made based on data collected
- Team work and improved employee morale and skills

5.1 Laws of Lean Six Sigma

The following are the laws of six sigma which lay down the foundation of effective improvements of processes by improving quality and cost and customer satisfactions:

Table 3: Laws of Lean Six Sigma

S.N.	Laws	Descriptions
1.	The Law of The Market	Also known as Zeroth Law is fundamental law which is absolutely indispensable. It focusses on Customer Critical to Quality followed by Return on Investment Capital (ROIC) and Net Present Value (NPV).
2.	The Law of Flexibility	It states the speed of any process is directly corresponding the flexibility of the process.
3.	The Law of Focus	It is related to Pareto Principle which states that eighty percentages of delay in any process is caused by twenty percentage of the activities. This principle prioritizes the where to focus first.
4.	The Law of Velocity (Little's Law)	It sates the average speed of flow through any process is inversely proportional to e work-in-progress (WIP) and the average variation in supply and demand.
5.	The Law of Complexity and Cost	It states that the complexity in the process adds more non-value, cost and WIP and vice versa.

5.2 Key Players

For implementing Lean Six Sigma in any business, all individuals across the company should directly or indirectly take part in it. Everyone in the business are involved and are being assigned with designated responsibilities [36]. The Table 4 below shows the list of some key players along with their roles:

Table 4: Key Players in Lean Six Sigma

S.N.	Players	Description
1.	Sponsor	➢ Provides financial support to pursue LSS
2.	Champion	➢ Responsible for managing and directing LSS efforts
3.	Master or Black Belt	➢ Leads the project ➢ Deliver solution on business issue
4.	Process Owner	➢ Control the process ➢ Responsible for making changes in the process
5.	Green, Yellow, White Belts and Project Team	➢ Assist Black Belts ➢ Identify and Collects all data and facts ➢ Follows LSS practices to find solutions

5.3 Lean Six Sigma Belt

Lean Six Sigma can be implemented successfully in any business only if all of the team members are aware of their responsibilities and fully devoted to the team project. The job and responsivities are not same for all team members. Accordance of the competence level of LSS, various colored belts are rewarded. These belts determine an expertise level of the holder on Lean Six Sigma.

Figure 18: Lean Six Sigma Belts [37]

5.3.1 While Belt

It is the basic introductory level where one gets familiar with the term LSS and its concepts [38].

5.3.2 Yellow Belt

It is for those who are to serve the LSS project team, as being a member of the same team. This level allows one to learn on how LSS works.

5.3.3 Green Belt

This level is achieved through intermediate training where the holders have deep understanding of LSS tools and techniques. It is the level where one can solely lead comprehensive LSS project but are often guided by one holding Black Belts. They work on part time basis.

5.3.4 Black Belt

This level is achieved through most vigorous training. Black Belts work on full time basis and can lead the most complex LSS projects and possess the coaching and leadership skills. They are the expert and train for the Green Belts certification.

5.3.5 Master Black Belt

Master Black Belts is the highest ranking with advance insights of LSS philosophy, methodologies, tool and techniques. They have extensive experience in the field and have exceptional LSS leadership and implementation skills.

5.4 When to apply Lean Six Sigma

Lean Six Sigma is a problem-solving tool however there is not any perfect timing or situation for it to be applied on business. It can be applied before and after the start of the business. But the important thing is, it should be put into practice continuously ever since it has been started.

- When there is a problem and the root cause is not known
- When the company wants to achieve the SMART (Specific Measurable Actionable Realistic Timely) goal
- Despite of numbers of attempts to solve the problem, the problem still exits
- When the company undergo possible threat on loss of the market
- When the company wants to peruse its sustainable quality culture

5.5 Problem Solving Tools

The most common Lean Six Sigma methodologies which are used in practice are DMADV and DMAIC. DMADV stands for Define, Measure, Analyze, Design and Verify. It is mostly used in design phase i.e. before launching a new product or a process where as DMAIC focuses on improving the existing process and product quality. Since this report is not designing any process or product, DMADV will not be discussed any further.

5.5.1 DMAIC Cycle

DMAIC Cycle is a well know 5 step methodology which is one of the most effective problem-solving method which uses LSS principles. DMAIC stands for Define, Measure, Analyze, Improve and Control. It has 5 consecutive stages starting from Define phase to Control phase. DMAIC can be defined as a structured (performing specific activities in specific order), data-based (collection data on every step) problem-solving (finding of root cause of problem and provide solutions) process [1].

DMAIC is a slow process, could take some time (~ 3-9 months [39]) to deliver the result but it is worthwhile method that will guarantee the expected outcome and sustainability of the business.

5.5.1.1 Define

The first stage of the DMAIC cycle is “Define” which elucidate what is the project and what are its scope. There is a pre-defined SMART goal (Specific Measurable Attainable Realistic Timely) and assigned responsibilities for the team members. There is also a shared understanding of the business problems and priorities for the project [1]. The define phase starts by creating a Project Charter which documents all the planning and targets of the projects. The sample of a Project Charter is shown in the Figure 19 below:

<table>
<tr><th colspan="6">Project Name:</th></tr>
<tr><td colspan="4">Business Case & Problem Statement</td><td colspan="2">Executive Sponsor

Project Champion</td></tr>
<tr><td colspan="4">Objective Statement & Scope
Objective:

In Scope:
Out of Scope:</td><td colspan="2" rowspan="2">Team Members</td></tr>
<tr><td colspan="3">Black Belt:

Green Belt:

Financial Analyst:</td><td>Investment</td></tr>
<tr><th>DMAIC</th><th>Plan Start – Plan End</th><th colspan="2">Operational Metric</th><th>Baseline</th><th>Target</th></tr>
<tr><td rowspan="4">Define

Measure

Analyze

Improve

Control</td><td rowspan="4"></td><td colspan="2">▪ <Metrics that will impact line operations, corporate measurements, profit & loss, etc.>
▪ <Indicate gross order of magnitude – if actual estimates are not available – describe value></td><td></td><td></td></tr>
<tr><td colspan="4">Defect Definition:</td></tr>
<tr><th colspan="3">Expected Benefits</th><th>Est. Savings (US$)</th></tr>
<tr><td colspan="3">Hard Benefits:
Soft Benefits:
Strategic/Other Qualitative Benefits:</td><td></td></tr>
</table>

16

Figure 19: A Project Charter Template [40]

Some of the define tools are SIPOC (Suppliers, Input, Process, Output, and Customers) Diagram and Value Stream Map [3.3.1]. SIPOC is a visual tool containing all the information of suppliers, its input materials, every step of the work, the output results and their customers.

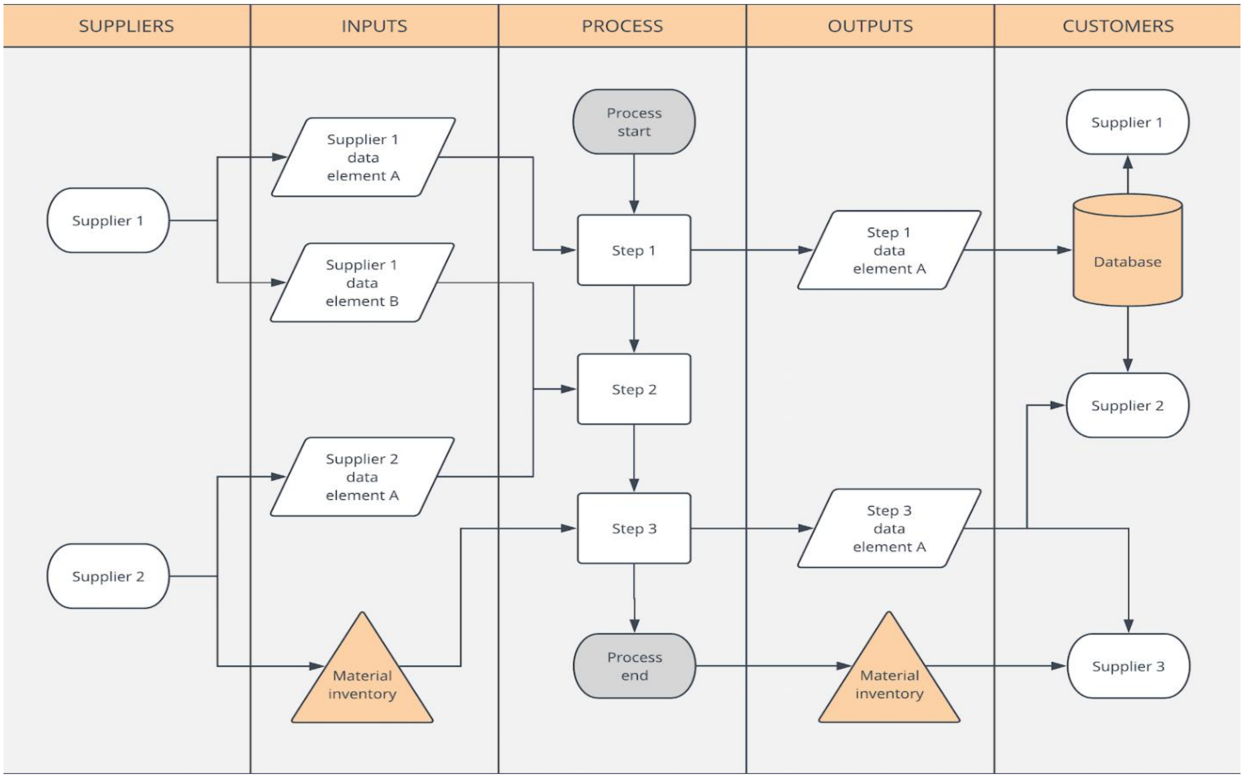


Figure 20: SIPOC Diagram [41]

5.5.1.2 Measure

In this phase, the current performance of the process is observed in more depth and the collection of the data are made to discover what is really going on in the process. The collection of data takes some time and effort. It is wise to plan how to start to collect the data and ensure that the data are reliable and trustworthy. Some of the common Measure tools are: Pareto Charts [4.1.7] and Time Value Map

Time Value Maps is bar graphs which shows how the time has been spent in the process and also indicated the amount of value add, non-value added and required non-value added time in the process.

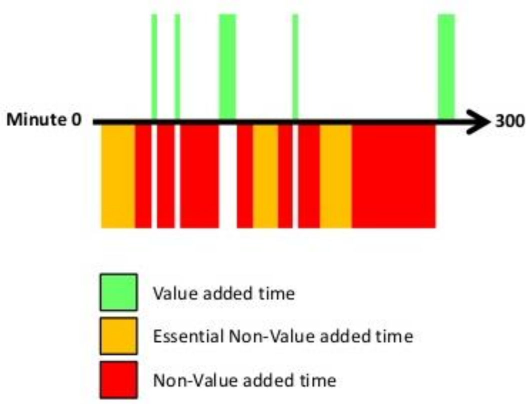


Figure 21: Time Value Added Chart [42]

5.5.1.3 Analyze

As data is collected and being review in Measure phase, the Analyze phase analyzes these results to confirm the source of the errors, waste and defects. This stage gives a clue about the real root cause of the problem by studying the pattern of the data mixing with the experiences and opinions. Some examples of Analyze tool are Brainstorming using Cause & Effect Diagram [4.1.1], Correlation Chart [4.1.8], Pareto Chart [4.1.7], etc.

5.5.1.4 Improve

The main purpose of this phase is to improve the process such that the problem stated in the Project Charter could be eliminated or reduced. The team should come up with various solutions. Brainstorming and use of creative and innovative ideas are very crucial at this stage. Selection and adaptation of the solution are made at this stage.

Some examples of Improve tool are: Pick Charts, 5S [3.3.7] and Poka-Yoke [3.3.6].

Pick Chart is one of the simplest yet very effective tool. It categories the series of ideas based on their payoff level, difficulty level, etc. Also, categories them into Possible, Implement, Challenge and Kill sections. This will assist any team to conclude the best idea(s).

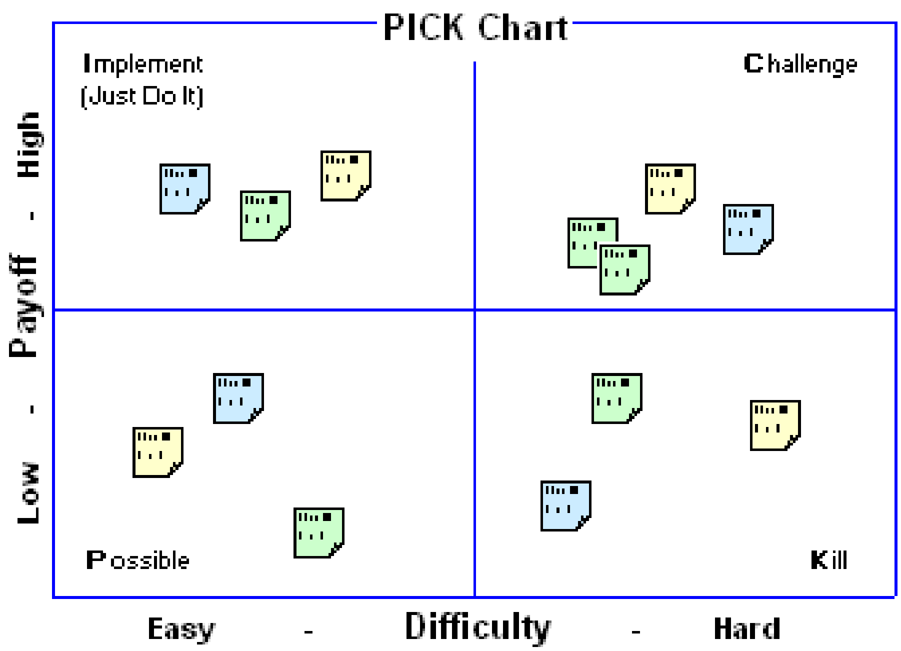


Figure 22: Pick Chart [43]

5.5.1.5 Control

This is the final phase of the DMAIC project. The focus in this stage is to make sure that the actions implemented in the Improve phase are well implemented and maintained. The goals set at the beginning of the start of the project are well meet. In control stage, the improved process are adopted in the business, the employers are trained accordingly and the outcome results are monitored using Control Charts [4.1.9].

Part I (B): PRACTICAL TRAINING EXERCISE IN LEAN SIX SIGMA

"Practice isn't the thing you do once you're good. It's the thing you do that makes you good."

-Malcolm Gladwell

The best way to learn is through practical trainings. This section covers some Lean, Six Sigma and Lean Six Sigma training exercises that are commonly use in practice. They are the start up training exercises for the beginners to collect some experiences in the field and provide a positive feeling of accomplishment after the completion of the training.

6 LEAN EXERCISES

Lean is about team work and engaging people in order to have a smooth flow in the process. It is also about learning and testing experiments. So, to learn and at the same time have some experience is very important. These are fulfilled by performing some practical training exercises.

Usually Lean exercises are self-learning methods in finding a solution to problems using collective individual effort from every member of the team. The training doesn't guide you on doing what to do in every step but encourage every member to use Lean principle to find the solution. In most cases, the results are promising and recognizable.

Any Lean exercise are a strong foundation to develop the skills and to think different and smart. However, it is only a piece of the puzzle. There are a lot happening in the real world. The only way to get better is to start collecting those pieces one by one either by trainings or experiences.

Some interesting Lean training exercises are described below:

6.1 5S Number Game

This game, as the name suggest, is about practicing 5S [3.3.7] Lean methodology. 5S is a series of steps that are put into practice to increase efficiency and productivity of the work. The aim of this game is to demonstrate how important 5S can be to perform the task.

The game consists of 90 set of numbers from 1 to 90. They are spread randomly into the sheet of the paper as shown in Figure 23: 5S Number Game Figure 23. The task is to mark numbers from 1 to 49 one by one in ascending order.

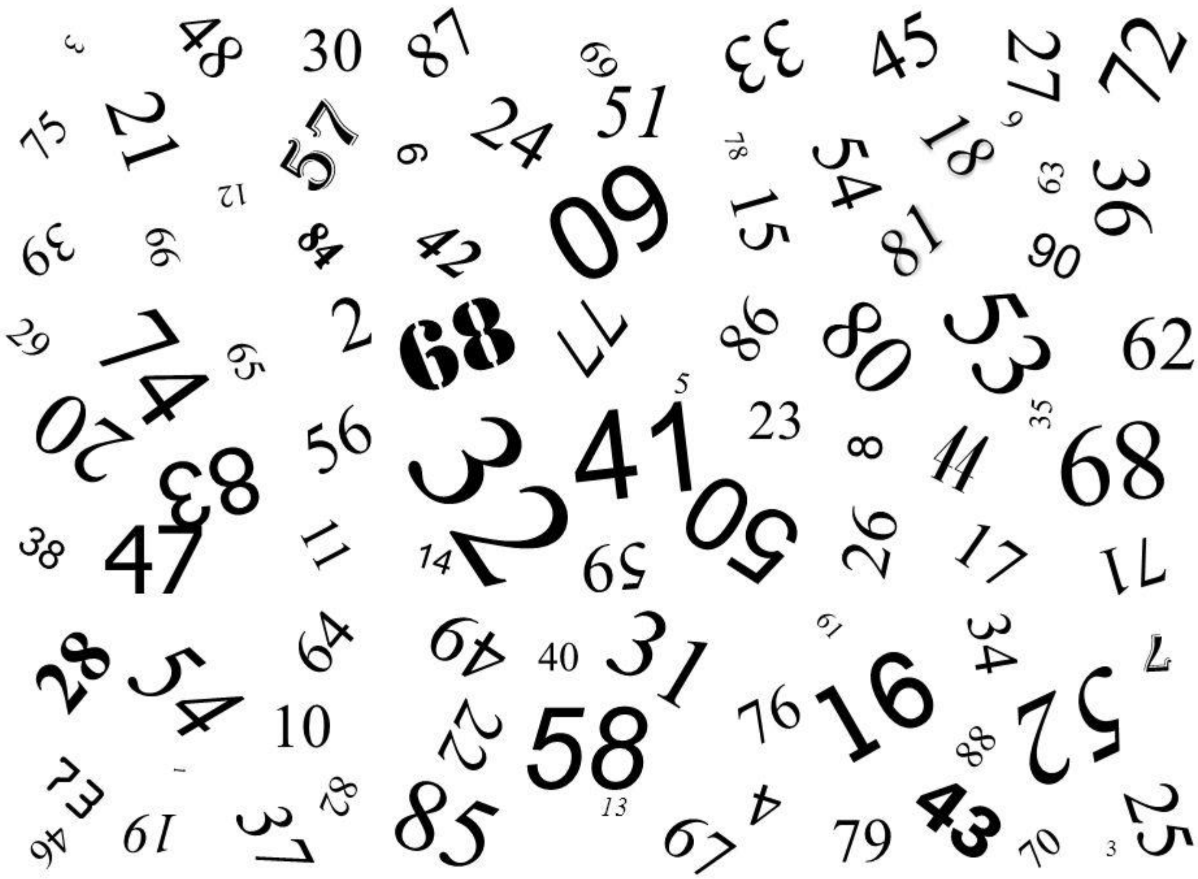


Figure 23: 5S Number Game [44]

The game advance by performing series of actions. On each step[1], the time taken by a performer to complete the task is recorded and are later compared for making conclusions.

Step 1:	Start to work	Mark number from 1 to 49 directly from the sheet as shown in Figure 23
Step 2:	Sorting	Take out numbers 50-90 (waste) and start to mark
Step 3:	Set in order	Put the numbers into a grid of size 3x3 such that number 1,2,3 and 4 are placed in 1st column bottom, 1st column middle, 1st column top and 2nd column bottom respectively and so on. Start to mark numbers
	Shine	Mark all first 9 numbers with different color For example. 1-9 mark with Red, 10-18 with Purple, etc. Start to mark numbers

[1] Figures for each step can be found in the APPENDIX A

Step 4:	Standardize	Put all the numbers in order. Example: 1, 2, 3, 4, ……, 49 Start marking.
Step 5:	Sustain	Keep practicing In this step, one can implement some innovative ideas to perform the task

Another application of this game is if two numbers are mission from the set. How easy or difficult will it be to locate it during Step 1 and Step 5 phase?

6.2 Lean Lego

Lean Lego is an interactive training exercise on Lean which allows the participants to experience how lean can optimize the process flow. The activity is targeted to be performed in a group of at least 5 people where each one takes a role of a Store Keeper, Construction Team 1, Construction Team 2, Supervisor/Quality Control and a Customer ([45]).

The exercise consists of sack of lego bricks of three different types and are available in different colors. The job is to construct the Animal and Non-Animal lego model according to a customer demand and deliver it to the customer.

Table 5: Lean Lego Exercise Task

Roles	Task
Store Keeper	Supply the bricks to the Construction Team
Construction Team 1	Construct the Animal lego bricks model
Construction Team 2	Construct the Non-Animal lego bricks model
Supervisor/Quality Control	Receive orders for a customer and checks for quality of the constructed models
Customer	Place an order of his own choice

The whole exercise is intended to run for more than one round. For each round, the date and time of the placement of order and delivery are recorded. The number of defects, number of models constructed and the models that passed the quality test are also noted for inspection.

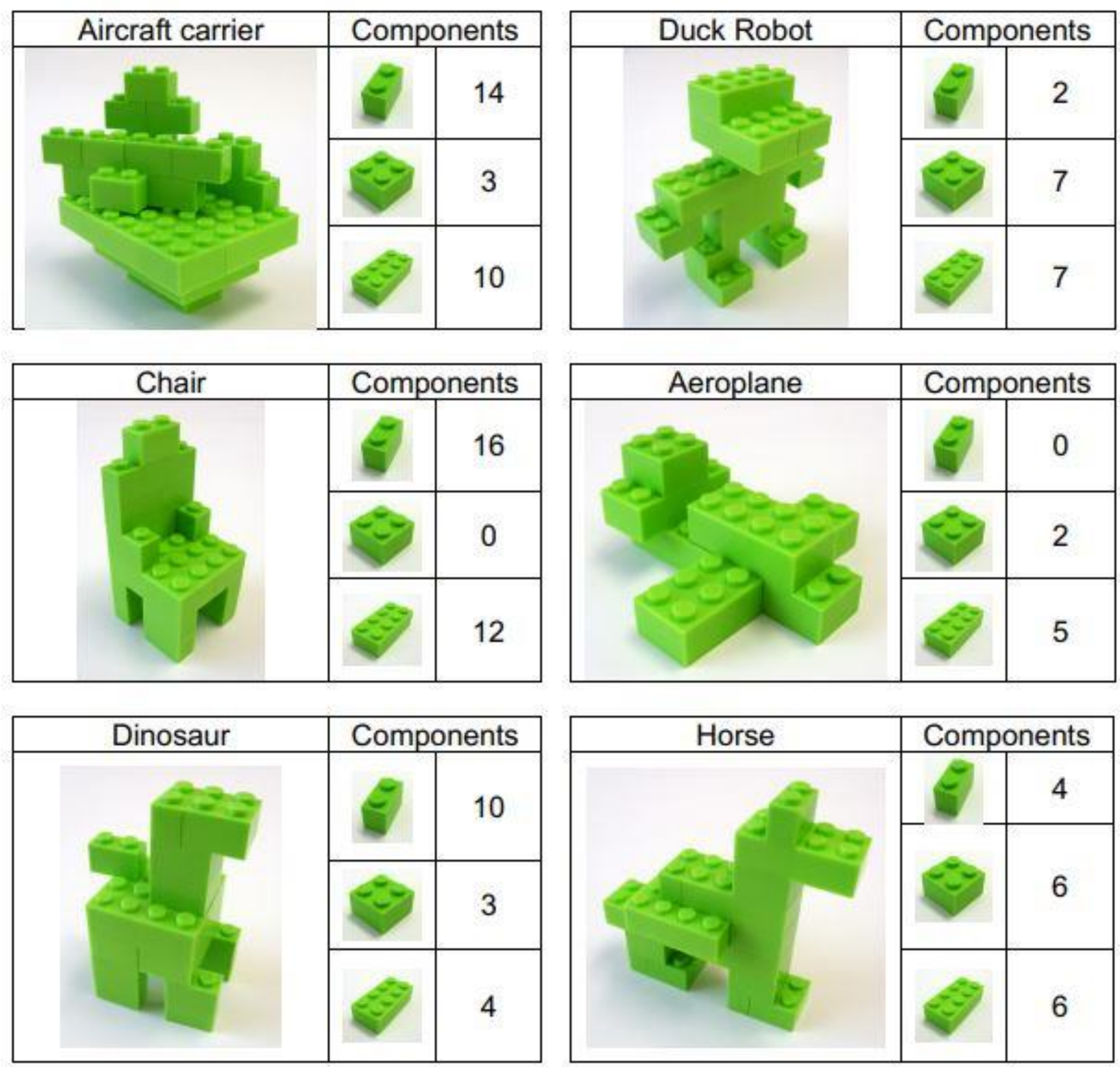


Figure 24: Components Required to Build the Lego Models ([45])

During Round 1, the participants are assigned different roles to perform the specific task. They are not allowed to talk or assist each other rather just focus on their job. The team members are placed at random order so that there are lot of walking and handling of lego bricks back and forth. The store keeper is given an unsorted pile of bricks. The construction team is strongly advised to follow the design catalog Figure 24. The customer can make any order (any colored model) even though it is not available in the store.

During Round 2, the participants could to communicate with every team member and allowed to assist each other. The store keeper gets pre-sorted bricks. If the participants find any wrong procedure, they could make complaint to the supervisor. For example, the components required for making a chair require only (16,0,2) bricks instead of (16,0,12) shown in Figure 24. The choice of colors available in the store are clearly displayed to the customer before taking an order. If required, the team can go for Round 3.

After the completion of this simulation exercise, the participants will have a great opportunity to learn about the following:

- To participate, evaluate and redesign the process
- To identify the waste that can be eliminated
- To learn about the lean tool such as 5S, Takt time, Just in Time, Pull System, etc.

7 SIX SIGMA EXERCISES

7.1 Experiment with Marbles and Toy Cars

This exercise can be carried out with the team of 3-6 people. The experiment requires set of marbles or toy cars, roll of sticky tape, flip-chart paper, chair and measuring tape [46]. The task is to roll down the marbles or cars from certain height along the slope and measure the distance travelled by it as it rolls over the ground floor.

During the experiment, the participants have to find out themselves on how to set up the experiment as shown in Figure 25 and how they will attach flip-chart paper on the chair so that marbles can travel along the same path all the time.

