Increasing Time Efficiency and Productivity using Lean Manufacturing and DMAIC Principles

Submitted in partial fulfilment of the requirements of the degree of

B.E. Production Engineering

By

Rishi Dasgupta

SAP ID: 60012170044

Project Guide: Prof. Dharam Ranka

Production Engineering Department

Dwarkadas J. Sanghvi College of Engineering

Vile Parle (West), Mumbai - 400056

2020-2021

Vision

To develop competent and socially sensitive technopreneurs for manufacturing and allied service sector.

Mission

1. To strive for academic excellence in engineering and manufacturing technology, by fostering innovative learning processes.

2. To establish state of the art infrastructure in order to create technopreneurs to cater to the demands of industry.

3. To drive and achieve technical and professional competency by curricular, co-curricular and extracurricular interaction with industry, allied professional societies and other nodal agencies.

4. To mould the students as responsible and outstanding technical professionals with excellent personality traits and high ethical standards capable of facing challenges of the industry and society at large.

Program Specific Outcomes

1. Candidates will be able to integrate issues related to design, manufacturing processes, tooling and assembly to resolve trouble shooting in manufacturing and achieve manufacturing effectiveness.

2. Candidates will develop competency in analyzing and improvising of manufacturing systems, operations and automation to achieve productivity enhancement.

3. Candidates will be able to explore various aspects pertaining to quality and bring about quality improvements through various tools and approaches in statistics, quality, reliability and experimental engineering.

4. Candidates will be able to apply appropriate managerial approaches in relevant areas of manufacturing to achieve continuous improvement and will be able to function effectively as a leader of a technical team.

Course Outcomes

CO1: Get familiarized with various technological trends, approaches and applications along with managerial exposure.

CO2: Demonstrate understanding of relevant application-oriented subjects in a better perspective.

CO3: Demonstrate understanding of various constraints of time and cost, within which goods are produced and services rendered in a specified quantum.

CO4: Describe the scope, functions and job responsibilities in various departments of an organization.

CO5: Develop a positive attitude, which will bring in a visible change in their approach while dealing with technical and interpersonal issues

CERTIFICATE

This is to certify that the project entitled **"Increasing Time Efficiency and Productivity using Lean Manufacturing and DMAIC Principles"** is a bonafide work of **"Rishi Dasgupta" 60012170044** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of **"Bachelor of Engineering"** in **"Production Engineering"**

Internal Guide

Prof. Dharam Ranka

Project Coordinator

Prof. Trupti Markose

VD Jewels Artison Pvt. Ltd.
Mumbai

External Guide

Mr. Deepak Jain

Associate Head/ Head of Production Department

Prof. Sandeep Vaity

Training and Placement Officer

Dr. Rajendra Khavekar

Principal

Dr. Hari Vasudevan

Project Report Approval for B.E.

This project report titled ***"Increasing Time Efficiency and Productivity using Lean Manufacturing and DMAIC Principles"*** by ***"Rishi Dasgupta"*** is approved for the degree of ***B.E. Production Engineering***.

Examiners: 1. ____________________

2. ____________________

Date:

Place:

Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Rishi Dasgupta

(60012170044)

Date:

VD Jewels Artison Pvt. Ltd.

June 30, 2021

TO WHOM IT MAY CONCERN

This is to certify that **Mr. Rishi Dasgupta**, student of Dwarkadas J. Sanghvi College of Engineering has successfully completed his 6 months internship project on **"Increasing Time Efficiency and Productivity using Lean Manufacturing and DMAIC Principles"** under the guidance of **Mr. Deepak Jain** from **January 1st, 2021** to **June 30th 2021**.

During the period of his internship; he showed the utmost diligence, punctuality and inquisitiveness.

We wish him all the very best for his future endeavours.

For V.D. Jewels Artison Pvt. Ltd.

VD Jewels Artison Pvt. Ltd. Mumbai

Mr. Deepak Jain
Chief Executive Officer

VD Jewels Artison Pvt. Ltd.

NO OBJECTION CERTIFICATE

This is to certify that **Rishi Dasgupta**, degree student of Production Engineering of Dwarkadas J. Sanghvi College of Engineering, Vile Parle (West), Mumbai – 400056 has satisfactorily completed his In-plant training from **01/01/2021** to **30/06/2021** at the **Production Department, VD Jewels Artison Pvt. Ltd., SEEPZ Andheri (E).** He has successfully carried out all the responsibilities allotted to him.