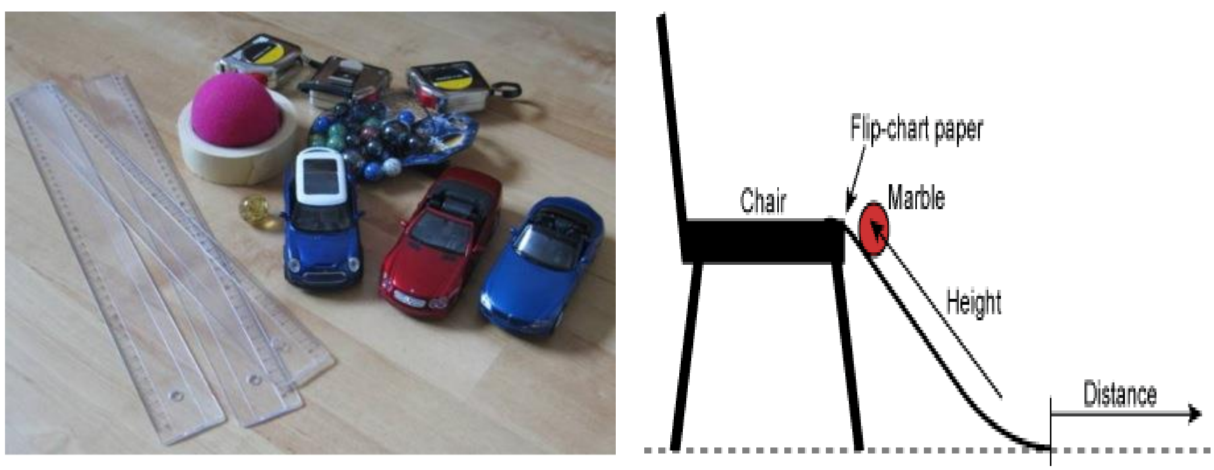


Figure 25: Six Sigma Practice with Toy Cars and Marbles [46]

Firstly, the participants carried out the rolling of marbles for at least 3 times each from different elevation. Then plot all the data in a scatter chart and find a Correlation Chart [4.1.8], also called as positive regression line. Now, participants can predict for a marble to travel a particular distance what should be the height of the slope. For example, if a customer what a marble to be rolled to a distance of 150±20 cm, the participant should be able to determine the height required by referring to the chart Figure 26. The experiment it now carried out to check if it meets the targeted distance. The results are plotted on a control chart [4.1.9] to study the nature of distribution of the curve. Usually, the normal distribution of the curve is preferred. When the numbers of defects are collected, the baseline sigma and six sigma can also be calculated. After that, their correspondence defects per million opportunities can be determined.

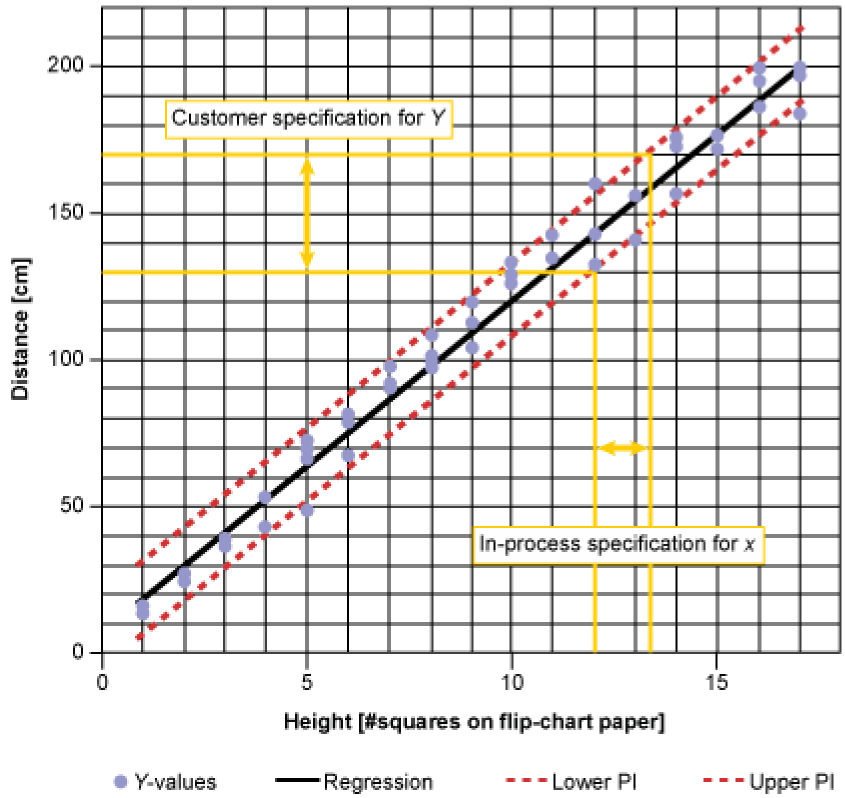


Figure 26: Correlation Chart [46]

7.2 Quincunx Demonstration on Process Variation

Quincunx is a device that help to simulate the manufacturing process by demonstration the range of variation that occur in the newly produced product. It consists of a collection of red beads and back and forth moving conveyor which allows beads to roll down to quincunx structure and settle down at the base. The collection of the beads at the base illustrate the distribution of the production along different columns. These distributions are the variation in the products that occur due the 5 M's (Man, Machine, Method, Material and Mother Nature).

Generally, when the Quincunx is run continuously making the process centered i.e. without adjusting the process, the bell-shaped distribution (Normal distribution) curve can be obtained. But when you adjust the process continuously after running few sample tests, it will make the distribution out of control i.e. the distribution is no longer a Normal distribution curve.

For example, a company was producing a product under its specification limit and the distribution of variation was normal. In order to increase the level of quality of the product, the company started to measure the quality of the product after producing some samples and based on that started to adjust the process. The same approach was used until the whole production was completed. The results were much worse than it was before.

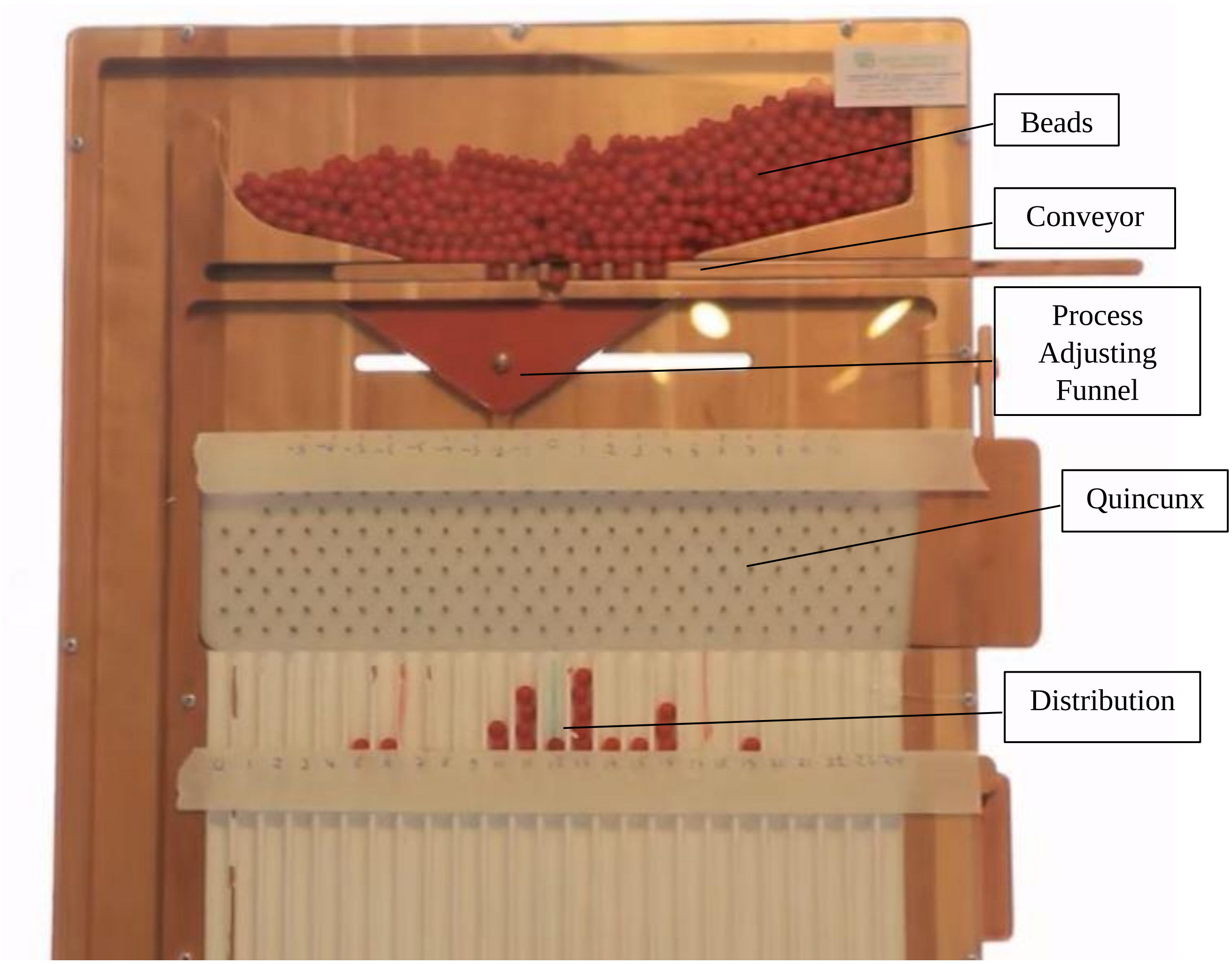


Figure 27: Quincunx [47]

8 LEAN SIX SIGMA EXERCISES

8.1 Statapult Exercise

Statapult is a team-based exercise for Lean Six Sigma practice. The Statapult kit consists of a Statapult set, cups, colorful marking stickers, marker, masking tape, ruler and a set of balls. This exercise can be performed in a group of 6-7 persons where each of them can take a role of a Marker, Shooter, Inspector, Sorter, Observer (1-2 persons) and Customer. The general layout of the exercise is shown in the Figure 28. This layout is only for the understanding purpose, the trainers have to develop their own layout scheme.

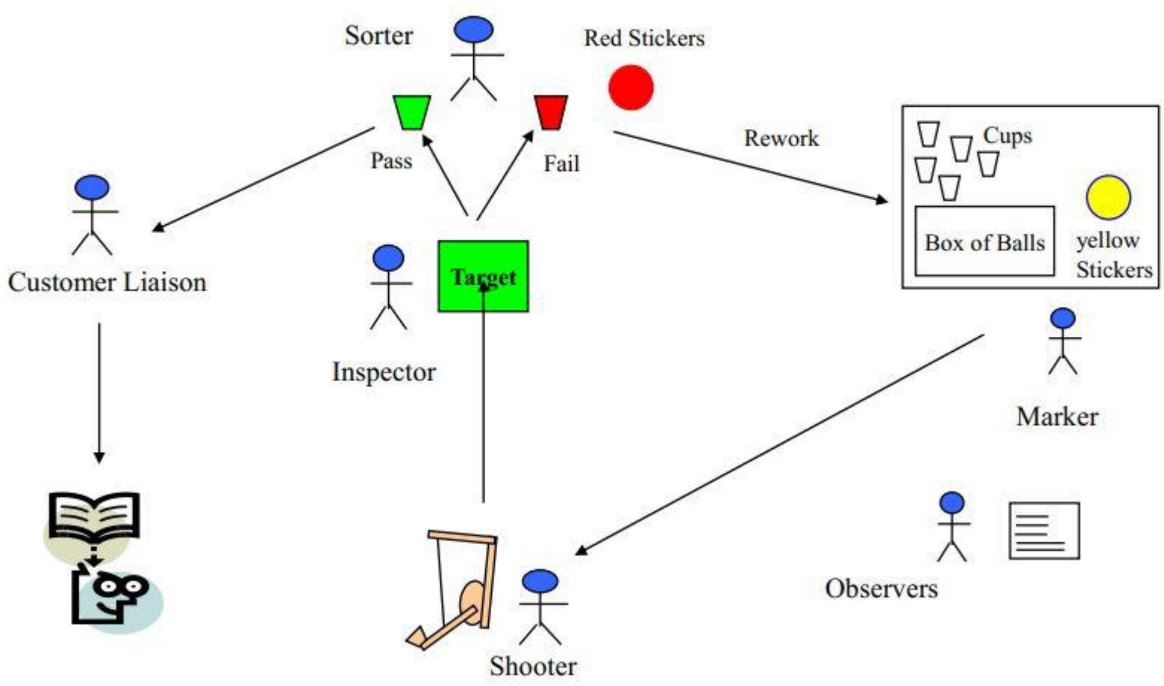


Figure 28: Layout for Statapult Training [48]

The task is to supply a ball to the Shooter who then shoot the ball. If the ball hits the target or falls under the specification limit, the ball is sent for delivery to the customer otherwise the ball is sent back to the box. The yellow sticker is attached to the ball before sending it to the Shooter. The balls which don't hit the target are considered as defects and are marked with red stickers.

Here is the list of some constraints and requirement which are strictly following during the process:

- A ball should be shoot at an angle of 167 degrees
- The ball must land ± 7.5 cm long and ± 15 cm wide along the target area.
- The ball which is delivered to a customer should not have any marking on it
- The ball must be transported in batches of 5
- The Statapult structure cannot be modified in any way, shape or form.

The exercise is divided into three phases:

Table 6: Statapult Exercise Phases

Phase	Objective and LSS tools
Phase I: Current Reality	Tells about the current situation of the process ➢ Prepare Project Charter ➢ Process Capability ➢ DPMO ➢ Control Charts
Phase II: Flow Improvement	Improvement of the flow ➢ Pull system ➢ Process Capability ➢ DPMO ➢ Control Charts ➢ Cost calculation
Phase III: Variation Reduction	Variation improvements ➢ Brainstorming ➢ Cause and Effect Diagram Analysis ➢ Source of Variation Matrix ➢ Improved control charts ➢ New cost calculation

During Phase I, the team are presented with a case indicating that the company has failed to earn profit and starts to lose its customer due to long lead time. The company wants to solve this issue as soon as possible thus forms a team to identify and solve the problem. The team will analyses the case and build a Project Charter. The team run the experiment for the first time and gathers all necessary data. The data are collected based on the range of distance hit by the ball around the target area. The team will execute all necessary calculation such as calculate, mean, standard deviation, process performance and capability, DPMO and plot control charts, etc.

In Phase II, the team will implement a pull system i.e. the simulation starts only after the customer place an order for the ball. In this phase, the team will use their experience from the phase I are more confident to perform the task. The 2nd experiment will start. New sets of data are collected, the team will repeat all the calculation once again. This time the team will also calculate the estimated unit cost price of the balls. The team is expected to have some positive results and some progress during this phase. By the end of this phase, the team will be able to figure out where to make changes to improve the process and quality.

Phase III is all about improving the processes and reducing defects. The team will try to find the what is going wrong with the process through brainstorming, cause & effect diagram, 5 Why?'s, etc. and set an action plan for next run of the experiment. The results from the new experiment must show some strong improvements especially in reduction in unit cost price and total lead time while meeting all customers and business expectation, if not Phase IV should be followed by it which basically is a repetition of Phase II and Phase III.

The completion of Statapult exercise demonstrate on how to achieve speed in the flow of the process and reduce variation & defects of the product using LSS methods.

8.2 Deming Red Bead Exercise

Deming Red Bead Exercise is developed by Dr. W. Edwards Deming is simple yet one of the most powerful Lean Six Sigma exercises. The experiment set up consists of a container containing approximately 80 % of white and 20 % of red beads and paddle with 50 holes in it to retrieve the beads on it. The experiment comprises of 4-6 workers, 2 quality inspectors who checks the defects produced, 1 inspector general who speaks out loudly the numbers of red bead produced individually and 1 recorder who keep the record of the performance. The task is to produce only white beads where the red beads are the defects. Out of 50 beads only 3 red beads are allowed i.e. at least 47 white beads should be produced out of 50 [49].

Before the start of the experiment, the facilitator/supervisor demonstrate the procedure on how to produce the beads using the paddle and strongly advised the workers to follow his steps.

Figure 29: Deming Red Bead Experiment [50]

Day 1

This is the training day for the workers where they learn how to use the paddle to produce the bead. However, the supervisor encourages every worker to “do right at the first time” and meet the target of 3 or less red beads. The experiment starts with every worker producing more than 3 beads (only in rare case someone meet the target). The workers who produced the lowest red beads are praised for their job while the highest red bead performer is put under probation for next trial. The recorder keeps the record of the beads produced by everyone.

Day 2

Before production, the supervisor warns everyone to meet the goal otherwise they have to cope with the consequences. The production starts but the result will be no better than Day 1. The top two better performer with lowest red beads were award with monetary benefits whilst the last two performers will be fired.

Day 3

The two best performers now work for two shift and starts to produce the beads. Since they are the best workers, they are supposed to perform their job at the highest level. But their performance would be even worse than before.

The company cannot afford any adjustment and will run out of business and declare the shutdown of the company.

The recorder displays all the defects results obtained from Day 1. They are then plotted into a control chart. The number of defects produced are seen that they have reasonable degree of statistical control and all the defects were under the control limits.

From this experiment, we can conclude that in many occasions, the system or process itself is incapable of producing quality products. In the above case, 20 % of red beads in the containers was the root cause for absolute failure in meeting the targeted goal. The management should have noticed about this fact, instead it spends so much time on workers which eventually result in the shutdown of the business. If the red beads in the container were controlled in advance, every worker could have produced the beads which meet the requirements. The rewards and sacking of personnel would never solve the case.

PART II: NEW LEAN SIX SIGMA TRAINING EXERCISE

"The bad system will beat a good person every time"

-W. Edwards Deming

"Tell me and I will forget. Show me and I may remember. Involve me and I will understand"

-Chinese Proverbs

Lean and Six Sigma are very powerful disciplines, though they both have separative initiatives, if applied together, have a very convincing result. Its benefits have been recognized globally as a result, there is a steep increase in its application throughout the world. Implementing LSS is not a one-day workshop, it is a long-term project. Therefore, it involves the employees, encourages them to work in a team and then train them on practicing various LSS tools to their daily work schedule. However, in most of the case, this doesn't happen. Any business firm only starts to seek for LSS when they started to face problem in their business. To run a LSS project to solve the problem is not an easy task. It might take a lot of time and it is costly. So basically, this thesis work is all about realizing how important LSS, what kinds of tools to use and how to implement them in your activities. The only way to learn about it is though practical trainings. This report is all about building a training exercise on LSS.

Often theoretical concept is insufficient to provide deep understanding on the topic. It must be followed by some sort of training courses so that they can get involved and learn through practical experiences. Similarly, with Lean Six Sigma, training exercises are recommended to realize its full potential and fruitfulness. However, the structure of the training course is not always same, it changes according to the level of competence required. To receive a Green Certificate Level within Lean Six Sigma, the training should involve the application of various Lean Six Sigma tools using a well-known DMAIC roadmap.

UiT-Narvik has been providing Lean Six Sigma training course using Statapult [8.1Statapult Exercise] for past 6 - 7 years to its Industrial Engineering Masters Students. The current training exercise have a major focus on Six Sigma principles rather than Lean. The team continuously work on to reduce variation of the range of the target hit by the balls and eliminate defects. And in addition, reduce the total lead time. The team uses majority of Six Sigma tools than Lean tool. Furthermore, the problem-solving method doesn't follow the DMAIC methodology. Hence, development of a new training exercise which have a fair contribution of both Lean and Six Sigma principles and tools was ineluctable. The project should cover the following elements:

- The exercise must follow the DMAIC structure and give training on these elements, with highest attention to Measurement and Analysis.
- Include measurable parameter(s) and flow (parts moving through the process)
- The exercise is to be designed for teams of ca. 6 students.
- The exercise is linked to the other courses in industrial engineering by using elements of for instance robotics, supply chains or logistics.
- The exercise may combine both practical tools and digital tools

9 DESIGN A TRAINING PROGRAM

First step in planning a training program is to set the training objectives. The training program should be designed and constructed in a way of conquering its objectives. These objectives not only help the trainer but also the trainee by providing a clear-cut picture of what they can achieve after the completion of the training program [51]. The followings are the objective of this new training exercise:

- Learn about Lean Six Sigma
- Implement Lean Six Sigma tools
- Overview on DMAIC structure
- Employ DMAIC process
- Develop an ability to solve problem using Lean Six Sigma

9.1 Learning Outcome

After completion of the training exercise, the participants should be able to

- Take part in real project dealing with Lean Six Sigma
- Implement Lean Six Sigma techniques in their daily/professional activities
- Develop an ability to solve problem using Lean Six Sigma
- Optimize their work level with perfection
- Identify various forms of Non value-added wastes and get rid of it

9.2 Outline Training Content

The training strongly focuses on developing technical skill of the participants through practical exercises. This can be achieved by defining a problem statement at the beginning of the training. The targeted goals are set, a current process and flow of the process are identified. The participants then are assigned with specific duties, roles and responsibilities and forms a team. The team run the simulation to identify and study the current status i.e. "as-is" of the process. After that, the team should use all relevant tools and methodologies to improve the process to achieve the targeted goal. After completion of the training the trainee should get the feeling of accomplishment of something big and worthwhile.

9.3 Physical Layout

The physical set or space available for the training should be determined in advance in order to design the structure and activities of the training. As the training is for the group of master's students, the available space could be either their own classroom or the laboratory room of the university. The space must fit group of 6-10 people with enough space for movement.

9.4 Possible Solution of the New Exercise

Before searching for solution, the main reason for seeking the necessity of a new exercise should be clearly recognized. Also, the topics and elements which are to be emphasized and covered during the exercise are needed to be stated clearly. This part is already mentioned at the introductory part for topic: PART II: NEW LEAN SIX SIGMA TRAINING EXERCISE, page.

49. With regards to the problem mentioned, the following list could be a possible solution for the new exercise:

9.4.1 Modify Statapult training

Modifying Statapult training exercise can be one of the easiest solutions. It already contains a pre-defined problem statement and all the necessary training equipment and tools. By implementing few ideas and concepts, it will be quite easy to add Lean concepts on it so that various Lean tools can also be put into practice for improvement.

Table 7: Modification of a Statapult Training

Possible Modification		Results	Lean Tools for improvement in next phase
Old	New		
Balls are of same color	Use colorful ball	Take customized order	5s: Sort different colored balls before store-keeper send them out
Inventory build at each stage due to batch size production	Use Kanban card	Near zero inventory	Kanban card: No replenishment until Kanban signal are received
No waste identification	Use Value Stream Mapping	Waste identification	VSM: identification of value add and non-value add
Flow in batch size with the help of human work force	Use of conveyor belt	One-piece flow of material	JIT: Zero inventory and significant reduction on lead time and elimination of waste

9.4.2 Multiple Training Activities with Lean Six Sigma Tools

Another possible solution could be conducting a multiple training activity where the students are trained to use various LSS tools one by one separately. This allow them to master majority of LSS tools which let them to implement those tools in their daily practices or while taking part in any improvement project. For this type of training activity, the students should work individually and develop oneself skills.

9.4.3 New Training Exercise

The next option would be to design and build a completely new training exercise. Developing a new training exercise by considering all the elements that are expected to be in this LSS training course will help to achieve the targeted goal for this project.

The new training exercise should be designed such that it has a clearly stated problem statement and their target goals to achieve after the completion of the exercise. Unlike Statapult exercise where students don't focus too much on improving the process flow and identification of waste (non-value activates), this exercise should take into account of these topics. This means that the training exercise should have a process where something is happening in each step of the process i.e. in statapult exercise value are being added by putting on the sticker mark on the ball but if the new exercise have something where the participants can actually perform the real value adding process, it will provide them a real feeling of the process. A process can be manufacturing of some parts, assembling of parts, packaging of items, manufacturing factory or any service industries.

New training exercise should provide students with all necessary information so that they can study, analyze and identify what is going wrong in the process.

9.4.4 Comparison

Comparisons based on some selection criteria:

Table 8: Comparison Table for Multiple Training Exercise with Lean Six Sigma

Alternatives / Selection Criteria	Modified Statapult training	Multiple training activities with Lean Six Sigma tools	New training exercise
Team work	√	-	√
Lean focus	√	√	√
Six Sigma focus	√	√	√
DMAIC methodology	√	-	√
Data and facts collection	√	-	√
Facilitate other Industrial engineering courses	-	-	√
UiT genuine exercise	-	-	√
Total Score	5	2	7
Rank	2nd	3rd	1st

Modified Statapult could have been the right exercise for this project but it not related to any Industrial engineering courses and most of all, Statapult is not UiT's creation. While Multiple training activities can only develop one's skill on LSS tools. New training exercise, being able to cover all the selection criteria, should be taken into account for this project.

9.5 Elements for New Training Exercise

9.5.1 Project Covering Aspects of Other Master Degree Courses

Before choosing the elements of the training exercise, once should briefly think about which topic can be used from the courses available in master course of UiT's Industrial engineering. The table below shows some of the possible topic that can be taken out for the exercise.

Table 9 Contents of the Courses that couldb be Included in the Training Exercise

Robotics in Manufacturing Systems	Manufacturing Logistics	Supply chain management	Virtual manufacturing
➢ Use of Industrial Robots ➢ Control and operation of industrial robot	➢ Production line ➢ Balance levelling ➢ Warehouse and inventory ➢ Handling, transport, storage and supply	➢ Product and information flow ➢ Supply and demand ➢ Connection between suppliers, manufacturers, customers	➢ Modeling of Manufacturing process ➢ Optimization of Manufacturing process

Table 9 Contents of the Courses that couldb be Included in the Training Exerciseshows some important contents of the courses. If any of these contents being able to include in the exercise, will give the students some concept about the courses. These are the courses that the students will be taking after completion of this training exercise and in coming semesters. So, including some of these concepts is a Win-Win for both UiT and students.

9.5.2 Selection of Process

It is very important to choose a process that has room for improvements. The trainees should feel the problem, refine the problem and deliver quantifiable and sustainable results at the end. Before making any selection of the process, one should keep in mind the followings:

- ➢ Has a problem within the existing process
- ➢ Has significant amount of non-value-added waste occurring in the process
- ➢ Has an ability to reduce lead time and cost
- ➢ Has an ability to reduce or eliminate defects
- ➢ Has measurable which can quantify the current reality

9.5.2.1 Some Processes and Their Link with Other Courses

Single operation process: It is simply one operation of a process such as welding, drilling, etc. Such process can be performed using industrial robot and could also assist in obtaining knowledge in the field which can be later use for virtual designing. But these processes don't serve so much with respect to Manufacturing Logistics and Supply chain management.

Assembly operation: Assembly operation can be the combination of two or more processes which can serve the courses like robotics, virtual manufacturing, may be Logistics but not Supply Chain Management.

Packaging and Delivery: This process might have a connection with Robotics, Virtual manufacturing, Logistics and also Supply Chain but not convincingly.

Manufacturing cell: It is a manufacturing factory which have all the process mention above and fairly cover the concepts Robotics, Logistics, Supply Chain Management and Virtual Manufacturing.

Table 10 Types of Process and Their Connection with the Industrial Engineering Cources

Courses / Selection Criteria	Robotics in Manufacturing	Manufacturing Logistics	Supply chain management	Virtual manufacturing
Single operation (e.g. Welding, drilling, etc)				
Assembly operation				
Packaging and Delivery				
Manufacturing cell				
			Strong	
			Fair	
			Weak	

The table above demonstrate clearly that application of the manufacturing cell can have the strong impact on the students regarding the other Industrial Engineering courses. Therefore, it will be taken into account for the exercise.

9.5.3 Choice of a Manufacturing Cell Layout

Size and layout of a manufacturing cell can vary based on their functions and layout. Instead of moving in this direction, a three most common manufacturing cell which are globally popular are selected and listed below:

- Beverage Industry
  A beverage factory produces a consumable drink for its customer. The process involved in this type of industry are cleaning bottles, filling, capping, labelling and packaging & delivery. Some industry chooses to produce their own bottles by putting a small plastic or glass pet glass into the heated parison which get blown and turn into the desired shape.

Figure 30: A Beverage Industry [52]

- Fast Food Restaurant
  Fast Food Restaurant are quick serving restaurant which produces fast food like burgers, fries, nuggets, etc. as soon as the order is received from the customer. The Figure 31: A Fast Food Restaurant shows the burger making process for McDonald’s.

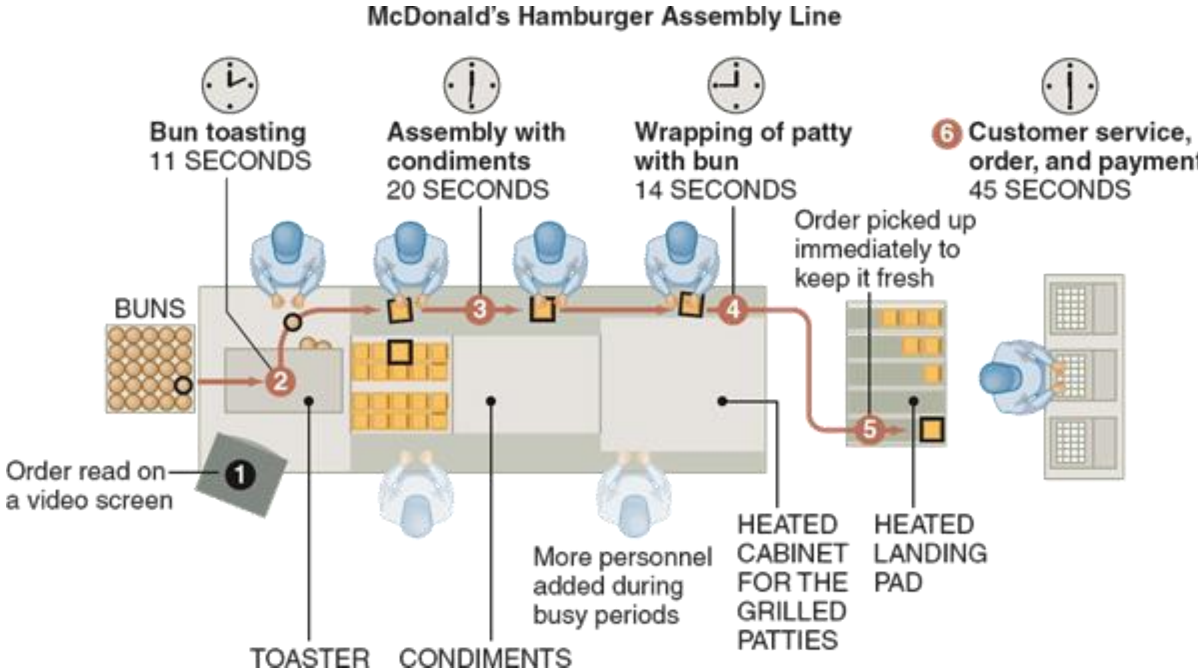


Figure 31: A Fast Food Restaurant [53, p. 69]

- Automobile Factory

  Automobile industry which is one of the first industry where the lean manufacturing principles were applied typically have the following processes. Sheet metal get pressed to shape various body parts of the cars, they get machined and painted followed by assembly of all the components to manufacture the final car.

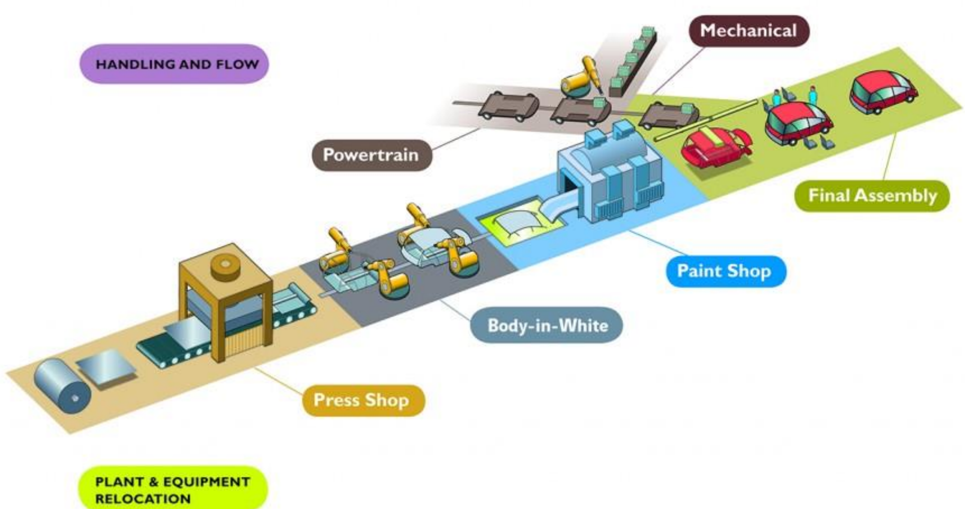


Figure 32: Automobile Factory [54]

The Table 11 discuss on the possible input, output and measurable parameters of these three-manufacturing cell if they are going to be applied for the training exercise. Every process that can be put into action and the training delivery materials are listed below:

Table 11: Various Manufacturing Cell Relating to Training Delivery

	Beverage Industry	Fast Food Restaurant (Burger)	Automobile Industry
Primary input requirements	Bottles	Buns	Auto parts
Output product	Filled bottles	Burger	Car
Training Materials	• Bottles • Washing Machine • Filling Liquids	• Buns • Condiments and fillings	• Car parts • Machine
Process	Cleaning bottles Filling Capping Labeling Packaging	Bun toasting Grilling Ingredient assembly Wrapping	Assembling of car parts
Measurable parameter	Liquid level, Quantity, Weight of filled bottles	Size, Height and weight of burger	Car dimensions

For the training purpose, it is not possible to visit these industries and carry out training exercise. But what could be done is, create a mini factory such that training can be carried out in a classroom. Complicated process can also be simplified and assumptions are also allowed.

For beverage industry, the availability of bottles are more than enough to perform cleaning, filling, capping, labelling and packaging process. The mini bottles of various size are easily available on stores (online) and can be used repeatedly. While for Burgers, it is not wise to use baked burger buns and other ingredients and make fresh burgers. The only possible way will be to make a Fake Burgers. If fake buns and ingredients are used, the burger making process will be just an assembling of those ingredients. Toasting, grilling and other process cannot be performed. Similarly, for manufacturing of cars, toy cars have to be used. The manufacturing of cars then will be only assembling of parts to make a car.

Table 12: Materials Required for Training Delivery for Various Manufacturing Cell

Types	Materials required	Processes	Availability
Mini Beverage industry	Mini bottles	Cleaning Filling Capping Labelling Packaging	Stores (online)
Mini Burger	Fake Buns and ingredients	Assembly	Hard to find or make special order
Mini Automobile industry	Toy cars parts	Assembly	Online store

Mini beverage industry has a lot of process compared to the other two, all these processes can be performed with the availability of an empty bottle only. From LSS perspective these processes can be modified or improved during the training period and at the same time variation, the bottles can also be controlled and monitored by measuring liquid level inside the bottles, its quantity or weight of the filled bottles and improved by taking necessary actions. Since a mini beverage industry has a lot of processes involve in it, which can be improved and have also control on variation & defect factors, it will be considered for the development of this training exercise as it has a potential to achieve LSS goals.

9.6 Modelling of a Beverage Factory

The main activity involved in beverage industry is to fill empty bottles with desirable liquid quantity and then, capped and labelled. The figure below shows the transformation of empty bottles into a final bottle. These are the only processes where the customers are willing to pay for it as values are being added on every step of it.

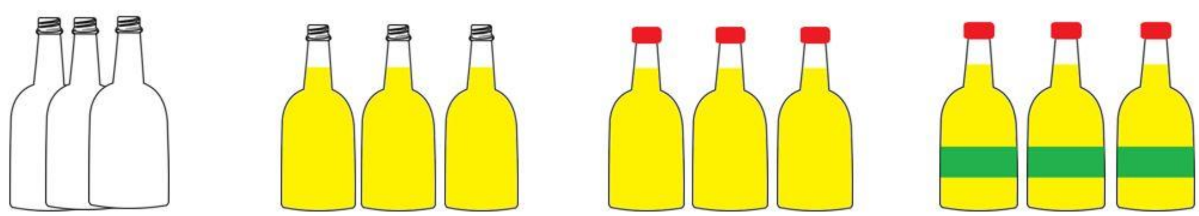


Figure 33 Bottles Transformation

A simple beverage factory consists of a store room, washing section, filling room, capping & labelling sections and packing department Figure 35. A store room stores all the empty bottles, caps and labels and sends out in different quantity according to the order made. The washing room cleans the bottles coming from the store room to make them contamination free and disinfected. The filling room fills the desirable amount and type of liquid inside the bottles and are send out for capping and labelling. When the bottles are capped and labelled, the bottles are collected, put on a crate of various size, packed, palletize and sent for delivery. Beside these, there are observers/inspectors who are responsible for quality inspection of these bottles. If these bottles failed to stay within the specification limit, the bottles are regarded as defects and are sent for re-work or discarded.

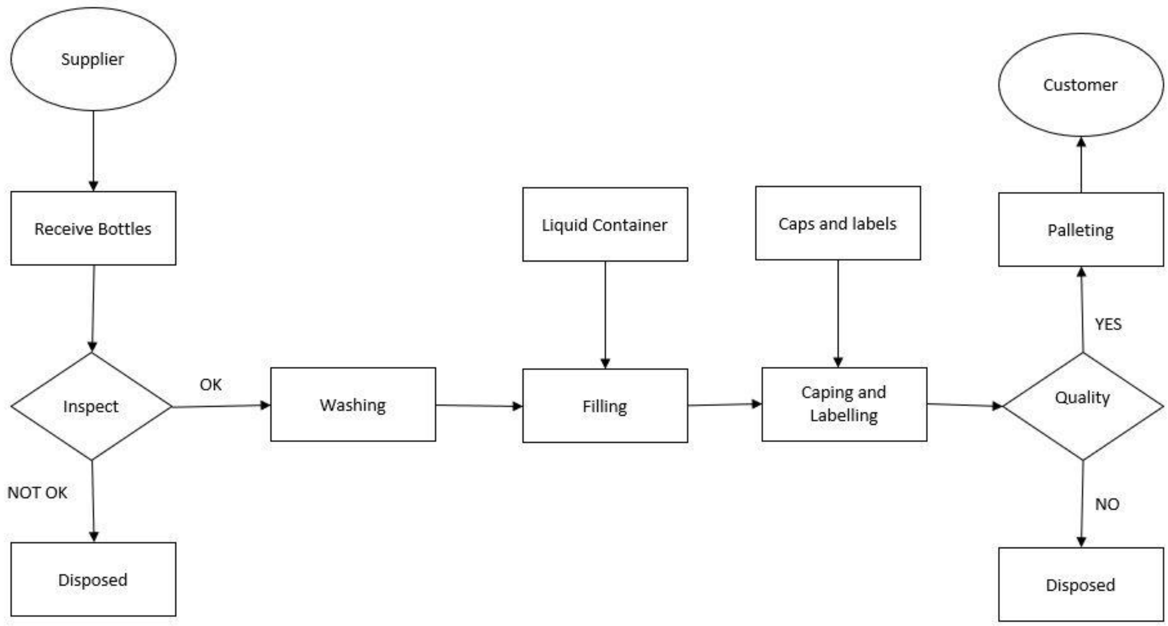


Figure 34: Flow Chart for a Beverage Factory

9.6.1 Departmentalized Layout

Figure 35 is a typical example of a departmentalized layout system. In this type of layout, each and every department are kept apart and operate independently. The workers are only concerned about their sectional task and doesn't care about other workers. This is a traditional layout system which typically work on a batch size production. A lot of inventory is built on each section which in terms of LSS is a waste. The movement of parts between departments will also take some time. The value is being added in lot size in each process and there is a lot of waiting time before addition of the next value in the next process. This layout out system will eventually make the whole process slow, hence increasing the lead time.

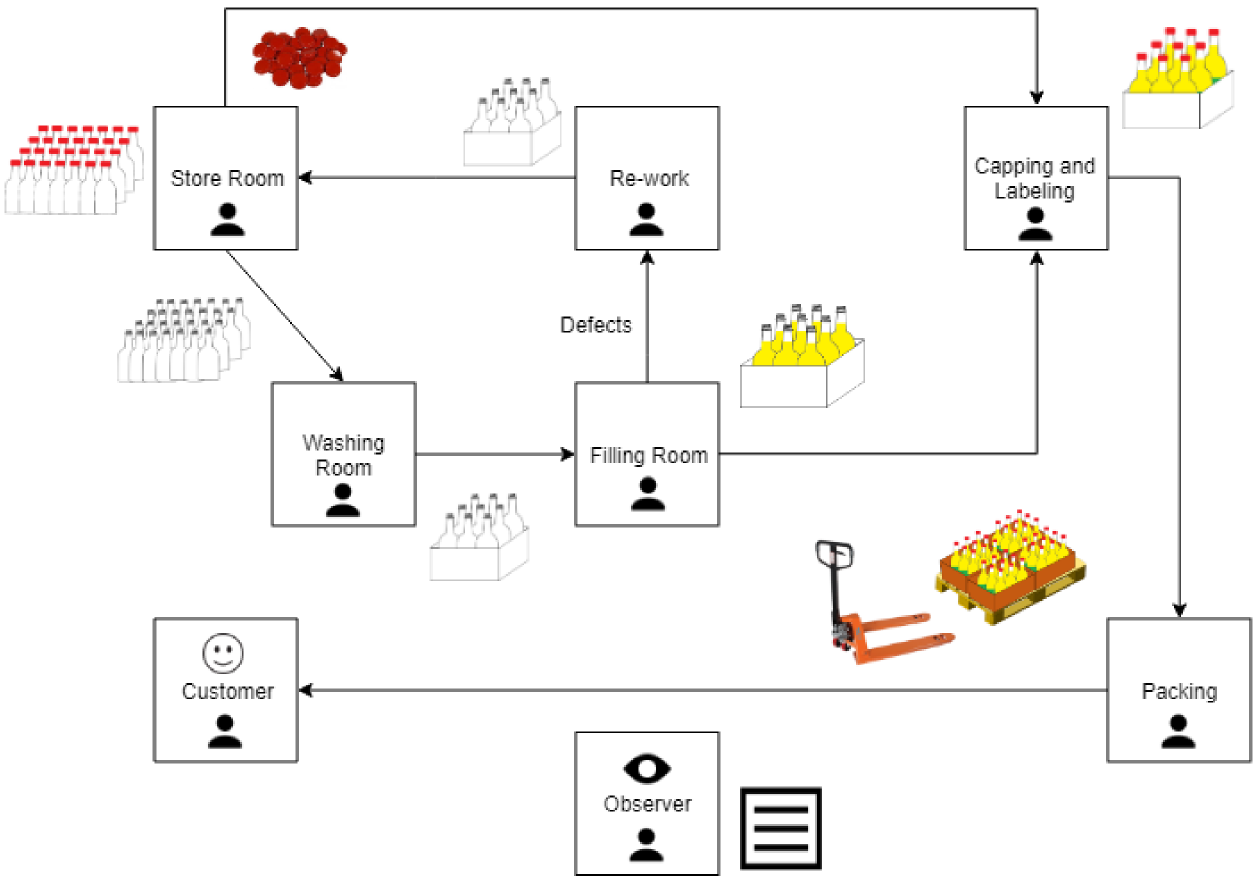


Figure 35: General Layout Diagram of a Beverage Factory (Departmentalized)

9.6.2 In-line Layout

In-line layout system Figure 36, the workflow is designed according to the sequence of the operations of the product such that only one piece of the product flow through all the process until the final product is produced. Only one part gets processed in each section at a time thus making the flow continuous. This layout, if run smoothly, have almost zero inventory built up. This is an improved layout version of the departmentalized layout. Since only one part get processed on each stage, the flow of value being added is also smooth and without waiting, it has comparatively low lead time than the formal one.

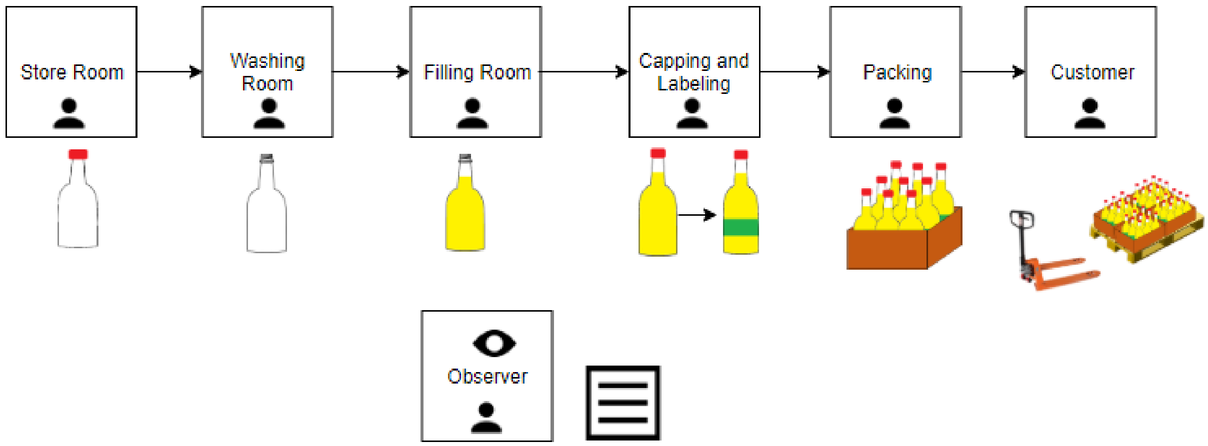


Figure 36: In-Line Production Layout

For the exercise, the students will be following the departmentalized layout set as a default to run the first experiment and it is expected that the student should come up with something similar to In-layout for the next run of the exercise which they will be using a part of an improved process.

9.6.3 Virtual Modelling

Before building a physical training kit, it is sensible to build a virtual model first and verify the outcome. A virtual model will demonstrate how the process is going to work and if things are not right, there is always a room for correction. VISUAL COMPONENTS® 4.1 has been used for the modelling of the entire layout. The layout is modeled keeping a factory line [represented by a zebra rectangle Figure 38 & Figure 39] which is 20 meter long and 12.5 meter wide as a default.

For the modelling, six stages have been kept in mind, a store room, a washing room, a filling section, capping and labelling section, packing and customer delivery point. All the models and machines are imported from the Visual Components library. For the simplicity, the connection between the process are linked by human work forces (Anna ♀ & Otto ♂), conveyor belts and a robot. The setup is run in a default speed. However, some settings have been modified to facilitate the batch production and one-piece flow of the bottles.

To investigate the outcome and for further analysis of the simulation, it is assumed that the customer has order 16 bottles and the time frame taken from the start till the delivery of ordered bottles is recorded.

The entire layout is programmed using three offline programming options:

- Programming with the program editor tab (robot movement control)
- Programming with work process (control of human workforce)
- Programming with python script (triggering senor, conveyor and robot action)

Table 13: Components Used for Modelling

Section	Components used for modelling	Task
Store room	Shape feeder	Send out bottles
Washing room	Rotary washer	Wash bottles
Filling section	Rotary filling machine	Fill the bottles
Capping Labelling	Bottle batch capper Bottle labelling machine	Put on the caps Put labels on
Packing	Generic robot	Pick and place bottles

9.6.3.1 Modelling of a Departmentalized Layout

For this set up [shown in Figure 38], the simulation is carried out for a production of bottles in a batch size of 4 bottles. In Figure 37, Anna is carrying 4 bottles from the store room to feed them into the washing machine, while Otto is carrying 4 filled bottles towards Capping section. Capping of 4 bottles will take place at a time followed by labelling in a similar manner. The robot will pack 4 bottles on a crate/box. The boxes are then palletized according to the customer order and are transported by a forklift for delivery.

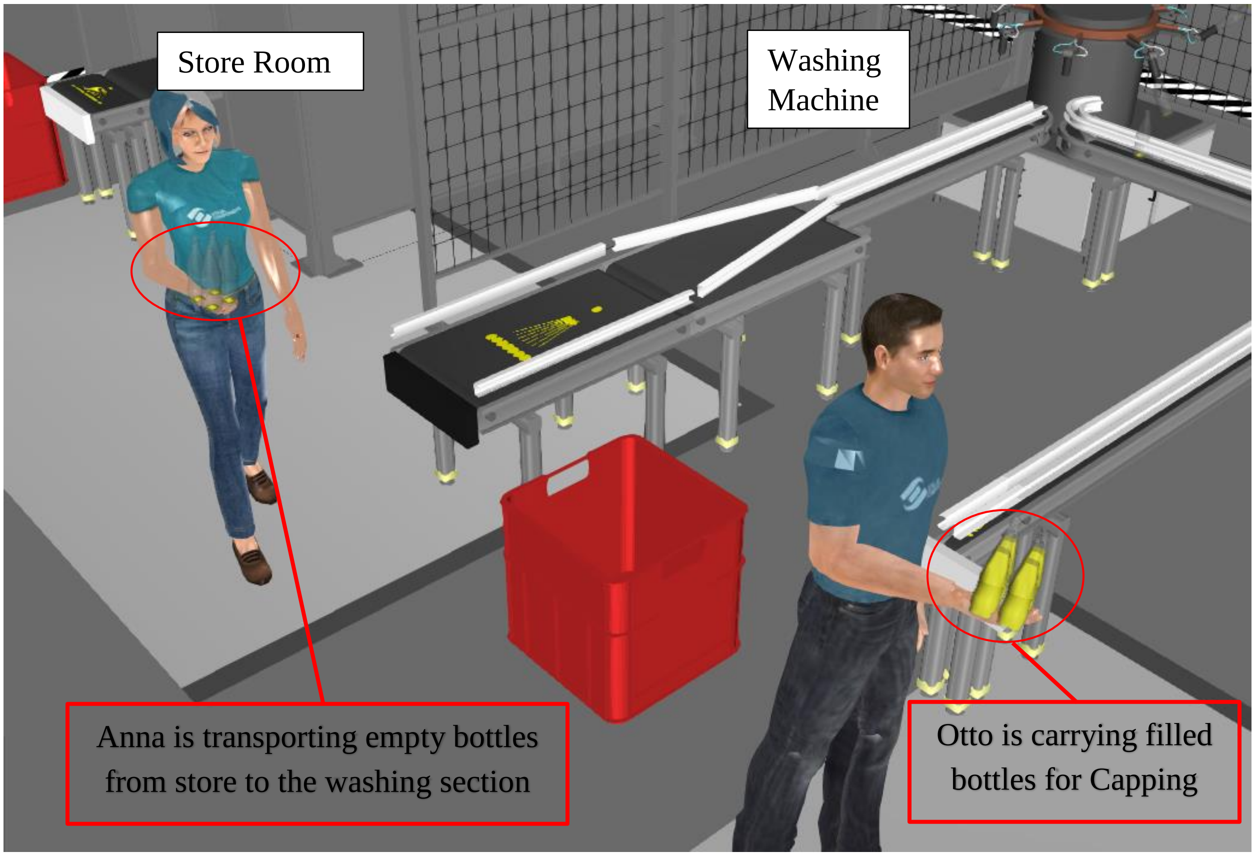


Figure 37: Handling of Batch -size Product

For this layout, to deliver 16 bottles in a size of 4x4, it took approximately 12.5 minutes to deliver the final product to the customer. This data is obtained by running the simulation of the layout in VISUAL COMPONENTS. Figure 38 captures the moment of the simulation where the forklift is ready to deliver the final product to the customer at the delivery point. Also, the lead time can be seen at the middle top.