He has been allowed to include the documents, data and sketches for which we have no objections. We sincerely appreciate all efforts made by him and wish him every success in the future.

VD Jewels Artison Pvt. Ltd. Mumbai

Mr. Deepak Jain

Chief Executive Officer

ABSTRACT

In the increasingly dynamic and competitive world of jewellery manufacturing, it is extremely important to be updated with the current industry trends and emphasise a policy of continuous improvement to be able to consistently improve and innovate on the production processes and be competitive on a global stage.

VD Jewels and Artisons Pvt. Ltd. manufactures a wide variety of jewellery items like rings, bracelets and earrings which are sold at retail markets abroad in countries like the United States of America, Japan and all over Europe. Since this company is relatively new in the market with less than a year of operation at SEEPZ, there is tremendous scope for improvement.

The project aims to increase time efficiency in various departments in the company according to Lean Manufacturing principles which utilises innovative industry trends to improve the established manufacturing practices, managerial logistics and promote better working conditions through higher shop-floor to Executive integration, streamlined manufacturing processes and focus on value to customer. This project also aims to address errors and bottlenecks which the company faces often during regular operation and suggests solutions for the same.

The first half of the project describes how Lean Principles were utilised to decrease tool idle time and improve working practices, thereby reducing overall non-value-added time by 50 minutes/worker daily and increasing time efficiency. Several tools like Kaizen, Kanban, 5S and Just-In-Time were used to optimise value-added time in product manufacturing.

The second half of the project describes how DMAIC principles were used to increase labour productivity in the Polishing Department by identifying high priority areas of improvement and analysing multiple alternatives over distinct criteria to provide an optimal solution to improving overall productivity in the polishing department by 3%.

List of Figures

List of Tables

Table of Contents

Chapter 1: Introduction

1.1 About VD Jewels and Artisons Pvt. Ltd.

V.D. Jewels and Artisons Pvt. Ltd. is a medium scale Jewellery manufacturing company established on 9th November, 2017 and located in the SEEPZ area in Mumbai, Maharashtra. The company designs and manufactures a wide variety of mass-produced as well as high end items such as rings, bracelets and earrings and exports them to clients from all across the world, including America, Europe and the Asia-Pacific Region. The company's authorized share capital is INR 45.00 lac and the total paid-up capital is INR 11.50 lac.