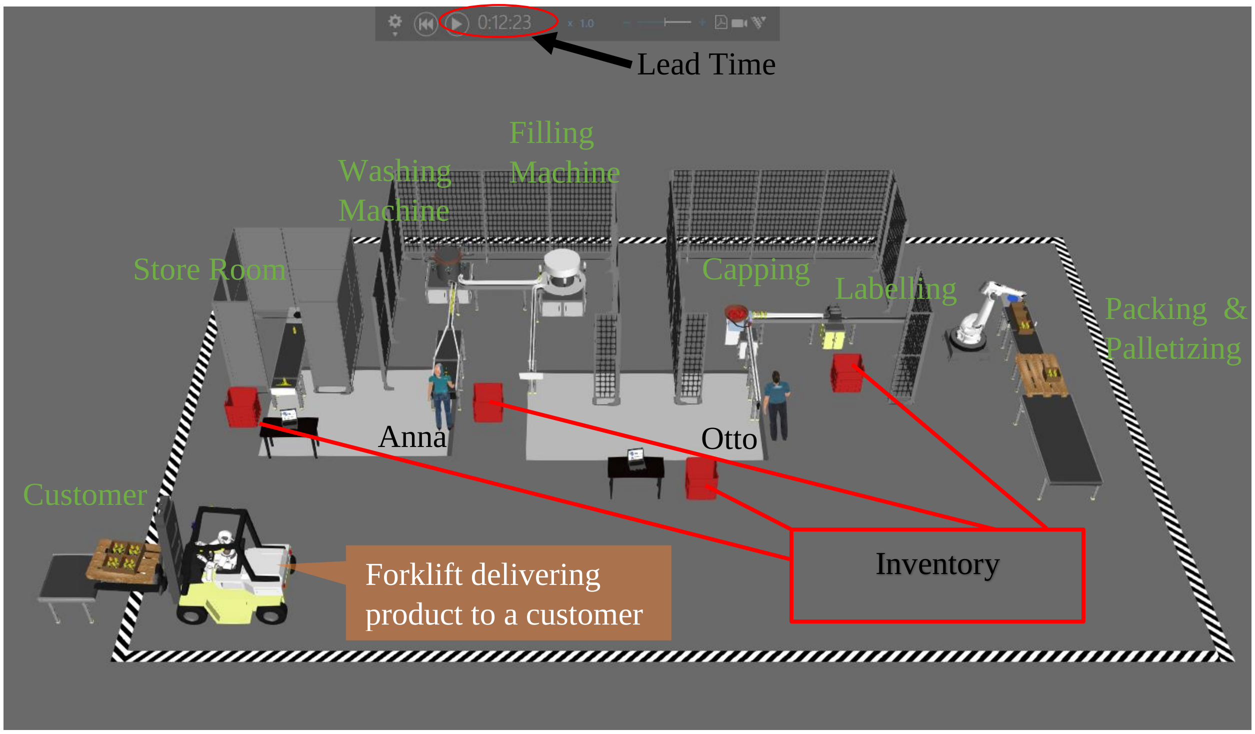


Figure 38: Virtual Model of a Departmentalized Layout

9.6.3.2 Modelling of a In-Line Layout

Figure 39 shows the model of an In-line layout setup, there is only change in the set up, all the components and setting are kept as in the departmentalized layout. However, some settings have been modified to facilitate one-piece flow of the product. Only one bottle at a time is being process in each unit, hence the flow is continuous. Now Anna and Otto don't have to wait for bottles to reach the batch size. They can simply stand up in one position, pick and place the bottles to the next stage. For the delivery of 16 bottles of same size mention earlier, it took approximately 7 minutes.

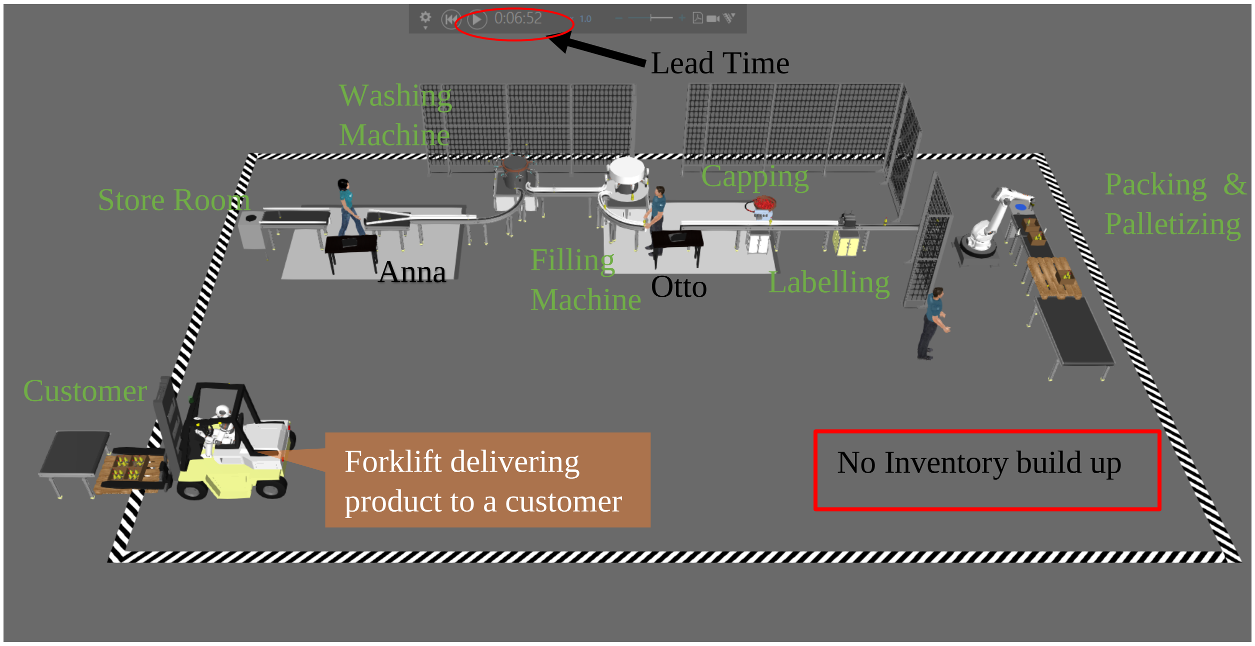


Figure 39: Virtual Model of an In-line Layout

9.6.3.3 Comparison

After completing these two simulations with different layout, the difference is quite vivid. The lead time for the delivery of 12 bottles for In-line layout is almost twice times less than that of Departmentalized layout. By changing few set up and a flow of a product, a huge difference in the lead time has been achieved. This layout could be a powerful tool to implement for the training exercise.

From the Lean perspective, this can be a perfect training exercise whilst from Six Sigma view, nothing has been done to check the quality or variation of the product. Using this layout is only one piece of the puzzle, not enough for the exercise. If some measurable parameter could be added to the layout, then variation on the products can be received which will then cover the Six Sigma concept as well. By doing this, a final piece of a puzzle could be discovered. Some quality inspecting parameters must be defined and added to this process. As for the above virtual layout, the washing machine, filling machine, capping and labelling machine, all are automatic, if those machines are to work manually meaning during the training exercise they have to be run manually, there will be some variation in their output. Upon defining a quality and setting some specification limits, the list of data could be collected. Those data could be then measured and analyzed to improve quality and variation on them. This Six Sigma principles can also be applied.

These virtual model layouts can also be used during the training session to demonstrate how the factory is working. This will allow the student to visually understand the manufacturing process.

9.7 Measurable Parameters

For collecting data, it is necessary to identify what to measure in advance. It could be the volume and height of liquid level that are filled inside the bottle, the weight of the bottle before and after the bottle is filled, operation time, time to complete each process and so on. Collection of any one or more of these mentioned data will facilitate the participant to analyze the result and seek for solutions if something is wrong. For example, while analyzing the volume of liquid inside the bottle, if majority of data are beyond or below the specification limit, it will be clear that something is wrong in the process. The team should immediately start to look for the cause of it and solve the problem.

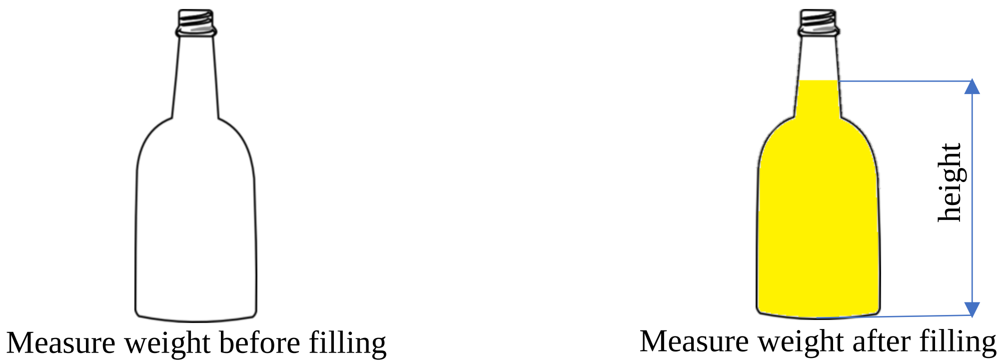


Figure 40: Measurable parameter for bottle

Table 14: Choice in Measurable Parameter

Parameter	Measuring tools (Examples)
Mass of the liquid	Electrical Balance
Volume of the liquid	Measuring tube
Height of a liquid level	Ruler, Caliper
Time [process]	Stop watch

Measuring parameter are very important aspect from Six Sigma perspective. This is the point where the students will be collecting the data. These data are then transferred to construct various LSS tool which they will run thoroughly during Measure, Analyze and Control phase of the DMAIC cycle.

The data will allow the student to determine the following important parameters:

- Total number of bottles processed
- Number of defects
- No of work-in-progress
- Process capability and performance
- DPMO
- Creation of control chart to investing the type of variation, etc

10 BUILDING OF A PHYSICAL LAYOUT

Before starting to build the training kit, one should keep in mind that this training exercise is for the master's students. It should fit inside the classroom or the available laboratory facilities. The equipment also should be light and portable so that the participants have possibility to change the layout set up.

The design and construction of the training kit was performed inside workshop lab by making the best use of what's available in the storeroom. Those which cannot be built and constructed inside the lab were bought from the online and local store.

10.1 Store Room

For the store room, the first thing to think about is mini bottles. To have these bottles physically available, the best and economical option is to buy them from online store. Before buying, the things that should be kept in mind are following:

- The bottles should come with caps (if possible, caps with different color)
- The bottles should be transparent (facilitates during measuring period)
- Capacity of bottles should be less than 50 ml (thus mini bottles)
- Buy at least 50 bottles

The bottles having the similar features was bought from ebay.com . 50 bottles having capacity of 15 ml each with 10 different cap colors were received and will be used for training.

The next thing is a container for storing these bottles. The size of it should be based on the total number of bottles available.

Figure 41: Mini bottles for a training exercise and a container

10.2 Washing Machine

The basic requirement for the washing machine is that it should be able to wash the bottles which come out from the storeroom. To buy a machine that could fit for this training won't be easily available and cheap. Building a simple machine using the materials available from the laboratory and a local store (market) can be a smart choice to make.

10.2.1 Design Concept

The Figure 42 below shows the first basic sketch for designing the machine. A submersible water pump and Y-sprinkler are being used to spark the water to clean the bottles. The bottles are kept inside the bottle crate/casing which sit on the wire-grid stand.

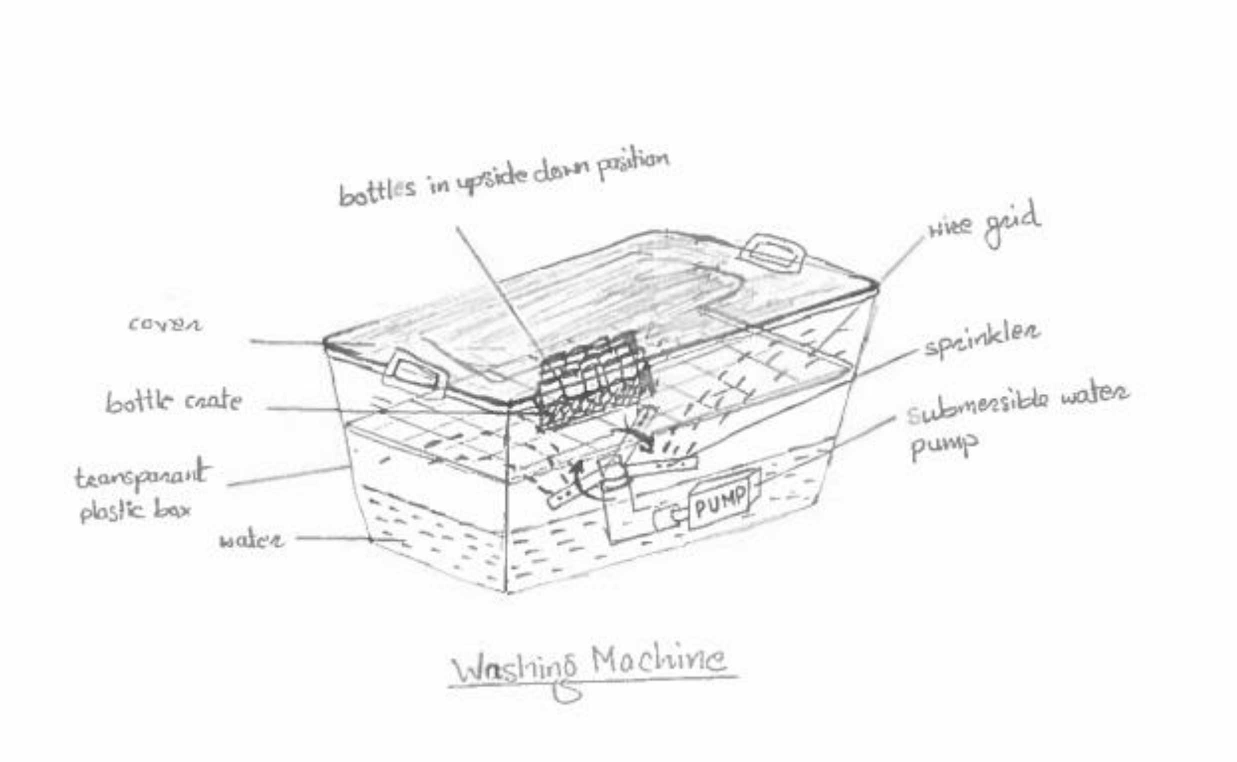


Figure 42: Sketch of a washing machine

10.2.2 3 D Modeling

After the concept sketch, the 3-D model was constructed using SOLIDWORKS. The plastic box has a dimension of 230x300 mm. All other parts fit inside the box. The assembled diagram is shown below:

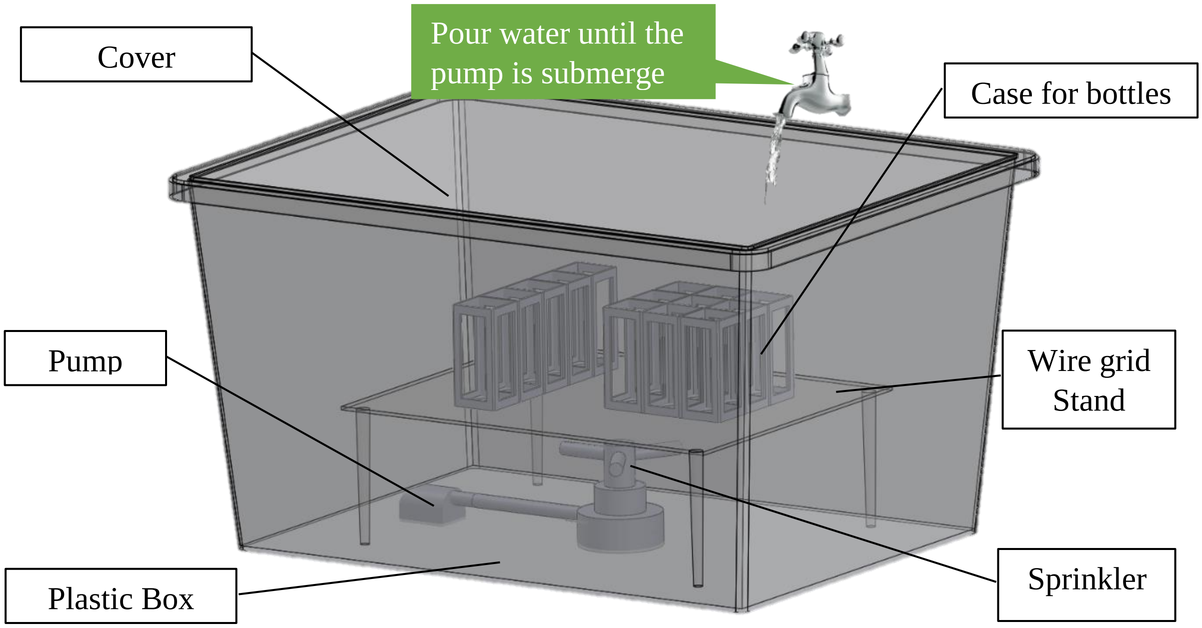


Figure 43: 3-D Modelling of a washing machine

10.2.3 Designed Washing Machine

From the 3-D model, the items which are needed to build the machine was quite clear and are as follows:

Table 15: Item for designing the Washing Machine

Items required	Quantity	Source
Transparent plastic box	1	Local Store
Box cover	1	Local store
Submersible water pump 5-12 voltage	1	Online store
Sprinkler	1	Local store
Wire grid with stand	1	Built using lab resources
Bottle crate	1-2	3 D print

The Transparent plastic box and cover are bought from the local store, while for sprinkler, Y-shaped sprinkler because complexity in design to constructed in lab, instead, a new sprinkler which can spark 8 different patterns was bought. The sprinkler is connected with a mini water pump which was also bought from online shop.

Figure 44: CAD Modelled Sprinkler, New sprinkler and a Mini Pump

For the bottle casing, the shape is too complicate to build in the lab. Therefore, the bottle casing was made using 3 D printer. Two different size of casing 3x3 and 5x1 was printed.

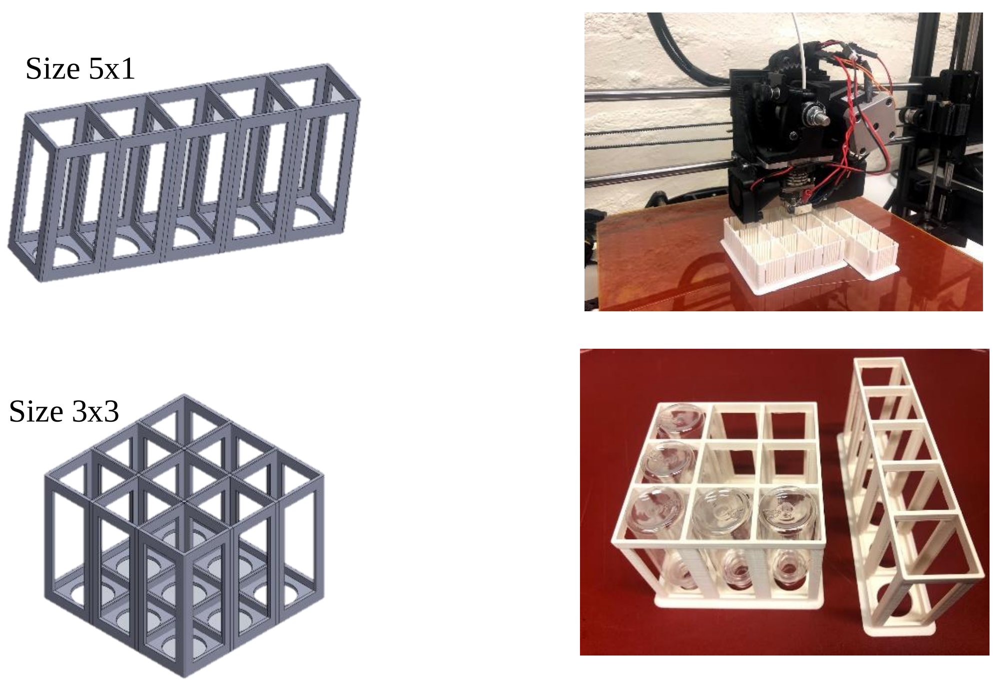


Figure 45: CAD Model, 3-D Printing and Printed Model with some bottles in upside position

A metal wire grid stand was made using the tools and equipment available at the university lab facilities.

Figure 46: Wire Grid Stand

The final assembly design of the washing machine which is shown below has the following features:

- Dimension of 230x300 mm
- Can clean 1-14 bottles at a time (or more depending on casing size)
- Run continuous until the power is switched off
- Less noise
- No leakage of water
- Adjustable discharge of flow
- 8 different patterns of spark

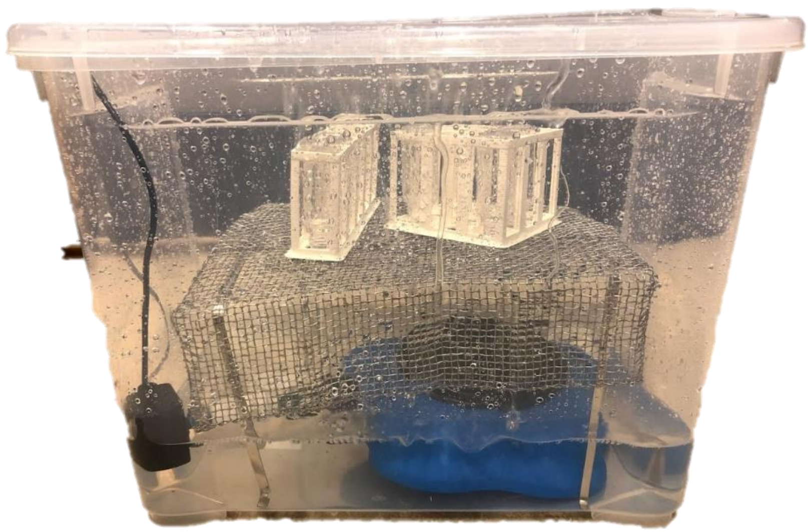


Figure 47: Washing machine

10.3 Filling Machine

Filling section is one of the core-part of the training exercise. If an automatic filling machine is used, the student won't be able to collect measurable data on which they can work together to improve the process. A manual filling of liquid using different apparatus shown in Figure 48 has been chosen for the training. These items were collected from the chemistry lab of the University.

Using these tools to pour 15 ml of liquid inside the bottle will be challenging. As a result, there will be wide variation on the data collected. At the later stage of the training, the students can use some other accurate tool to perform the task. One example could be a use of syringe of 15 ml capacity which will the make the process fast, easy and accurate.

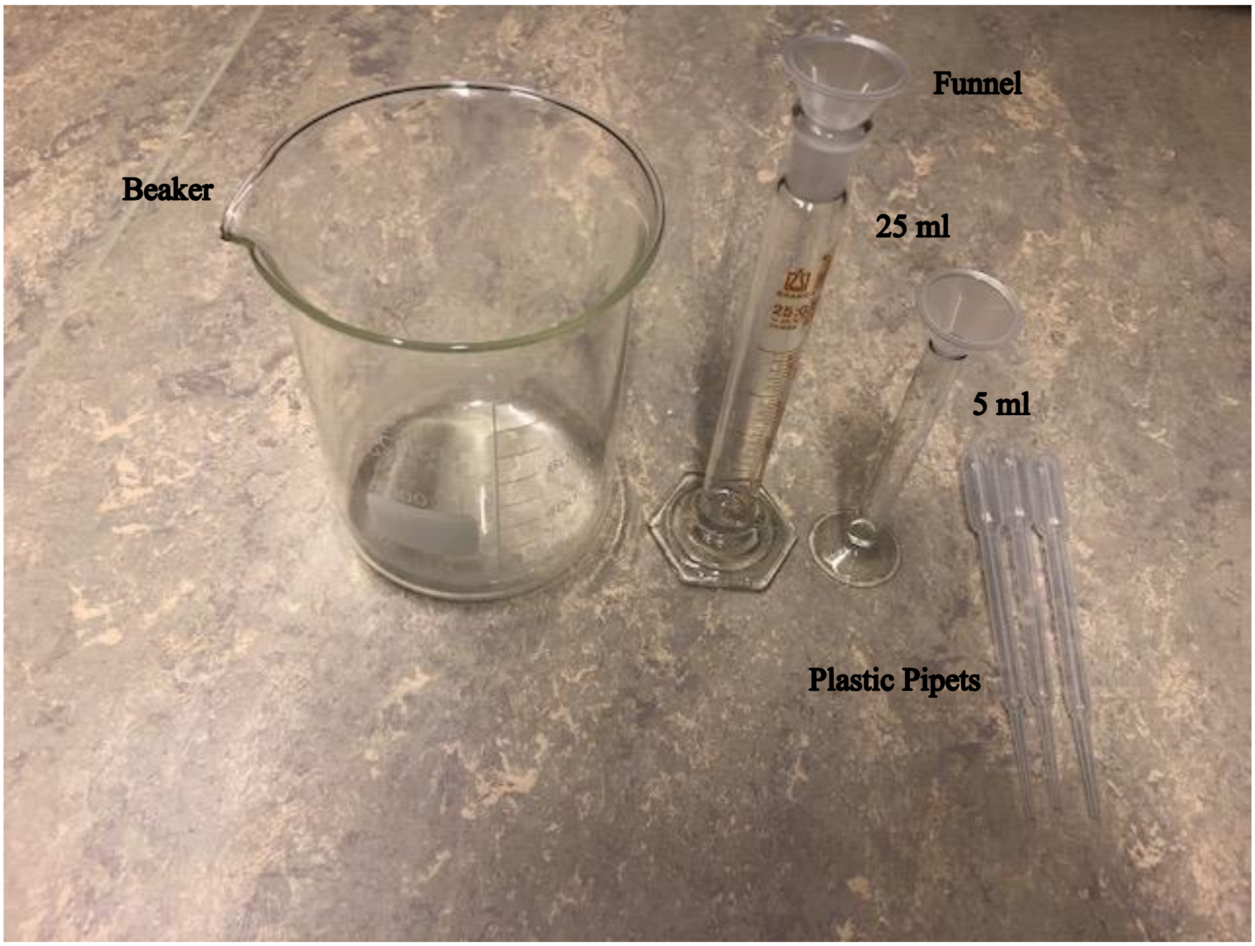


Figure 48: Apparatus for filling liquid

10.4 Capping and Labelling

There will be no machine used for capping and labelling process, both operations are performed manually. First the cap is put onto the bottle and then label is attached on its body. The caps are collected from the store room. (N.B. Store room of this exercise)

The label [Figure 49] is designed keeping the logo of the university at right and the name of the university & training exercise on the middle. On the left is QR code figure which will drag the user to the Industrial Engineering Course page on the official university site.

Figure 49: Label for the bottle

10.5 Crate and Pallet

After the bottle are capped and labelled, the bottles need to be packed inside a box. The only requirement of the box is that it should fairly-firmly hold the bottles and the caps should be visible.

The two different size of crate were designed; 5x2 & 2x2 using cardboard. A pallet was made out of Foam material; size 160x160 mm. The palletizing operation is performed by a robot which is controlled manually. The robot [Figure 51] is a diy self-assembly robot which was bought from the online shop.

The delivered product must have a bar code on them. These barcode are randomly generate code which are used only for demonstration.

Figure 50: Finished Bottles before Palletizing

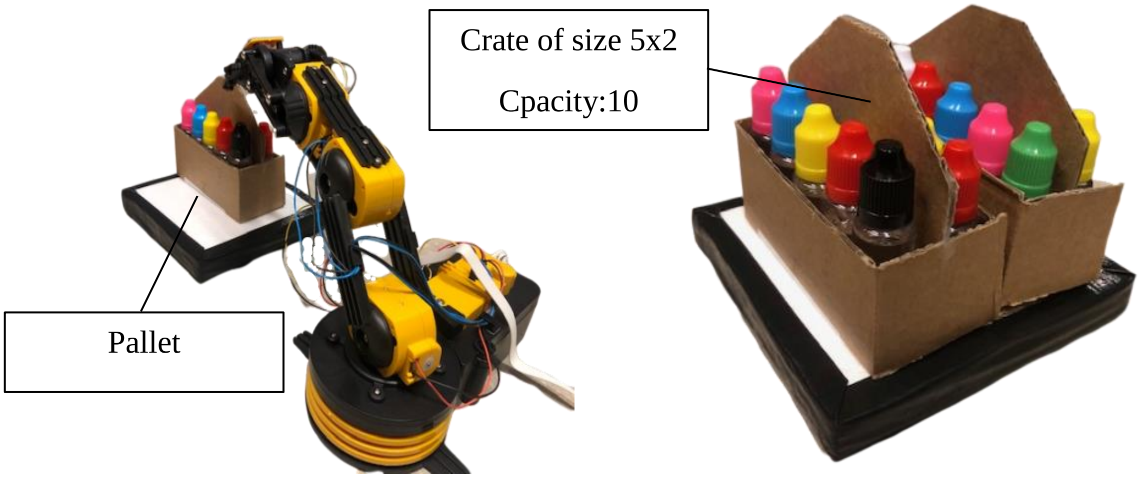


Figure 51: Bottle Crate and Pallet

10.6 Conveyor belt

Though conveyor belt isn't necessarily required for departmentalized layout, it is one of the key elements in In-layout system. A conveyor belt smoothly serves a one-piece flow of parts between processes. This makes the process faster by eliminating unnecessary movement of parts and human workforces. Some requirement of a conveyor belt for this training exercises are as follows:

- Simple, Light and portable
- Belt should be at least 1 m long
- Enough power to transport filled bottles
- Adjustable speed control
- Should have a straight constant motion

10.6.1 Design Concept

The initial concept for the conveyor design [shown in the Figure 52] consists of an electric DC motor connecting with the roller #1 which will drive the belt. Roller #2 rotates freely at the speed of roller #1. The belt and rollers are supported by two metal plates which stand on the ground with four leg support.

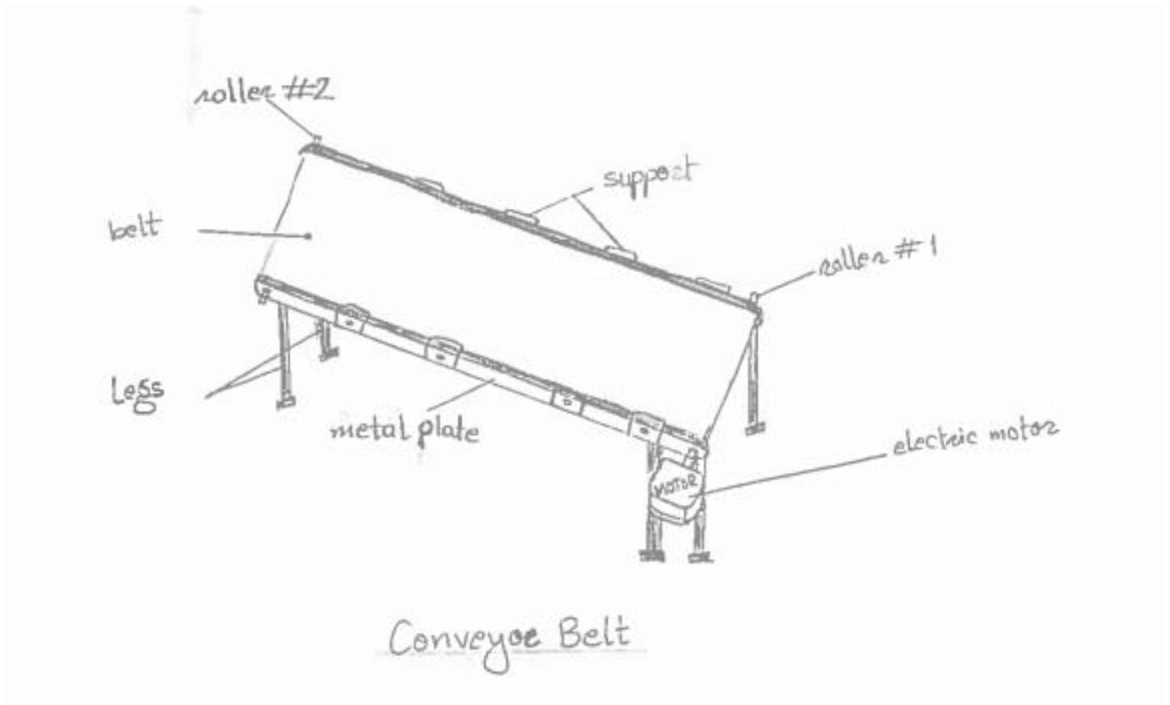


Figure 52: Design Concept of a Conveyor Belt

10.6.2 3-D Modeling

Before building 3-D model of a conveyor belt, a visit was made at the workshop laboratory of the university to check the resources that are available and could be used. Plenty of metal plate, cylindrical rod, V-Slot Aluminum bar with T-Nuts were discovered. Cylindrical rod can be machine in the turning machine to make desired shape of rollers while V-Slot Aluminum bar can be used as a support for the conveyor belt. V-Slot bar has T-Nuts inserts inside its groove area. These nuts can slide all way along the groove area, which will give some possibilities in adjusting the length of the conveyor belt and can also give support to electric motor. Since it has a rectangular cut-V section profile and are flat & light, instead of long four legs, V-Slot bar can replace them.

Here is the list of items that will be used for the design:

Table 16: Material Required for Conveyor Belt Design

Items	Material	Source
Belt	Rubber or plastic	UiT workshop Laboratory
Metal plate	Iron/Aluminum alloys	UiT workshop Laboratory
V-Slot Aluminum bar	Aluminum	UiT workshop Laboratory
Electric DC motor	Any	Local store/ Online
Roller	Any cylindrical rod	UiT workshop Laboratory
Bearings	Any	Store

A 3-D model was constructed on SOLIDWORKS, an assembly view of the conveyor is shown in the Figure 53 and the item used to construct the model can be shown in the Figure 54. The size of the conveyor belt is approximately 1500x80 mm (Belt area).

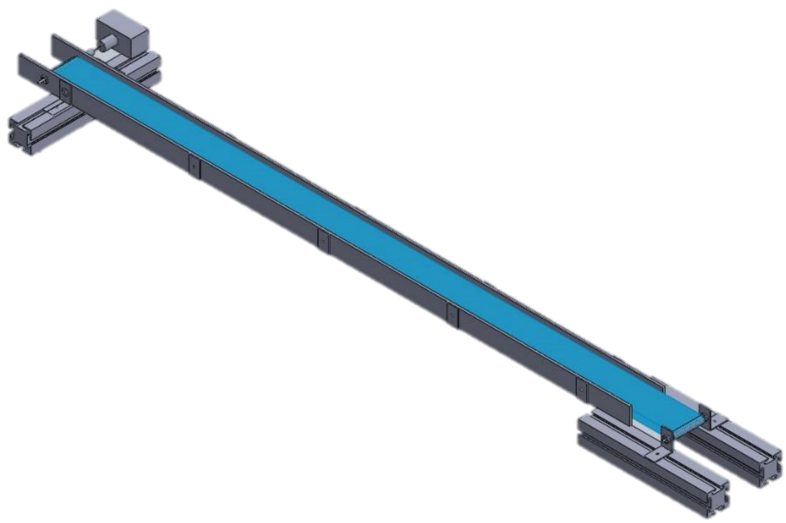


Figure 53: 3-D CAD Model of a Conveyor Belt

The exploded assembly view of the conveyor belt has shown the details of parts used to construct it. Nuts, bolts, washers, electrical circuits, etc. are ignored here but will be taken into account during the construction phase.

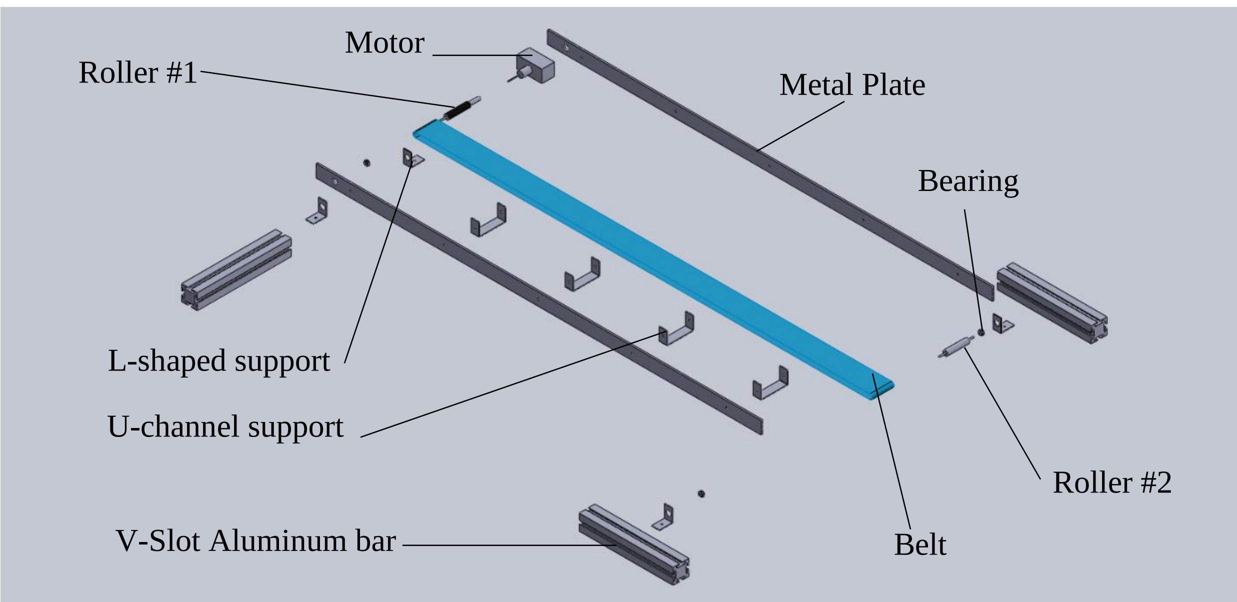


Figure 54: Exploded View of a Conveyor Belt

10.6.3 Build a Conveyor Belt

Before starting to build a conveyor belt, the DC motor was first ordered. Upon arrival of the motor, its output shaft was inspected. The size of output shaft was 3 mm hexagonal shape. So, special type of Roller #1 [refer to Figure 54] was modelled again on SOLIDWORKS to fit the output shaft inside the roller. The modified roller was produced by 3-D printer. An extra gear was added to the shaft firstly to support the 3-D printing because the shaft was too small [Ø 8mm] and long [130 mm] and secondly, the power can be shared to drive another belt [just in case]. The Roller #2 was produced by machining a cylindrical rod by feeding it into the turning machine.

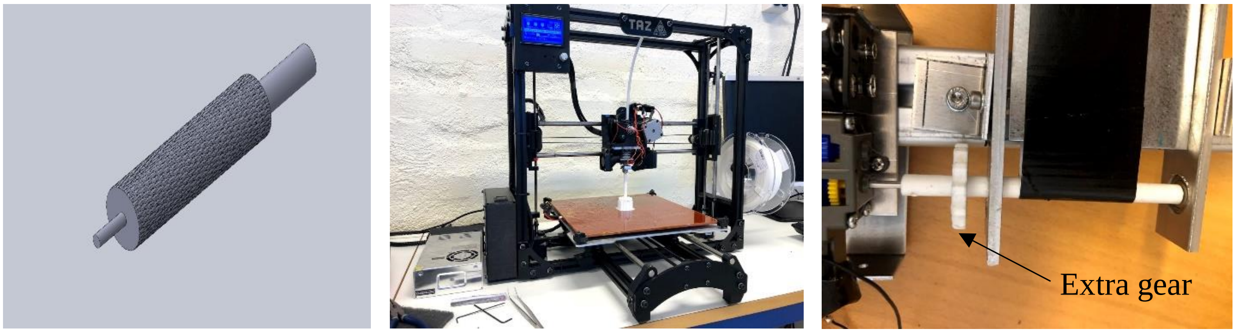


Figure 55: Roller #1 Modification [Left: CAD model, Middle: 3-D printer printing the modified Model, Right: Modified model]

The frame was constructed using 2 metal plate and 4 x U-channel support on it. Both rollers were inserted with the bearings attached on them [refer to Figure 56]

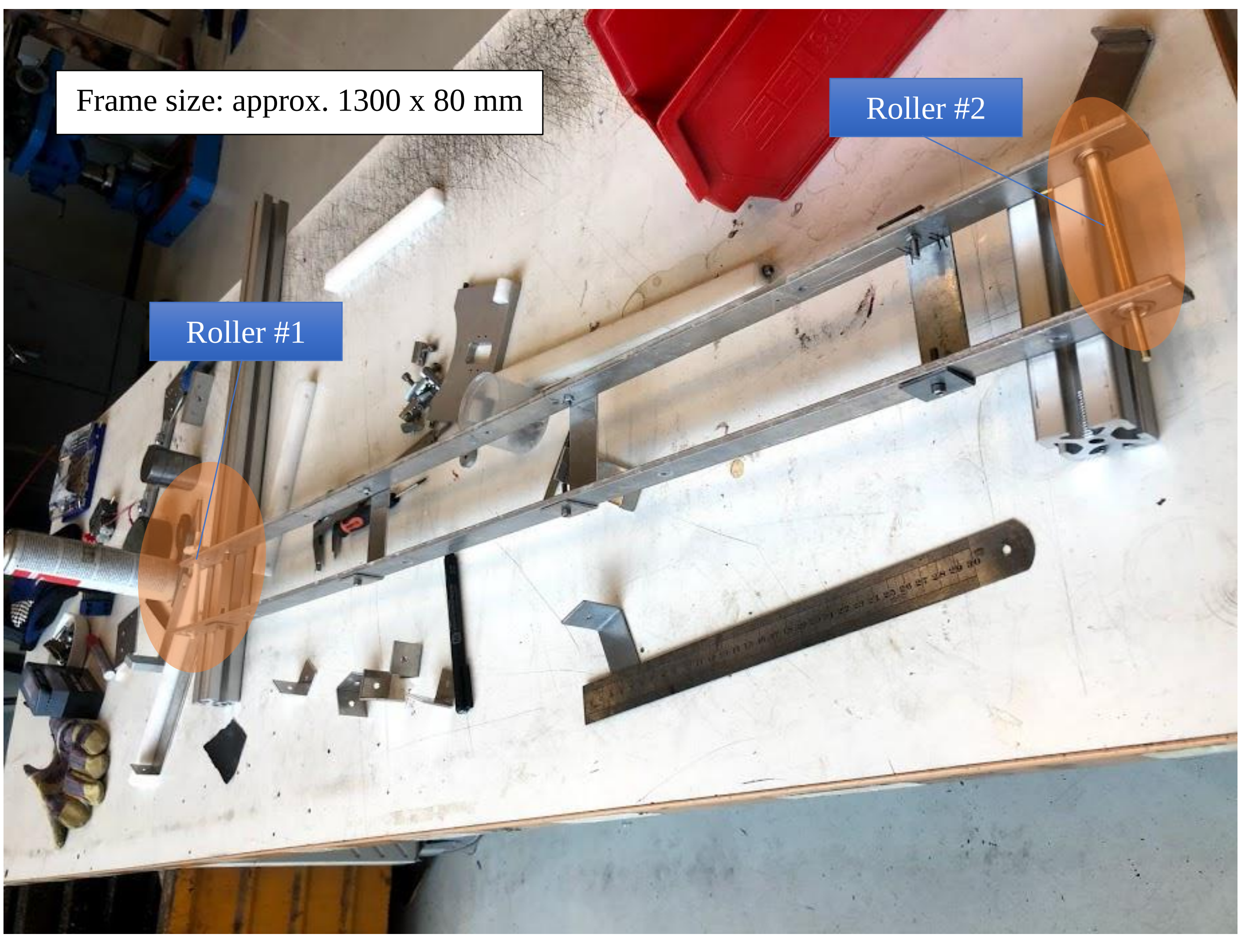


Figure 56: Frame for a Conveyor Belt Design

After that, the rest of the parts were constructed using cutting, drilling, shaping operation and then assembled, the final product can be seen in the Figure 57.

Figure 57: Constructed Conveyor Belt

Table 17: Parts Used in Conveyor Belt Design

Items	Quantity	Size
Metal plates	2	1200 mm, 4 mm thick
Sheet metal	1	1000 x 78 mm
Roller #1	1	Ø 8mm, 130 mm
Roller #2	1	Ø 8mm, 130 mm
Belt	1	1300 mm
U-channel support	4	2.5 x 30 x 90 mm
L-shaped support	6	30 x 30 mm, 2.5 mm thick
V-Slot Aluminum bar	2	40 x 40 x 225 mm
V-Slot Aluminum bar	1	40 x 40 x 280 mm
Bearing	4	Ø 4 mm
M4, M5, T-Nut [bolts, nuts, washer]	N/A	Standard

The Table above show the information of different parts used for the conveyor belt design. Some noticeable features of the constructed conveyor belt are listed below:

- Variable speed
- Forward and reverse motion
- Adjustable length of the conveyor belt
- Two-way power supply: 3-5.5 v battery or charger cable
- High torque approximately 2276 gf/cm
- Rpm: 38 [ideal speed]
- Adjusting screw on the base leg of a conveyor belt for levelling

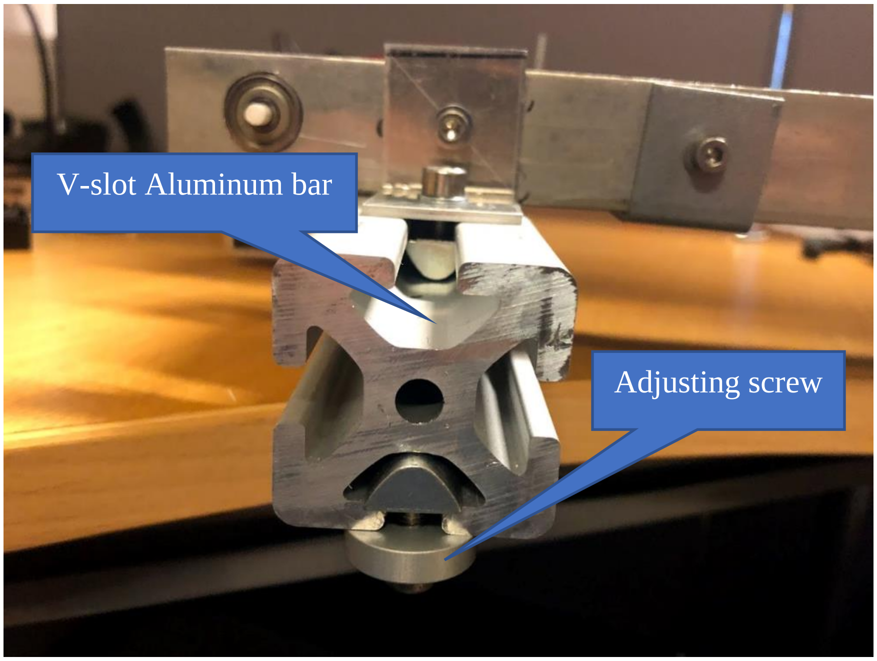
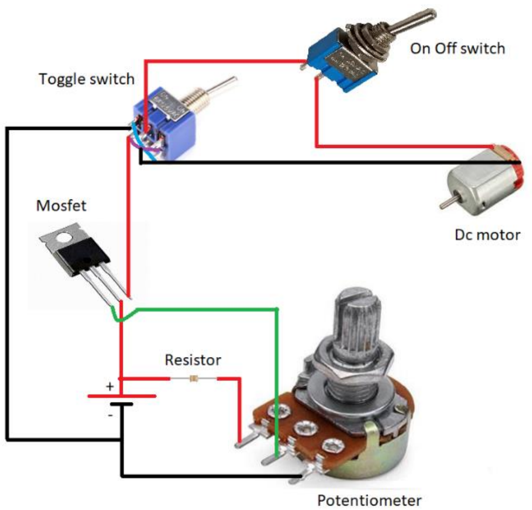


Figure 58: Adjusting screw

10.6.4 Circuit Diagram

Figure 59 shows the circuit diagram connection used for operation the conveyor belt. This circuit allow the conveyor to operate with variable speed and also change its direction. To change the speed of the conveyor, turn the knob of the potentiometer clockwise or anti-clockwise. Use the toggle switch to switch the direction of movement of the belt. The Moset in the circuit can be configured as source follower. It has an ability to open and close the circuit depending on the amount of voltage applied on it and also can magnify the current flowing thorough it which will produce fine output effect. Mosfet itself can act as a switch but for ease extra On/Off switch is added on the circuit.



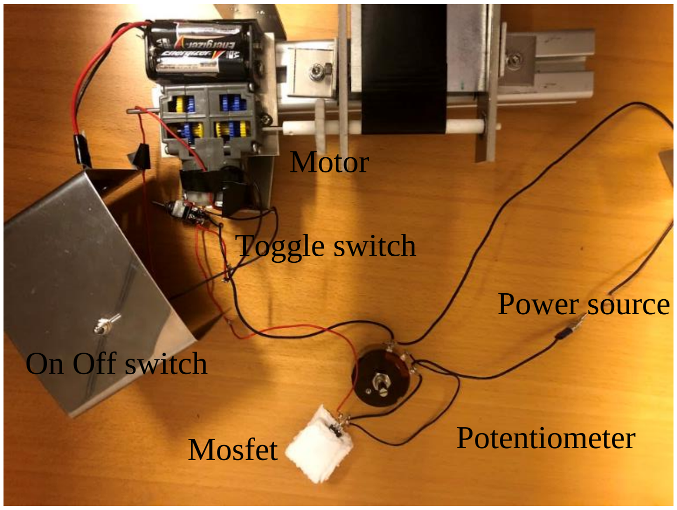


Figure 59: Circuit Diagram for a Motor operation

10.7 Cost Summary

By ignoring the cost value of the materials and items that were collected form UiT Lab facilities. The following items were bought from local and online store. Total building of the whole training kit cost is approximately NOK 1750.

Table 18: Cost Summary Table

Store Section	Bottles	NOK105
Washing Section	Plastic box	NOK 50
	Cover	NOK 20
	Sprinkler	NOK 75
	Submersible water pump	NOK 70
Palletizing and Packing	Toy Industrial robot	NOK 550
	Robot USB Interface	NOK 450
Conveyor Belt	Dc electric Motor	NOK 130
	Gearbox	NOK 130
Miscellaneous	D-Batteries x 4	NOK 99
	Battery casing	NOK 30
	Wood Glue	NOK 37
Total Cost	-	NOK 1746

11 TRAINING DELIVERY

After completion of the design part, now it is time to define the content of the training exercise. As mentioned in earlier sections, this training exercise is a project-based training work where the students are given a case on which they work together to solve the problem. During the whole training period the students will be following the DMAIC methodology to investigate, analyze and solve the problem.

11.1 Problem statement

The problem statement should address the current status of the company, its targets and objectives. It clearly presents what is the current problem of the company and their expectation for future. Here is one of many examples of a business case which can be used for the training purpose:

A new small-scale beverage company "ABC company" which was established a year ago has not been able to flourish its business. ABC is producing a special consumable liquid for the people living in the North of Norway especially in Narvik Region and it aiming to extend its business to the nearby cities.

Meanwhile, ABC started to lose its customer in Narvik. A lot of complaints have been received regarding the amount, quality, handling and delivering of the bottles. Due to this, a company is losing a significant amount of money and are under serious threat to shut down the industry.

Figure 60: A Problem Statement [55]

The manager doesn't seem to know what went wrong. In fact, he is very surprised with this outcome. According to him, everything is working well, there have never been any fault in the manufacturing process and all the workers are skilled & are working fine. However, he came

to know one thing that because of very long lead time, the customers started to lose their patience – thus start to seek other options. *Now ABC wants to implement LSS to restore and spread its business profile. Thus, looking for a team to run this project. This job has been granted to the participants of this training exercise where they will try to find the solution to the problem.*

11.1.1 Existing Layout

The existing layout of a process should be departmentalized which is run with a batch size flow of the product on the production line. The layout setup is prepared by a team leader or the instructor. [For more information refer to section 9.6, Page no.58]

11.1.2 Key Roles

There are 8 different roles for the training activity which the team leader or instructor must assign during the training period within the team. Multiple roles can be performed by a single person.

Table 19: Roles and Responsivities for the Exercise

Roles	Persons	Responsibilities
Store keeper	1	➢ Receive empty bottles from the seller ➢ Delivers bottles to the washing section as requested
Bottle Washer	1	➢ Wash the empty bottles
Liquid Filler	1	➢ Fill the empty bottles
Capping and Labelling	1	➢ Put on caps and labels on filled bottles
Packing and pelleting	1	➢ Pack and palletize the bottles
Observer	1	➢ Documents reality
Re-work	1	➢ Collects the defects
Customer	1	➢ Collets the order

11.1.3 Constraints & Requirements Description

Here is the list of constraints and requirements which should be strictly followed during the 1st simulation period. As for 2nd experiment, constraints could be modified but only upon facilitator's approval.

11.1.3.1 Exercise Constraints

- The bottles coming out from the store sections are defects free. Any physical damage on bottles afterwards are the aftermath of mishandling or wrong process.
- Washed bottles are neat, clean and contamination free
- Washed bottles cannot be handled with bare hands
- Filling liquids should not be touched
- Outpouring of liquid is not allowed
- Caps and labels are defect free

- Only filled bottles which pass the quality test are capped and labelled respectively. Note: Labelling before capping operation is not allowed
- Label should be applied only on specified area and should be clear & smooth without any wrinkle or crease
- The inspector has full authority in quality inspection
- The inspector will keep record of all data collected
- The finish bottles are palletized by a robot
- Specified dimension of label and area to attach on the bottle

11.1.3.2 Customer Requirements

- Customized order must not take longer time for delivery
- Finished bottles should be well packed
- Pass/Fail data for each bottle must be collected
- All data must be collected "real time" during the exercise period
- Takt time & Lead time

11.1.3.3 Business Requirements

- Bottles must be produced in a batch size
- Workers need to focus only on their assigned job
- Workers must perform at their highest level otherwise may result in Probation/Expulsion
- Production start only after receiving customer order

11.1.3.4 Machinery Requirements

- Modification of a washing machine is not allowed
- Filling liquids are defect free
- All machine available are irreplaceable

11.1.4 First draft of project charter from sponsor

First draft charter is a rough note which is created by receiving information from the Manager or Owner of the factory while having an initial meeting regarding the existing problem with a LSS Black Belt or a Project Manager. Usually, includes very brief information about the problem, its targeted goals and the amount they are willing to spend for the project.

Table 20:First Draft of the Project Charter

Problem statement	Short description of the current business problem
Business impact	Effect on the business activities
Goals	Expectation and target goals (what does the company want)
Timeline	Specify the time frame
Initial budget	How much the company can offer for the project?
Project Manager	Name of person who will lead this project

Upon mutual agreement between project leader and business representative, the deal will be made, a team will be formed and LSS project is ready to go.

11.1.5 Assign Roles and Mention Task Responsibilities

The team leader should assign role to each member before carrying out the first experiment. Every member should be clear about their task and responsibilities [Refer to Table 19].

Table 21:Task Responsibilities for the Training Exercise

Operation	Methods	Task
Inspection of bottles	Visual inspection	• Check for damage, cracks, discolor, etc. • Check size and shape • Count bottles
Washing bottles	Washing machine	• Feed the bottles into the machine • Take them out and manage
Filling liquids	Filling machine	• Fill desirable amount of liquid in the bottles • Filling with special care
Quality inspection	Visual inspection	• Inspect the liquid quantity (Refer to 9.7) • Inspection of leakage • Sort the bottles between good & defective ones
Capping and labelling	Special machine	• Put on the caps and label on each bottle
Packaging and Pelleting	Manually	• Pack, palletize and ship • Use robot to palletize

11.1.6 Output Requirement on Each Processes

It is also important to be clear about the output requirement of the process. In case, if it failed to meet those requirements, the products are considered as defectives ones and won't to processed further.

Table 22: Output Requirement in Each Processes

Processes	Output requirement
Store and inspection	• Bottles and caps are free of defects • Bottes and caps are transported separately
Washing bottles	• Bottles are neat, clean and contamination free • Reused bottles are free from old labels • Washed bottles cannot be handled with bare hands
Filling Liquid	• Pouring amount must be accurate every time for each bottle • No outpouring of liquid is permitted
Inspection	• Check for quality • Liquid levels are scrutinized
Capping and labelling	• Capping followed by labeling are performed manually • Labels are attached on bottles only on specified area • Labels should be clear and smooth, free of wrinkle or crease
Packaging and Pelleting	• Bottles are packed and palletized according to customer requirement

11.2 Phase I: Current Reality

Phase I is all about finding about the current reality of the process and identifying waste in the process. During the time period, the team will carry out the first experiment, collect data and inspect analyze those data by the application of various LSS tools. At the end, the team should come up with the list of solutions that could solve the problem that are occurring in the process. Its main objectives are:

- Document "as-is" process
- Identify value-added and Non value-added process
- Quantifying "as-is" process

11.2.1 Phase I: Application of DMAIC

Phase I covers first three major steps of DMAIC methodology; Define, Measure and Analyze.

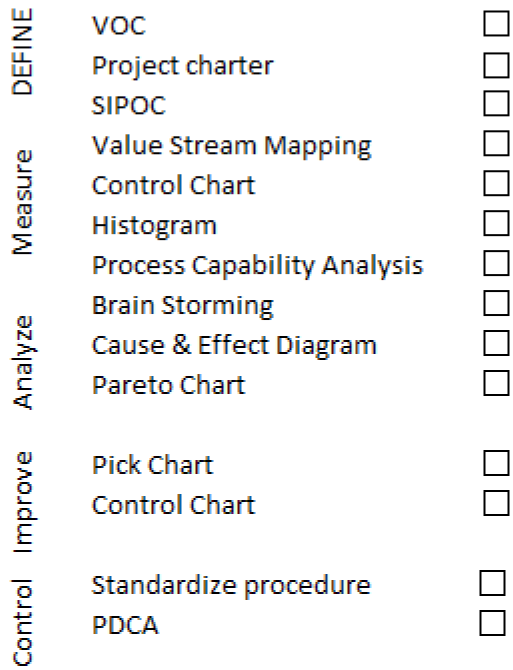


Figure 61: LSS Tools under DMAIC Structure

The first thing the team need do is start collecting the feedback and review from the customers. If possible, the team should try to communicate with the reliable customer to discover what are their expectation, priorities, preference and aversions [56]. Based on these facts, the team can now prepare a list based on Voice of a Customer (VOC). This will allow them to identify its critical to quality (CTQ). For example: If a customer wants low product cost, its CTQ would be cost per unit. Similarly, if VOC is short delivery time, its corresponding CTQ would be lead time. This will allow the team to work already on something before even starting to collect data.

Next thing is to create a clear and concise Project charter [5.5.1.1, Page no. 35]. In addition, the charter should also state SMART goals, project scope information, cost of operation and its projected benefits.

The team should now define what are the measurable parameter that they will use during the training exercise. Every member should be clear on what, how, when to measure and collect the data. The measured data are verified according to the specification limit.

Now the team is ready for the 1st Run of the beverage factory simulation. The simulation will start right after the customer place an order and ends only after the customer receives his order quantity of product.

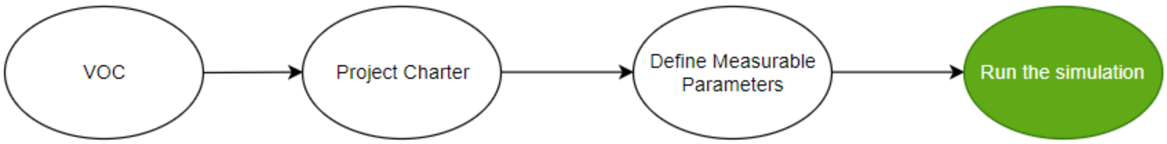


Figure 62: Things to do before the run of the simulation

While running the simulation, for each bottle which are being processed, the measuring parameter (for example: volume of the liquid quantity and its weight are recorded) in a separate sheet of paper. If these values are under the specified specification limit, the bottle are forwarded to the next process, otherwise they are regarded as defects and are sorted out. The process will run continuously until the delivery is made.

Table 23: Specification Limits

Measures	Liquid level	Weight of a bottle
Target		
Upper specification limit (USL)		
Lower specification limit (LSL)		

Table 24: Sorting the Product

S.N.	Liquid Volume	Weight	Status
			Pass/ Fail

After the completion of the simulation, the following information can be received:

- #1 Customer order
- #2 Total bottles processed
- #3 Number of defects processed
- #4 Work in progress
- #5 Takt time
- #6 Total Lead time

The cost per unit of the bottles produced can be calculated using the formula shown in Table 25:

Table 25: Cost Calculation

S.N.	1st Experiment	Formula
1.	Yield	Customer order/ Total bottles processed
2.	Available Time	Takt time * Customer order
3.	Non-Value Time	Abs [(Total lead time) - (Available time)]
4.	Time Penalty Cost	(Non-Value time) * NOK 100 cost per sec
5.	Work-In-Progress Cost	(Work in progress) * NOK 500 cost per unit WIP
6.	Rework Cost	(Number of defects) * NOK 1500 cost per failure

7.	Warranty Cost	(Customer order) * NOK 100 warranty cost per unit
8.	Cost of Poor Quality	Rework + Warranty Cost
9.	Total Cost	Time penalty cost + Work in progress + Cost of poor quality
10.	Cost Per Unit	Total Cost / Customer order

The cost per unit is a crucial figure both from business and customers perspective. Therefore, the team should work at their best level to reduce it whilst maintaining the quality.

After the completion of the 1^{st} experiment and cost calculation, the team now sit together to identity different 7 form of waste [refer to 3.1] and brainstorm the ways to get rid of the Non-value added waste in the process. They will also create a SIPOC [5.5.1.1] diagram and a Value Stream Mapping [3.3.1] to further facilitate in identification of wastes.

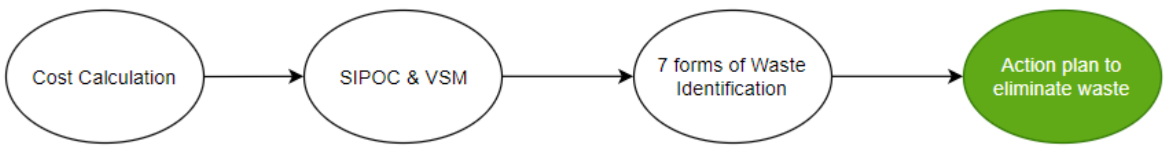


Figure 63: Things to Do Before Executing an Action Plan

Statistic Calculation

For the statistical calculation use the data collected during the experiment from Table 24. Calculate Mean ($\bar{x}$) and Standard Deviation (σ). Using the formula from 4.1.10, Calculate the Process Capability indexes to determine whether the process is centered and capable or not. Also calculate DPMO, using Baseline formula and its corresponding standard normal curve area [Refer to APPENDIX A].

The data collected can be also converted into following charts to investigate the nature of the data and analyze its variation:

Table 26: Statistical Charts

Charts	
Normality plot	• To check the normal distribution of the data collected
Histogram	• To determine normal distribution of the data • To determine skewness and kurtosis
Control chart [4.1.9]	• Detecting special cause of variation • Monitor process • Study trend pattern of data

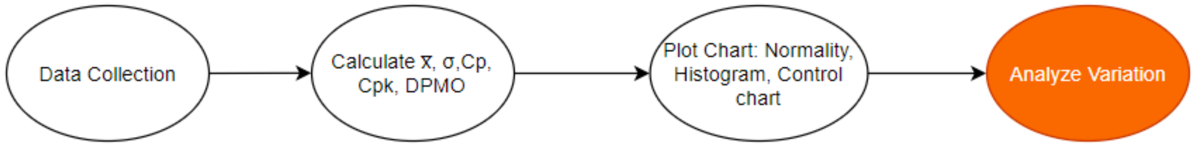


Figure 64: Statistical Tools for Analyzing

Identifying and Verifying Causes

Normally, during the 1st run of the experiment, it is expected to have a wide range of variation in product quality & quantity and encounter too many defects in products. This step helps in identifying the true root cause of the problem.

- Identify the causes of the problem through Brainstorming
    - Gather ideas
    - Consolidate ideas
- Identify the caused using "5 why?" [4.1.3]
- Identify using Cause and Effect Diagram [4.1.2]
    - Identify and list the causes based on "6 M's of variation" [4.1.1]

After identification, list out the number of causes of the problem, create a Pareto Chart [4.1.7] and apply 80 - 20 rule to prioritize those causes which have adverse effect on the problem. From the remaining list of causes, create a SOV matrix. A SOV matrix consists a list of sources of variation or causes and their respective action plan to eliminate those variation. All the action plans are categorized on a PICK-Chart based on their severity level [easy, difficult] and pay-off level [low, high]. PICK, stands for Possible, Implement, Challenge and Kill, encourages on choosing those action plan which can be implemented immediately.

With the completion of PICK-Chart, Phase I of the training activity is completed.

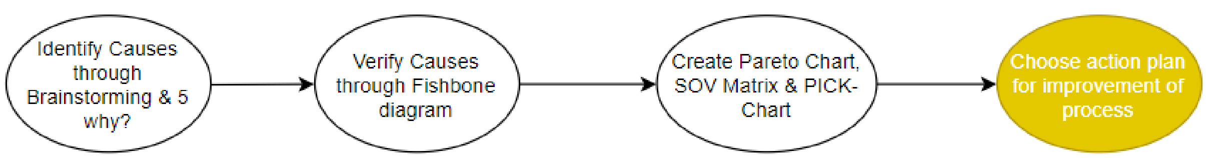


Figure 65: Methods of Choosing Action Plans

11.3 Phase II: Improved Process

Phase II is all about using experience from the Phase I to improve the process and reach the targeted goals. In the phase II, the team should execute some or all of the following actions before starting the 2nd experiments:

- Eliminate batch size production to one-piece flow production
- Change layout from departmentalized to other layout (for instance: In-line)
- Execute the action plan which are discussed from PICK-Chart

- Implement PDCA [3.3.8] on every process
- Standardize work procedure (washing time, movement of robot, etc.)
- Remember to implement list of Action plan for eliminate waste
    - Implement 5 S [3.3.7]
      The bottles caps could be sorted in advance. If there is customization in customer order
    - Pull system (use of Kanban cards) [3.3.10]
      Kanban cards allow the team to perform when and when not to

After implementation of all these action plan, the team is ready to run the 2nd experiment. However, the constraints and requirements description for the training exercise remains the same and cannot be changed [11.1.3].

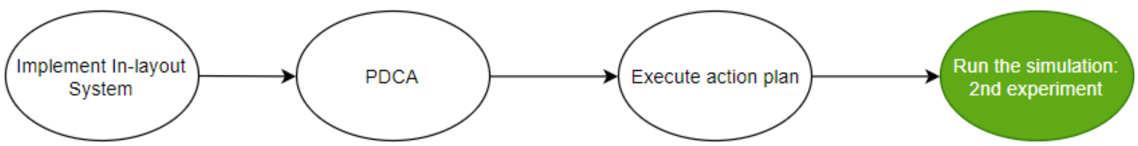


Figure 66: Run the 2nd Experiment

Statistic Calculation II

A new set of data are collected, the team will calculate new cost per unit price and will repeat all calculation and action performed in Statistic Calculation I.

The team will once again analyze the variation of the data through Normality Plot, Histogram and Control Chart.

At this point, the team should be able to meet all targeted goals and objectives. If not, the team will once again go through "Identification and verification of causes" and comes up with new action plan, implement in the setup once again and run the experiment for the 3rd time.

As soon as the target goals are meet, the team will document the result and the team will be dismissed.

12 STUDENT MANUAL & EXCEL MODEL

To serve as a training material, the training exercise also have a student manual and Excel Model.

12.1 Student Manual

A student manual contains all descriptions regarding the training course and a complete guide that will escort the students through-out the training period.

12.2 Excel Model

Along with the student manual, the student will also be using an interacting Excel Model for exploiting various LSS tools during the training period. The principal idea of using an Excel Model is to provide student a quick access on LSS tools (only those which are relevant for this training exercise) so that they do not have to spend time on creating them rather they can utilize that time to brainstorm various ways in improving the flow & speed of the process and reducing variation on the product.

The Excel Model is designed such by inputting some parameters, the excel will automatically generate LSS charts and figures which the students are supposed to use during the training period. Multiple spreadsheets have been used such that the student will know where they are and what they are working on.

The Model have been constructed using following methods:

- Assigning functions and formulas on cells
- Visual Basic Programming
- Adding buttons and checklist
- Attaching macros

To run this model, the first thing the student need know is, they must have a "*Developer*" tab on the excel window. If not, it can be added by following this path:

File>Options>Customize Ribbon>Main Tabs>Check on Developer>OK

For easy user interface with the excel program, the input boxes (cells) are filled with light orange color while the summary results boxes are filled with light green color.

12.2.1 Inside the Model

Check List

The first Worksheet on the model is LSS Project Check List. It contains all the list of all LSS tools under DMAIC format which the students will be using during the training period. The checklist contains an interactive check box, when the box is checked, it turns green. All the check box must be checked (which means all the tools have been used during the training period) in order to finish the training activity. If some are missing, this check box will visually show which tools are due to complete.

To illustrate, in the Figure 67, SIPOC, Process Capability Analysis and Pick Chart are not checked and are due to complete.

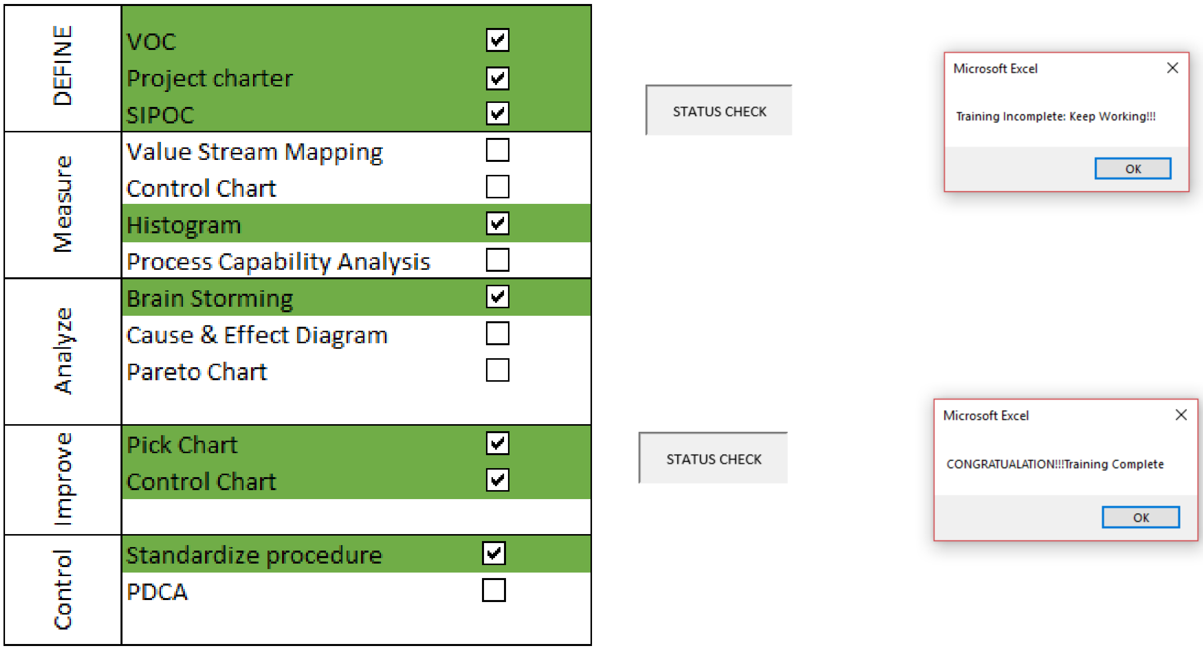


Figure 67: Checklist (L), Status Check Box (R)

In addition, the check list has ***status check box***, by clicking on it, the user can get updated information about the project. If all the check lists are marked, the ***status check box*** will display "Congratulation!! Training Complete", if not it will display "Training incomplete: Keep Working". [For VBA codes, refer to AppendixE.1]

Template Tools

The Model also includes templates for Project Charter, Lean Waste Identification table, SIPOC diagram and Value Stream Mapping (VSM).

Input Data worksheet

In this section, the students should input the results obtained from the experiment.

- Input the specification limits
- Customer order
- Number of bottles processed & Work-in-process
- Takt time and Lead Time
- List of data (for example: Liquid volume for each bottle which are processed)

Table 27: Input Box for Data Collected

INPUT BOX						
	Water Volume			Weight of a bottle		
S.N.	1st Experiment	2nd Experiment	3rd Experiment	1st Experiment	2nd Experiment	3rd Experiment
1						
……						

Table 28: Input Parameters

INPUT BOX			
	1st Experiment	2nd Experiment	3rd Experiment
Customer Order			
Total Bottles Processed (n)			
USL			
LSL			
Number of Defects			
Work-In-Progress			
Takt Time			
Total Lead Time			

Statistics

Under the Statistics worksheet, click on the Button (at the top of worksheet): "Run the Model: 1st Experiment" to calculate all statistical parameter. Successful completion of statistic calculation will print out a message box with text "complete calculation#1". This way, the user will get notified of the task being completed. [For information refer to AppendixE.2]

Figure 68: Button for Running the 1st Experiment

The excel will automatically calculate all the statistical parameter including Cost per unit. If they want to generate Normality Plots, Histogram with Normal Distribution Curve and Control Chats, just click on their respective buttons. To delete all the charts, click on "Delete All". The students have also possibility to customize the chart format. All edits will be saved automatically.

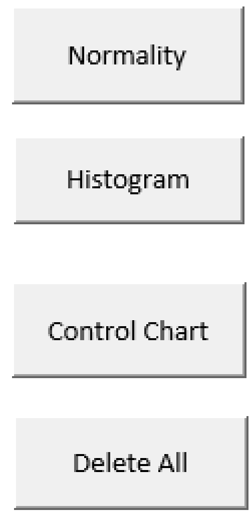


Figure 69: Buttons for Creating Statistical Charts

Fishbone Diagram

To generate the fishbone diagram, the students first need to identify the major problem of the process and based on that, should enter the list of possible causes that are contributing to a main problem and sort them with respect to 6 M's (Measurement, Manpower, Materials, Mother Nature (environment), Methods & Machinery). [For information refer to AppendixE.3]

Table 29: Input Box: Fishbone Diagram

INPUT BOX	1. Measurements	2. Manpower	3. Materials
	➢		
	➢		
	4. Environment	4. Methods	6. Machinery

Note: There are only 5 section to list the possible causes for each M's. If there are more than 5 causes for a single M (for example: 7 list of cause under Measurements), the team should stop and try to resolve them first and afterwards come back to Fishbone diagram.

Only first 3 list of causes for each M's are displayed on Fishbone diagram to eliminate unpleasantness and chaotic diagram, however the rest of the list will still be considered for Pareto Diagram and so on.

Then Click on DIAGRAM to create a Fishbone diagram, CLEAR to clear the text on the diagram and DELETE DIAGRAM to delete the diagram.

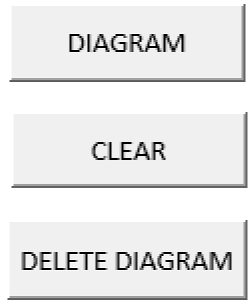


Figure 70: Button for Creating Fishbone Diagram

Pareto Chart

To generate the Pareto Chart, Use Scoring Method [57] to prioritize the list of causes mentioned in Fishbone diagram by assigning weight and score value on scale of 1-10.

Table 30: Input Box for Pareto Chart

		INPUT BOX		
S.N.	Causes	Weight	Score	Points
….	*Automatically adopted from Fishbone			

To generate Pareto Chart, check on "Create pareto Chart" and uncheck to delete it. [For information refer to AppendixE.4]. Pareto Chart will automatically sort out the list of cause into major causes and minor causes. Major causes, area of interest, will get transferred to the SOV matrix for further analysis.

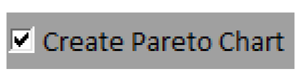


Figure 71: Pareto Chart Checkbox

SOV Matrix and PICK Chart

In this section, assign Action Plan for every source of variation. SOV are automatically generated after the pareto chart is constructed. For each, Action Plan categorize them according to its severity level (Easy or Difficult) and also Pay Off lever (Low or High).

Table 31: Input Box: SOV and PICK Chart

Source of variation	Action Plan	Severity	Pay-OFF	PICK Category
*Only Major Causes from Pareto chart				

Now, click on "Create PickChart" to generate Pick Chart. Similarly, click on Clear "PickChart" and "Delete PickChart" to clear and delete the chart respectively.

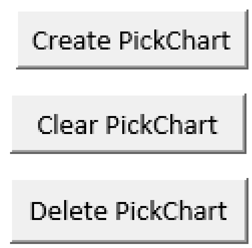


Figure 72: Button for Creating a Pick Chart

The PickChart will allow student to choose those action plan which can be implemented and forget about those which fall under the kill section. The team has possibility to choose the action plans which fall under the possible and challenge category but at their own risk and expense.

Statistics II

After implementation of action plan, the team will run the 2^{nd} experiment. The new data collected are transferred on Input Data Box on Data worksheet. Then go to the Statistics worksheet, click on the Button (at the top of worksheet): "Run the Model: 2^{nd} Experiment" to update the calculation and enjoy the excel features.

Figure 73: Button for Running the 2^{nd} Experiment

The excel has also possibility to run the model for 3^{rd} experiment. Usually, the desirable results are obtained during the run of 2^{nd} experiment.

13 TEST RUN OF THE TRAINING EXERCISE

To testify the training exercise, a test experiment was carried with a test team (total 6 person). The training exercise was performed inside the UiT classroom [shown in Figure 74]. A trail run was carried out before starting the simulation just to make clear of what the team have to do.

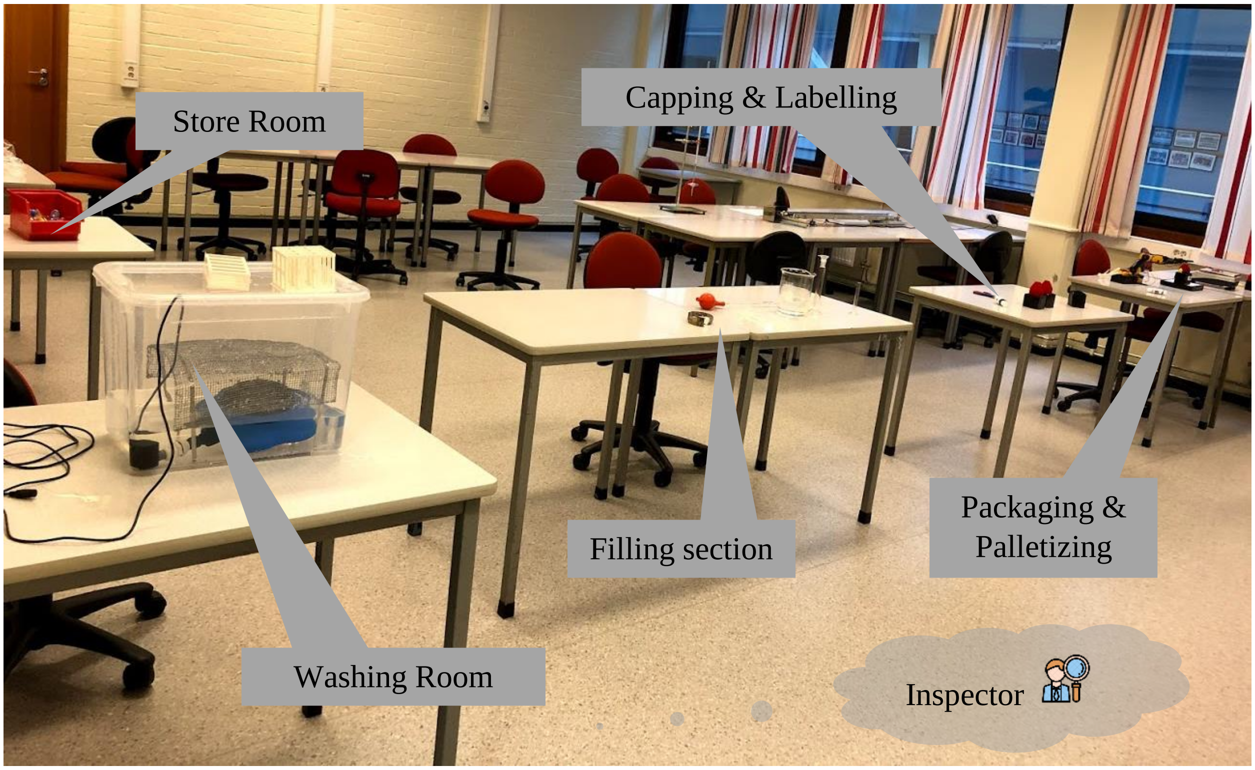


Figure 74: Departmentalized set up for Test Run

13.1 First Simulation

As discussed earlier in above sections, the first layout set up was done according to departmentalized layout system.

After explaining and assigning task for every team member, the 1st experiment was started. The main points are shown below:

- Target 15 ml (liquid inside the bottle)
- Customer order: 20 bottles
- Batch production size: 4
- Washing time: 15 seconds
- Task for filling 15 ml was performed using 5 ml tube (pouring thrice)

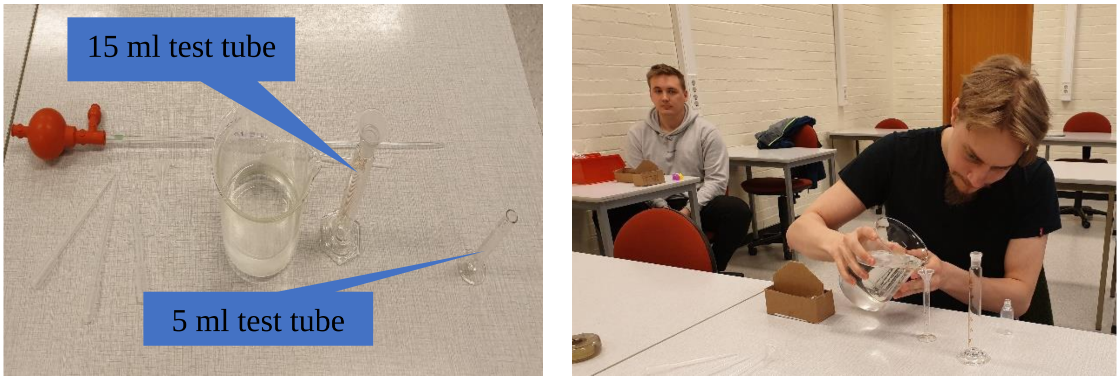


Figure 75: Measuring Tool for Filling and Performing Filling Operation [P.C. Espen]

- Capping followed by labelling
- Robot is used for palletizing
- As soon as the customer order was fulfilled, the products were delivered through delivery point

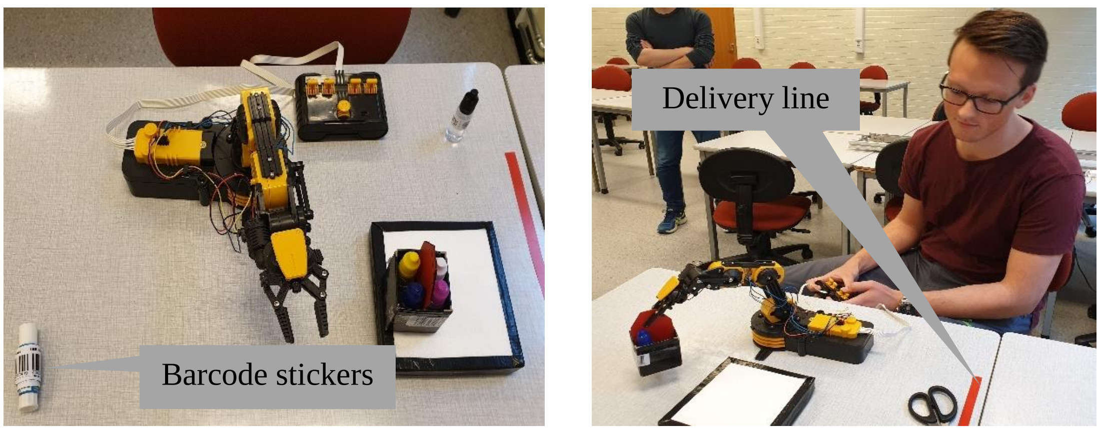


Figure 76: Robot Performing Palletizing Operation [P.C. Espen]

13.1.1 Analyze with VSM I

As soon as the simulation was over, a SIPOC [AppendixC.3] and a VSM [refer to AppendixC.4] was created to investigate the process and identify the amount of value added and non value-added time.

For the departmentalized layout, the total value-added time which has been used to produce a finished bottle was discovered to be 61 seconds. While the Non value-added was 175 seconds. This time refer only to a production of one single bottle. But due to its layout set up and its batch size production, 4 bottles have to be sent to start the process.

This shows that if a customer ordered one bottles, this type of layout will take approximately 230 seconds of lead time with 3 extra bottles.

N.B. The time was recorded during the start of the simulation when the first batch of product was dispatched

13.1.2 Simulation Results:

After all the bottles were delivered to the customer, the following data are collected: (For details refer to APPENDIX C)

Table 32: Situation Results

Parameter Collected from Simulation	1st Experiment
Target	15
Customer Order	20
Total Bottles Processed (n)	40
USL	15.3
LSL	14.5
Number of Defects	14
Work-In-Progress	6
Takt Time (Customer) [sec]	30
Total Lead Time (seconds)	792

To produce 20 bottles, total of 40 bottles were processed. There were 14 defective bottles and 6 work-in-progress. The total time taken to complete the 1st simulation was approximately 13 minutes.

13.2 Second Simulation

Before starting the simulation, the team had a few minutes to brainstorm on how to improve the process and reduce the number of defects that they produced during the 1st experiment. The team came up with the following ideas:

- Introduce one-piece flow instead of batch size production
- Get rid of 5 ml tube, introduce of high precision liquid transfer pipette to transfer liquid into the bottle
- The team chooses U-line set up and a conveyor belt

The Figure 77: New Setup: 2nd Experiment show the new set up decided by the team member as a part of their improved process. The red line with arrows is indicating the path and flow of the parts. The task to perform the simulation remains the same. However, this time, each section will process one bottle at time.

As earlier, the simulation starts only after receiving the customer order. The store keeper then sends out a bottle to the washing section by placing it on a conveyor belt. The washing man picks the bottle and starts to wash it (5 seconds for each), put it back to the conveyor for the Liquid filler to pick and filled the liquid. A bottle then gets capped and labelled before it will be packed and palletized for the delivery.

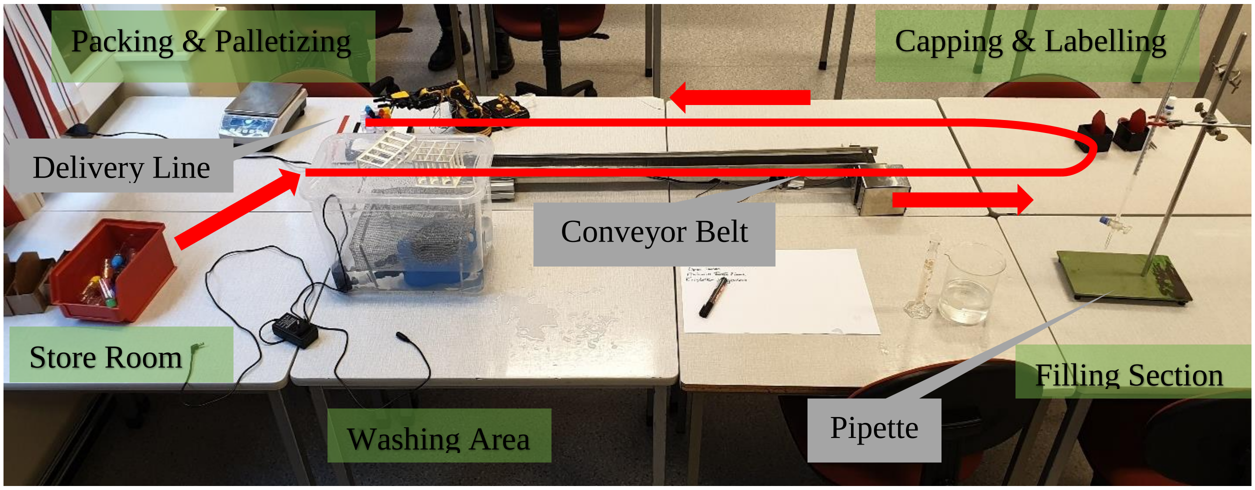


Figure 77: New Setup: 2nd Experiment [P.C. Espen]

13.2.1 Analyze with VSM II

A new VSM [refer toAppendixD.2] was created. There is only one flow of product at a time, the amount of value-added time and non value-added time taken by this layout is 21 seconds and 13 seconds respectively.

So, if a customer orders a single bottle, it will take only approximately 35 seconds to deliver it to the customer without any inventory buildup.

N.B. The time was recorded during the start of the simulation when the first product was dispatched

13.2.2 Simulation Results:

After all the bottles were delivered to the customer, the following data are collected: (For details refer to AppendixC.2 & APPENDIX D)

Table 33: Simulation Results for 2nd Experiment

Parameter Collected from Simulation	1st Experiment
Target	15
Customer Order	20
Total Bottles Processed (n)	26
USL	15.3
LSL	14.5
Number of Defects	2
Work-In-Progress	4
Takt Time (Customer)	30
Total Lead Time	350

For the second simulation, it took only 350 seconds i.e. approximately 6 minutes to complete the customer order. This is quite an achievement. Out of 26 bottles, 20 were delivered to a customer while 2 were defective and 4 left as work-in-progress.

13.3 Results Summary

Comparing the outcome from both experiments, the team was able to perform better during the 2nd experiment. By making few changes on the process and layout, the team was able to perform the task in a remarkably short time period, producing very few defects. The team was also able to reduce the cost price per unit from 5035 to 3175 [Table 34]. Cp & Cpk were also improved. However, the process is still not fully capable and centered [4.1.10] even though the average mean was approximately equaling to the target value of 15.

Table 34: Results Summary

Highlighted Parameter	1st Experiment	2nd Experiment
Cost Per Unit	5035	3175
Mean	14.82375	15.05769231
Standard Deviation	0.413550527	0.161054219
C_p	0.322411228	0.827878549
C_{pk}	0.260951588	0.501503352

The collected data was transferred to an Excel model, the statistic calculation was obtained instantly. But for the analysis part, the team didn't have enough time to go through LSS tools for improvement of the process and enjoy the excel model. Instead, they sat down together, brainstorm the ideas and consolidate ideas. These ideas were put into action for the 2nd experiment. There were some noticeable improvements [refer to Table 32,Table 33 & Table 34].

The whole test run took round about 1.5 hours. Even at this short time, the team was able to improve by fulfilling both Lean and Six Sigma goals. This exercise if conducted more systematically using DMAIC methodology, it has a huge potential to train and give LSS project experiences to the students. In addition, at the end, the students felt that they have achieved something worthy.

14 COMPARISON WITH A STATAPULT EXERCISE

After successful completion of the test run of the designed training exercise, it is quite rational to go back to the Statapult training exercise once again and compare with the New exercise training. A Statapult training is a summarized version of this New training exercise. The training starts by creating a project charter and then conduct the 1st experiment, collect data and analyze it. Next, it tries to improve the flow by implanting pull system and a team experience from the 1st experiment, thus cover Lean section. Then, it lists out some possible improvement solutions, implement it and run the 3rd experiment. It skips the use of various LSS tools during the process, doesn't follow DMAIC roadmap and is more of a Six Sigma Training exercise.

The exercise doesn't have noticeable process to perform. The only thing that's happening is a Statapult shooting the ball towards the target, the rest are all about assuming the process i.e. for example values are being added on the balls by simply putting stickers on them. So, there are not enough areas to improve the flow of process and speed.

Another noticeable thing is defects are identified only on the target area zone where the Statapult is shooting the ball towards whereas in the new exercise, defects are defined almost at every process step [refer to 11.1.6].In addition, the Statapult doesn't have any layout changes for the 2nd experiment and still choose to produce using batch size production.

Whist the new training exercise, a well-structured DMAIC problem solving tool, is about a simulation of mini beverage factory where in every step of the process, the values are visible and are being added and are prone to take any improvements. For instance, the change for improvement can be as follows:

- At the store section, the bottles and caps with different color could be sorted in advance
- A bottle washer can find ideal time for washing bottles or learn to use different flow pattern of the sprinkler for washing
- Digital or any other improving tools can be used in filling section
- Different techniques can be used for capping and labelling
- Different size of bottle crates can be used, manual robots can be replaced by programmable ones

The main point is all the participant get to take part and are involved in the process by creating value on it. By the use of their knowledge and experience, they can now identify and suggest a better solution for performing the same task. In this way, they can improve both Lean and Six Sigma principles. Following DMAIC will guide them towards perfection.

Moreover, the new exercise covers a lot of elements which the students will be learning on other courses in advance. While working in a group and running the LSS project themselves, the students can gain some project management skills, by dealing entire process from suppliers to the customers, they can learn about supply management and logistics. Similarly, a use of robot for packing will give them an idea of how industrial robot work and so on. Statapult doesn't have any of these. Hence an application of this new exercise has lots of benefits. After all, this can be UiT's own training exercise and have a possibility of using it for multiple purposes.

15 DISCUSSION AND CONCLUSION

Lean Six Sigma is a discipline that are built from past experiences. It is relentless pursuit of making thing better and better, leading towards the perfection. The choice of UiT on updating the training exercise on LSS itself is a LSS approach to make the exercise better. On applying LSS for the development of the new exercise, its success is inevitable.

The development of new exercise for this thesis has also more or less applied LSS techniques. Firstly, a review on the theoretical concept on LSS was completed which was followed by review on various LSS training exercise including Statapult. Some drawback of the Statapult were identified. Based on that a new scope for the new training exercise was defined. Keeping those scope as a baseline, a list of possible solutions was proposed. After digging deep, the choice of using a beverage factory was made for the exercise which was later confirmed and verified by building a virtual model. After that an entire training kit was constructed and were tested with the test team. The test was proven to be successful as the test team were able to perform well by producing some convincing output result even at the short period of time. From this outline, it can be felt that for the development of a new exercise, a DMAIC roadmap have been followed.

Now about the exercise, the new training exercise has fulfilled all its pre-defined project scope and reached its objectives. The new exercise has been designed such that it can be performed in a group of approximately 6 persons. It has also been able to cover many of its contents to the other courses in Industrial engineering. In addition, the training kit is light and portable and can be transformed and performed anywhere. An availability of a student manual and an Excel model will definitely boost its application allowing the students to utilize their significant amount of time in group discussion and brainstorming. This will certainly improve the quality of outcome which they will come with for the improvement process.

Moreover, the new training exercise is a problem-solving project-based exercises. It is a mini version of a real process where the students can gain some live experience of what's happening in the process as the take part in it. As a result, they can instantly identify which process is a bottleneck, not working properly, or too easy, etc. In other way, every participant can at least share their experience on running the process and list out what is good about it and what could be done to make it work better and later, they work together in a group to achieve their common goal. This will no doubt give some promising result. In this way, the students will have a feeling of achieving something worthwhile and can learn a valuable lesson.

This new exercise is also adaptive to changes, the complexity of the training activity can be increased by allowing narrow margin for errors, adding customize order of any quantity & size of bottles and different variant of liquid, by using part detecting sensor on the conveyor belt, using programmable robot for picking and placing and so on. This way the students will face more challenge in controlling quality and managing flow of the process.

To conclude, after the completion of this exercise, the students will be able to visualize the possibilities in implementing LSS techniques in their daily as well as in their professional activities. They will also be able to look at the problem in a different way and solve them professionally Besides, they will be more than capable to take part in a real project which are based on LSS or any optimizing and quality improving processes.

As for now, this exercise is limited to the engineering students, by making few changes in the process depending on the nature of training exercise, it can be used to train people of different professions. Another possible application of this training exercise could be to train the local people who works in service industries like local restaurants, cleaning companies, grocery stores, pub, etc. such that they can put their best performance with higher efficiency at work with ease by changing some layout set up and eliminating non value wastes.

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APPENDIX A STATISTIC CALCULATION

AppendixA.1 Formulae

Mean	$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} X_i$
Standard Deviation	$s_x = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} (\bar{X} - X_i)^2}$
Range	$R = highest\ value - Lowest\ value$
Upper Control Limit (X_{mean})	$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\bar{R}$
Lower Control Limit (X_{mean})	$LCL_{\bar{x}} = \bar{\bar{X}} - A_2\bar{R}$
Upper Control Limit (R)	$UCL_R = D_4\bar{R}$
Lower Control Limit (R)	$LCL_R = D_3\bar{R}$
Process Capability Index (C_p)	$C_p = \frac{USL - LSL}{6\sigma}$
Process Centered Capability Index (C_{pk})	$C_{pk} = min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$
Process Performance Index (P_p)	$P_p = \frac{USL - LSL}{6s}$
Process Centered Performance Index (P_{pk})	$P_{pk} = min\left(\frac{USL - \mu}{3s}, \frac{\mu - LSL}{3s}\right)$
Baseline sigma (z)	$z_{USL} = \frac{USL - \bar{X}}{s_x}, z_{LSL} = \frac{\bar{X} - LSL}{s_x}$
Histogram: Number of Classes (k)	$k = \sqrt{n}$
Histogram: Class width w	$w = \frac{R}{k}$

AppendixA.2 Statistical Process Control Constant Table

n	A2	A3	B3	B4	d2	D3	D4	E2
2	1,88	2,66	0,00	3,27	1,13	0,00	3,27	2,66
3	1,02	1,95	0,00	2,57	1,69	0,00	2,57	1,77
4	0,73	1,63	0,00	2,27	2,06	0,00	2,28	1,46
5	0,58	1,43	0,00	2,09	2,33	0,00	2,11	1,29
6	0,48	1,29	0,03	1,97	2,53	0,00	2,00	1,18
7	0,42	1,18	0,12	1,88	2,70	0,08	1,92	1,11
8	0,37	1,10	0,19	1,82	2,85	0,14	1,86	1,05
9	0,34	1,03	0,24	1,76	2,97	0,18	1,82	1,01
10	0,31	0,98	0,28	1,72	3,08	0,22	1,78	0,98
11	0,29	0,93	0,32	1,68	3,17	0,26	1,74	
12	0,27	0,89	0,35	1,65	3,26	0,28	1,72	
13	0,25	0,85	0,38	1,62	3,34	0,31	1,69	
14	0,24	0,82	0,41	1,59	3,41	0,33	1,67	
15	0,22	0,79	0,43	1,57	3,47	0,35	1,65	
16	0,21	0,76	0,45	1,55	3,53	0,36	1,64	
17	0,20	0,74	0,47	1,53	3,59	0,38	1,62	
18	0,19	0,72	0,48	1,52	3,64	0,39	1,61	
19	0,19	0,70	0,50	1,50	3,69	0,40	1,60	
20	0,18	0,68	0,51	1,49	3,74	0,42	1,59	

[25]

AppendixA.3 Standard Normal Curve Area

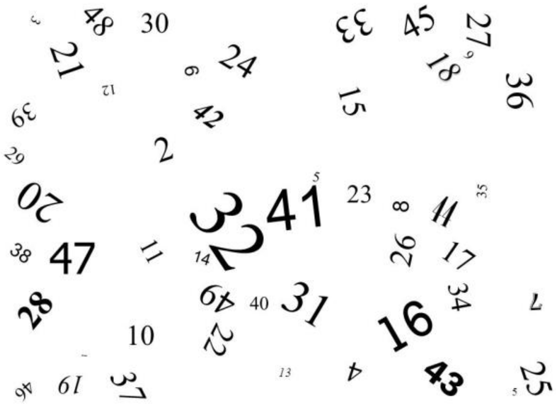
STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-3.9	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00004	.00003	.00003
-3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
-3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00008	.00008	.00008	.00008
-3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
-3.5	.00023	.00022	.00022	.00021	.00020	.00019	.00019	.00018	.00017	.00017
-3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
-3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
-3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
-3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
-3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00104	.00100
-2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139
-2.8	.00256	.00248	.00240	.00233	.00226	.00219	.00212	.00205	.00199	.00193
-2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00280	.00272	.00264
-2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
-2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
-2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
-2.3	.01072	.01044	.01017	.00990	.00964	.00939	.00914	.00889	.00866	.00842
-2.2	.01390	.01355	.01321	.01287	.01255	.01222	.01191	.01160	.01130	.01101
-2.1	.01786	.01743	.01700	.01659	.01618	.01578	.01539	.01500	.01463	.01426
-2.0	.02275	.02222	.02169	.02118	.02068	.02018	.01970	.01923	.01876	.01831
-1.9	.02872	.02807	.02743	.02680	.02619	.02559	.02500	.02442	.02385	.02330
-1.8	.03593	.03515	.03438	.03362	.03288	.03216	.03144	.03074	.03005	.02938
-1.7	.04457	.04363	.04272	.04182	.04093	.04006	.03920	.03836	.03754	.03673
-1.6	.05480	.05370	.05262	.05155	.05050	.04947	.04846	.04746	.04648	.04551
-1.5	.06681	.06552	.06426	.06301	.06178	.06057	.05938	.05821	.05705	.05592
-1.4	.08076	.07927	.07780	.07636	.07493	.07353	.07215	.07078	.06944	.06811
-1.3	.09680	.09510	.09342	.09176	.09012	.08851	.08691	.08534	.08379	.08226
-1.2	.11507	.11314	.11123	.10935	.10749	.10565	.10383	.10204	.10027	.09853
-1.1	.13567	.13350	.13136	.12924	.12714	.12507	.12302	.12100	.11900	.11702
-1.0	.15866	.15625	.15386	.15151	.14917	.14686	.14457	.14231	.14007	.13786
-0.9	.18406	.18141	.17879	.17619	.17361	.17106	.16853	.16602	.16354	.16109
-0.8	.21186	.20897	.20611	.20327	.20045	.19766	.19489	.19215	.18943	.18673
-0.7	.24196	.23885	.23576	.23270	.22965	.22663	.22363	.22065	.21770	.21476
-0.6	.27425	.27093	.26763	.26435	.26109	.25785	.25463	.25143	.24825	.24510
-0.5	.30854	.30503	.30153	.29806	.29460	.29116	.28774	.28434	.28096	.27760
-0.4	.34458	.34090	.33724	.33360	.32997	.32636	.32276	.31918	.31561	.31207
-0.3	.38209	.37828	.37448	.37070	.36693	.36317	.35942	.35569	.35197	.34827
-0.2	.42074	.41683	.41294	.40905	.40517	.40129	.39743	.39358	.38974	.38591
-0.1	.46017	.45620	.45224	.44828	.44433	.44038	.43644	.43251	.42858	.42465
-0.0	.50000	.49601	.49202	.48803	.48405	.48006	.47608	.47210	.46812	.46414

APPENDIX B 5 S NUMBER GAME



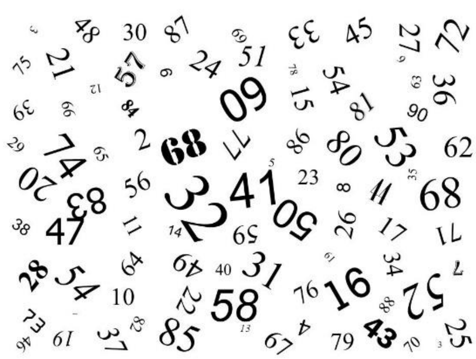
Sort

Set & Shine

Numbers from 1 to 49

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	

Standardize



Find the missing numbers?

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17		19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41		43	44	45	46	47	48	49	

Now find the missing numbers?

[44]

APPENDIX C RESULTS FROM 1ST EXPERIMENT

AppendixC.1 Departmentalized Set up

P.C. Espen

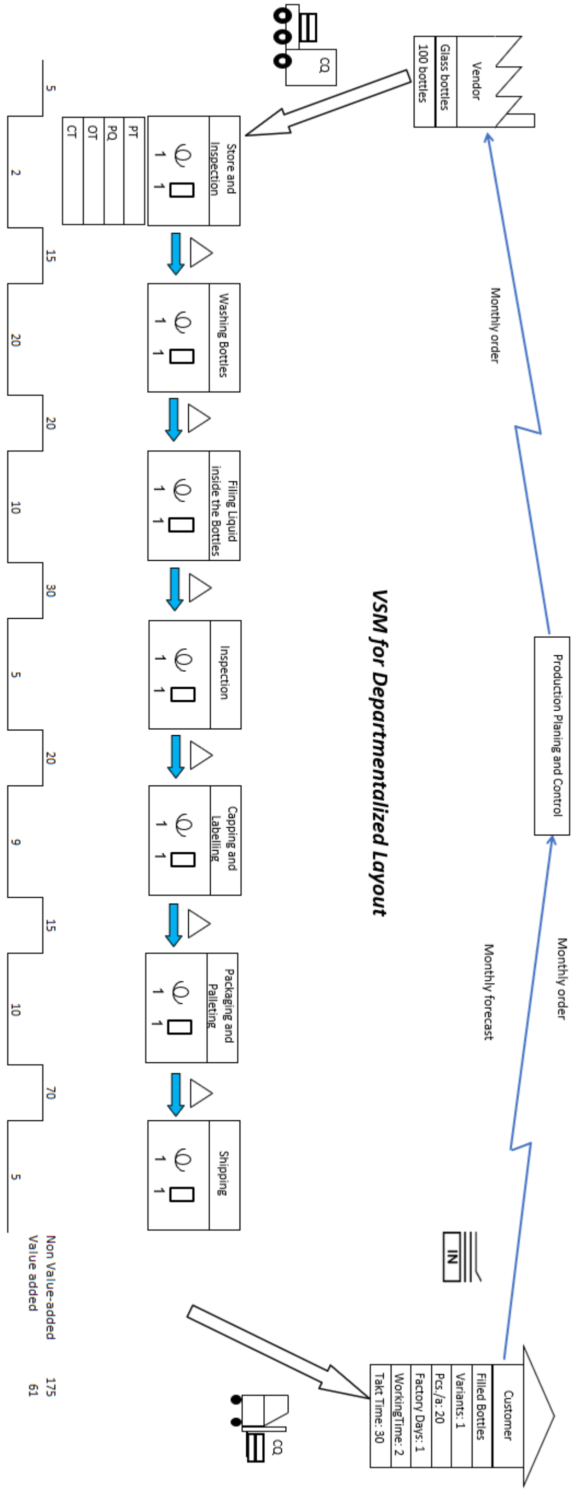
AppendixC.2 Experimental Data

	Water Volume		
S.N.	1st Experiment	2nd Experiment	3rd Experiment
1	14.1	15.1	
2	15.6	15	
3	14.7	14.8	
4	14.7	15.05	
5	14.9	15.05	
6	14.9	15.15	
7	14.8	15.15	
8	15.1	15.2	
9	14.4	14.85	
10	15	14.8	
11	14.9	15.05	
12	14.4	15.15	
13	15.65	15.15	
14	14.6	15.3	
15	15.4	15	
16	15	15.1	
17	15.4	15	
18	15.3	15	
19	14.9	14.75	
20	14.2	14.9	
21	14.9	15.25	
22	14.8	15	
23	14.7	15.05	
24	14.5	14.95	
25	14.7	15.35	
26	15.2	15.35	
27	14.4		
28	14.1		
29	15.2		
30	14.3		
31	15		
32	15		
33	14.4		
34	15.2		
35	14.2		
36	14.5		
37	15.2		
38	15.2		
39	14.3		
40	15.2		

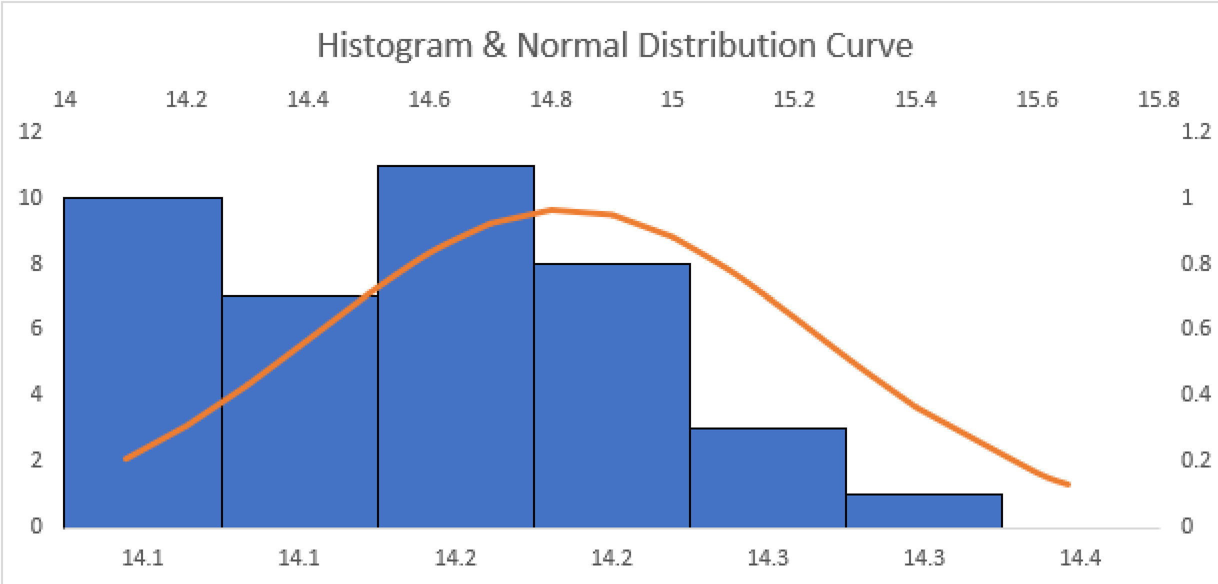
AppendixC.3 SIPOC

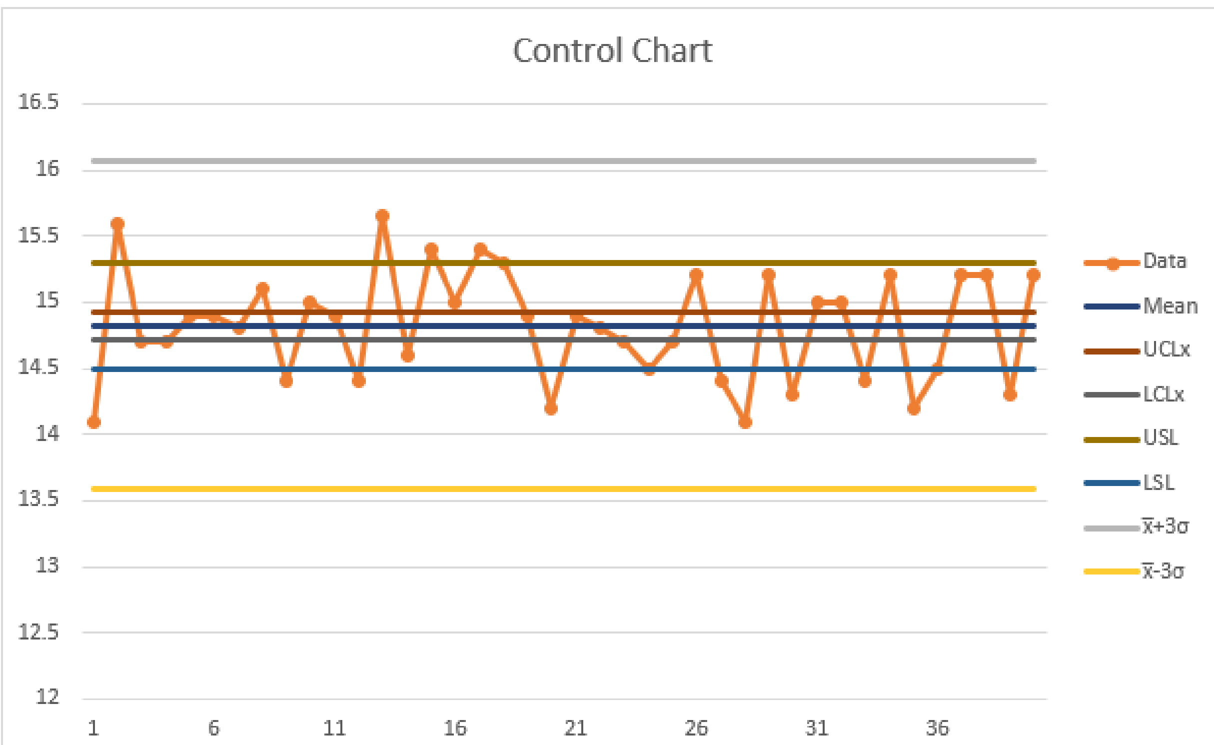
Suppliers	Inputs	Process	Outputs	Customers
Store Keeper	Bottles and Caps • 4 bottles • 4 Bottle caps	Store and Inspection	Bottles • Bottles • Defects are disposed	Washing Section
Washing Section	Bottles • 4 Bottles	Washing Bottles	Cleaned Bottles • Bottles in lot size	Filling Section
Filling Section	Cleand bottles and Liquids • Cleaned bottles • 4 bottles at a time	Filling Liquid	Filled Bottles • Filled bottles	Inspector
Inspector	Filled Bottles	Inspection	Good Filled bottles • Defects are sent for rework or are disposed • Measure volume of the liquid level	Finishing Section
Finishing Section	Good Filled bottles • Bottles caps • Label stickers	Capping and Labelling	Finished Bottles • Bottles with caps & labels on • Leakage inspect	Packaging
Packaging	Finished Bottles • Finished Bottles • Bottle crates • Barcode stickers	Packaging and Palleting	Packed Bottles • 4 Bottles per crate • Palletized according to customer demand • Deliver to customer	Customer

AppendixC.4 VSM



AppendixC.5 Histogram and Control Chart



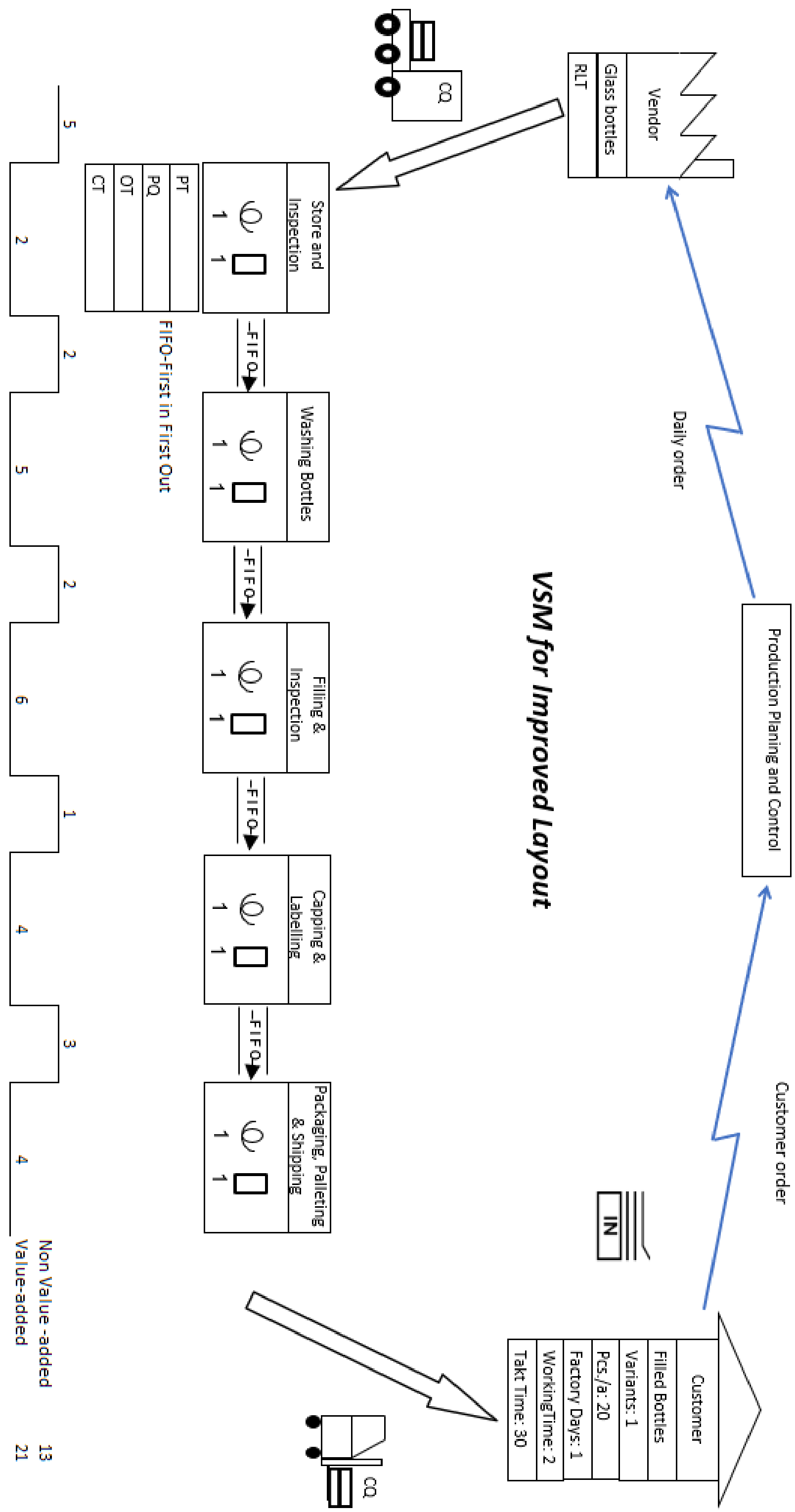


APPENDIX D RESULTS FROM 2ND EXPERIMENT

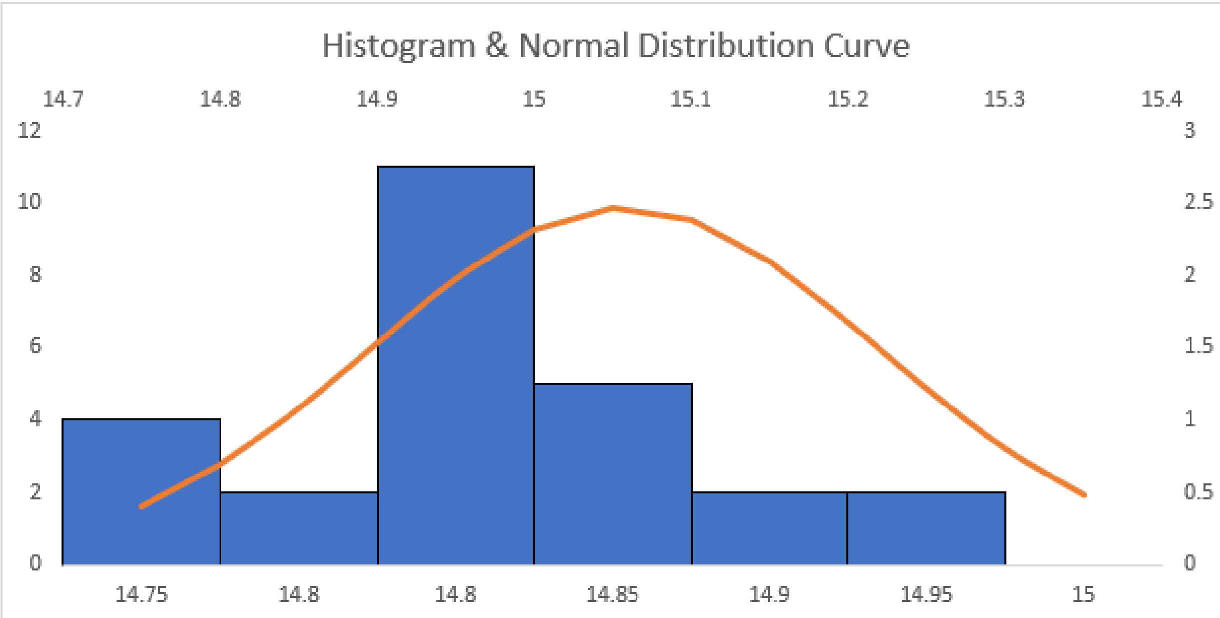
AppendixD.1 U-Line Set up

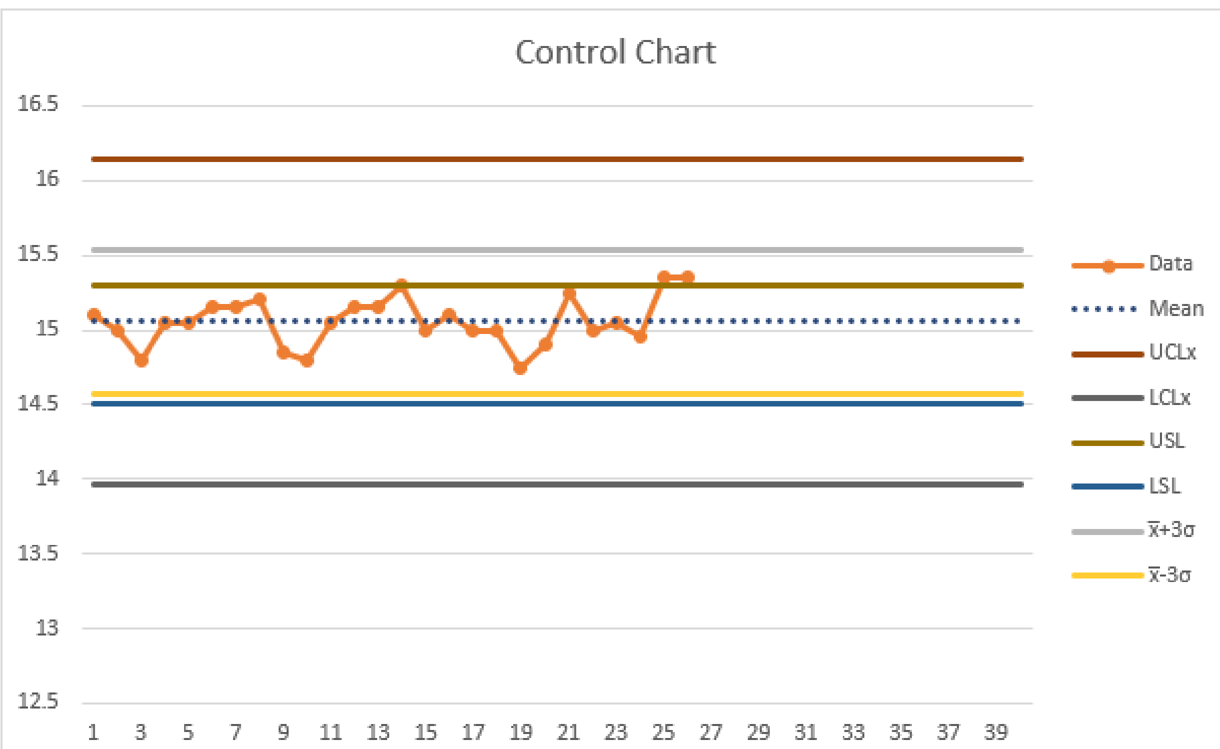
P.C. Espen

AppendixD.2 VSM



AppendixD.3 Histogram and Control Chart





APPENDIX E SOME VBA EXCEL CODES

AppendixE.1 Check List Status Check

```
Sub Macro1()
'
' Status check for CheckList LSS Project
'
Dim aaa As String
b11 = Range("j15").Text
aaa = b11
MsgBox (aaa)

'
'Range("J15").Select
    'ActiveCell.FormulaR1C1 = _
        "=IF(AND(R[-8]C[-3]:R[1]C[-3],R[3]C[-3]:R[4]C[-3],R[6]C[-3]:R[7]C[-3])=TRUE,""Training Complete"",""Training Incomplete"")"
    'Range("J16").Select
End Sub
```

AppendixE.2 Statistics: 1st Run of the Experiment

```
Sub sorting()
'1st Run of the Experiment

Range("G:H").ClearContents
ActiveSheet.Cells(4, 7).Select
Selection.Characters.Text = "S.N."
ActiveSheet.Cells(4, 8).Select
Selection.Characters.Text = "Data"

ActiveSheet.Cells(5, 24).Select
Selection.Characters.Text = "Cost per unit"
ActiveSheet.Cells(6, 24).Select
Selection.Characters.Text = "Mean"
ActiveSheet.Cells(7, 24).Select
Selection.Characters.Text = "Standard Deviation"
ActiveSheet.Cells(8, 24).Select
Selection.Characters.Text = "Cp"
ActiveSheet.Cells(9, 24).Select
Selection.Characters.Text = "Cpk"

Worksheets("Statistics").Cells(1, 2).Value = Worksheets("Data").Cells(11, 17).Value
Worksheets("Statistics").Cells(2, 2).Value = Worksheets("Data").Cells(12, 17).Value
Worksheets("Statistics").Cells(3, 2).Value = Worksheets("Data").Cells(13, 17).Value
Worksheets("Statistics").Cells(12, 2).Value = Worksheets("Data").Cells(14, 17).Value


'Transfer data from Data worksheet
r = 8
Do While Worksheets("Data").Cells(r, 3) <> ""
Worksheets("Statistics").Cells(r - 3, 8).Value = Worksheets("Data").Cells(r, 3).Value
```

```
Worksheets("Statistics").Cells(r - 3, 7).Value = r - 7
r = r + 1
Loop
'Sort out the data in ascending order

    Range("H5:H44").Select
    Selection.AutoFill Destination:=Range("H5:I44"), Type:=xlFillDefault
    Range("H5:I44").Select
    Range("I5").Select
    Range(Selection, Selection.End(xlDown)).Select
    ActiveWorkbook.Worksheets("Statistics").Sort.SortFields.Clear
    ActiveWorkbook.Worksheets("Statistics").Sort.SortFields.Add2 Key:=Range( _
        "I5:I44"), SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:= _
        xlSortNormal
    With ActiveWorkbook.Worksheets("Statistics").Sort
        .SetRange Range("I5:I44")
        .Header = xlGuess
        .MatchCase = False
        .Orientation = xlTopToBottom
        .SortMethod = xlPinYin
        .Apply
    End With
Worksheets("Statistics").Cells(5, 25).Value = Worksheets("Data").Cells(39, 17).Value
Worksheets("Statistics").Cells(6, 25).Value = Worksheets("Statistics").Cells(4, 2).Value
Worksheets("Statistics").Cells(7, 25).Value = Worksheets("Statistics").Cells(5, 2).Value
Worksheets("Statistics").Cells(8, 25).Value = Worksheets("Statistics").Cells(14, 2).Value
Worksheets("Statistics").Cells(9, 25).Value = Worksheets("Statistics").Cells(15, 2).Value

'Print message box ****complete calulation#1****
Dim aaa As String
aaa = "complete calculation#1"
MsgBox (aaa)

End Sub
```

AppendixE.3 Fishbone Diagram

```
Range("u29:u33")
    Range("j18:j22").Copy Range("u34:u38")
    '-------------------------
    d8 = Range("d8").Text

    b11 = Range("b11").Text
    f11 = Range("f11").Text
    j11 = Range("j11").Text
    b17 = Range("b17").Text
    f17 = Range("f17").Text
    j17 = Range("j17").Text


    b12 = Range("b12").Text
    b13 = Range("b13").Text
    b14 = Range("b14").Text
    f12 = Range("f12").Text
    f13 = Range("f13").Text
```

```
f14 = Range("f14").Text
j12 = Range("j12").Text
j13 = Range("j13").Text
j14 = Range("j14").Text
b18 = Range("b18").Text
b19 = Range("b19").Text
b20 = Range("b20").Text
f18 = Range("f18").Text
f19 = Range("f19").Text
f20 = Range("f20").Text
j18 = Range("j18").Text
j19 = Range("j19").Text
j20 = Range("j20").Text

'-------------------------------
'Paste text on the Fishbone diagram

ActiveSheet.Shapes("Text Box 247").Select
Selection.Characters.Text = b11
ActiveSheet.Shapes("Text Box 248").Select
Selection.Characters.Text = f11
ActiveSheet.Shapes("Text Box 249").Select
Selection.Characters.Text = j11
ActiveSheet.Shapes("Text Box 250").Select
Selection.Characters.Text = b17
ActiveSheet.Shapes("Text Box 251").Select
Selection.Characters.Text = f17
ActiveSheet.Shapes("Text Box 252").Select
Selection.Characters.Text = j17

ActiveSheet.Shapes("Text Box 244").Select
Selection.Characters.Text = d8

ActiveSheet.Shapes("Text Box 174").Select
Selection.Characters.Text = b12
ActiveSheet.Shapes("Text Box 175").Select
Selection.Characters.Text = b13
ActiveSheet.Shapes("Text Box 176").Select
Selection.Characters.Text = b14
ActiveSheet.Shapes("Text Box 194").Select
Selection.Characters.Text = f12
ActiveSheet.Shapes("Text Box 195").Select
Selection.Characters.Text = f13
ActiveSheet.Shapes("Text Box 196").Select
Selection.Characters.Text = f14
ActiveSheet.Shapes("Text Box 204").Select
Selection.Characters.Text = j12
ActiveSheet.Shapes("Text Box 205").Select
Selection.Characters.Text = j13
ActiveSheet.Shapes("Text Box 206").Select
Selection.Characters.Text = j14

ActiveSheet.Shapes("Text Box 207").Select
Selection.Characters.Text = b18
ActiveSheet.Shapes("Text Box 208").Select
Selection.Characters.Text = b19
```

```
    ActiveSheet.Shapes("Text Box 209").Select
    Selection.Characters.Text = b20
    ActiveSheet.Shapes("Text Box 235").Select
    Selection.Characters.Text = f18
    ActiveSheet.Shapes("Text Box 238").Select
    Selection.Characters.Text = f19
    ActiveSheet.Shapes("Text Box 239").Select
    Selection.Characters.Text = f20
    ActiveSheet.Shapes("Text Box 216").Select
    Selection.Characters.Text = j18
    ActiveSheet.Shapes("Text Box 217").Select
    Selection.Characters.Text = j19
    ActiveSheet.Shapes("Text Box 218").Select
    Selection.Characters.Text = j20

    '--------------------------



End Sub



Sub Clear_Fishbone()
' clear text on Fishbone diagram
    Range("U9:U38").Select
    Selection.ClearContents
    Range("t9:t38").Select
    Selection.ClearContents
    Range("U9:U38").Select
    With Selection.Interior
        .Pattern = xlSolid
        .PatternColorIndex = xlAutomatic
        .ThemeColor = xlThemeColorDark1
        .TintAndShade = 0
        .PatternTintAndShade = 0
    End With


    ActiveSheet.Shapes("Text Box 247").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 248").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 249").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 250").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 251").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 252").Select
    Selection.Characters.Text = ""

    ActiveSheet.Shapes("Text Box 244").Select
    Selection.Characters.Text = ""

    ActiveSheet.Shapes("Text Box 174").Select
    Selection.Characters.Text = ""
```

```
    ActiveSheet.Shapes("Text Box 175").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 176").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 194").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 195").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 196").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 204").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 205").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 206").Select
    Selection.Characters.Text = ""

    ActiveSheet.Shapes("Text Box 207").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 208").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 209").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 235").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 238").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 239").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 216").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 217").Select
    Selection.Characters.Text = ""
    ActiveSheet.Shapes("Text Box 218").Select
    Selection.Characters.Text = ""


End Sub

Sub deleteFishbone()
'
' delet Fishbone diagram
'
    ActiveSheet.Shapes.Range(Array("Group 8198")).Visible = msoFalse

End Sub
```

AppendixE.4 Pareto Chart

```
Private Sub CheckBox1_Click()
 Worksheets("SOV matrix").Range("A:A").ClearContents
If CheckBox1 = True Then
    ActiveSheet.Shapes.Range(Array("Chart 3")).Visible = msoTrue 'Active chart

    ActiveWorkbook.Worksheets("Pareto Chart").Sort.SortFields.Clear
```

```
    ActiveWorkbook.Worksheets("Pareto Chart").Sort.SortFields.Add2 Key:=Range( _
        "I8:I60"), SortOn:=xlSortOnValues, Order:=xlDescending, DataOption:= _
        xlSortNormal
    With ActiveWorkbook.Worksheets("Pareto Chart").Sort
        .SetRange Range("B8:I60")
        .Header = xlGuess
        .MatchCase = True
        .Orientation = xlTopToBottom
        .SortMethod = xlPinYin
        .Apply
     End With
    'numbering for SOV matrix
        r = 8
        Do While Worksheets("Pareto Chart").Cells(r, 12) <> ""
        Worksheets("SOV matrix").Cells(r - 1, 1).Value = r - 7
        r = r + 1
        Loop

Else

    ActiveWorkbook.Worksheets("Pareto Chart").Sort.SortFields.Clear
    ActiveWorkbook.Worksheets("Pareto Chart").Sort.SortFields.Add2 Key:=Range( _
        "B8:B37"), SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:= _
        xlSortNormal
    With ActiveWorkbook.Worksheets("Pareto Chart").Sort
        .SetRange Range("B8:J60")
        .Header = xlGuess
        .MatchCase = True
        .Orientation = xlTopToBottom
        .SortMethod = xlPinYin
        .Apply
    End With
    ActiveSheet.Shapes.Range(Array("Chart 3")).Visible = msoFalse 'Delete chart
    'numbering for SOV matrix
            r = 8
        Do While Worksheets("Pareto Chart").Cells(r, 12) <> ""
        Worksheets("SOV matrix").Cells(r - 1, 1).Value = r - 7
        r = r + 1
        Loop
End If


End Sub
```