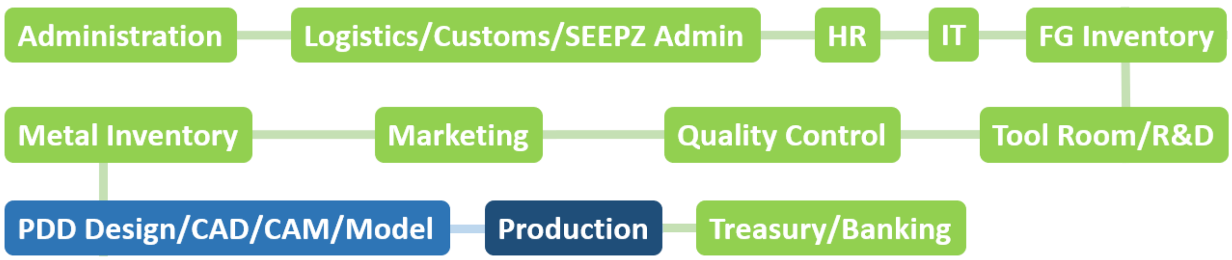


Fig.1 Departments in the Company

`1.2 Company Hierarchy

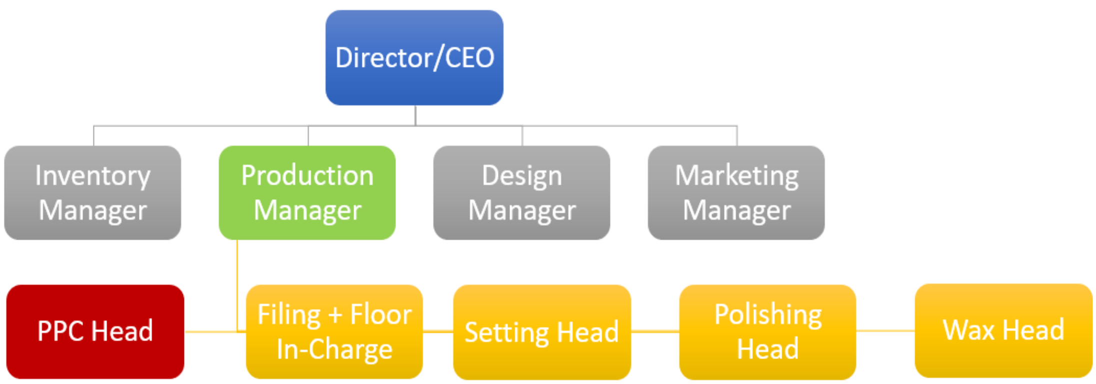


Fig.2 Company Hierarchy

The company follows a hierarchical management strategy (ref. fig. 2) with the Director/CEO on top followed by the Inventory manager, production manager, design manager and marketing manager among other senior level managers. I worked in the production department (ref. fig.1) which had managers for the PPC department, filing (Floor in-charge), Setting department, polishing department and wax department.

1.3 Project Overview

The project is divided into two sub-projects, titled “Increasing Time Efficiency using Lean Manufacturing Principles” and “Increasing Productivity using Six Sigma DMAIC Principles”. This paper will discuss the problem statements in both the projects as well as analyse and suggest improvements made using various time-study analyses in multiple departments.

Chapter 1 aims to provide a brief description of the company, their products, history, managerial hierarchy and the scope of the company.

Chapter 2 aims to provide information on the various steps followed in the manufacturing of the products discussed in chapter 1, along with the various technologies and practices followed by the company. This serves as an important context for reference in subsequent chapters.

Chapter 3 aims to provide an introduction to the concept of Lean Manufacturing, describing the various types of wastes that are generated in a company and tools to minimize wastage and increase productivity. This chapter also contains two case studies to provide evidence on the benefits of applying lean manufacturing principles in a company.

Chapter 4 aims to further elaborate on the previous chapter by appropriating the tools discussed above into the context of the jewellery industry and discusses practical implementations made in the company to increase time efficiency and productive output.

Chapter 5 aims to provide information on enterprise level resource planning software and how the company can benefit from using a two-layered MES-ERP approach to further integrate the Shop Floor, PPC and Sales departments.

Chapter 6 aims to identify methods in which Six-Sigma can be used to increase productivity using the DMAIC Method. Various ideas for identifying weighted priorities for total productivity using AHP technique are discussed with a practical utilization of the DMAIC method to improve the polishing process and increase overall productivity. Utilisation of TOPSIS methodology has been suggested for future use in identifying weighted priorities in the company.

Chapter 7 aims to provide a conclusion to the project and states the effects and outcomes of the various activities carried out and the results of implementing the above discussed Lean Manufacturing techniques.

Chapter 8 aims to elucidate the future scope of improvements in the company.

Chapter 2: Manufacturing Process Sequence

VD Jewels and Artisons Pvt. Ltd. produces a variety of high-end jewellery items as well as mass produced auxiliary pieces (ref. fig.4) which are sold at retail markets abroad. Some of the frequently manufactured products include rings, bracelets, chains and earrings which pass through a series of manufacturing steps in a sequential order. The major processes are described below in order of chronology:

2.1. Designing Department:

The process cycle begins in the Designing department with the CAD modelling of the product based on client specifications (ref. fig.3). The designing team is presented with a process sheet (ref. fig.5) which is created in collaboration with the client based on their requirements. The process sheet contains detailed descriptions of the design, critical measurements and weight specifications along with appropriate local and global tolerances. Based on the design specifications specified in the process sheet, the following steps were taken by the design team:

a. The design team creates a hand sketch using the critical dimensions provided and adds additional dimensions to evaluate product weight expectations and manufacturing strategies.

b. The hand sketch is converted to a CAD model using proprietary software. This CAD model is passed onto the project manager for further evaluation as well as the marketing and sales department to create product renders.

c. Appropriate materials are added to the model and the expected weight is noted down.

d. The weight is compared with the desired tolerance specifications as provided by the client.

e. If all requirements are met, the CAD design along with graphical renders are provided to the client for final approval.

f. After approval, the CAD design is passed onto the Rapid Prototyping Department (RPT) where the 3D printed master model is created. This master model will serve as the blueprint for all other copies of the product.

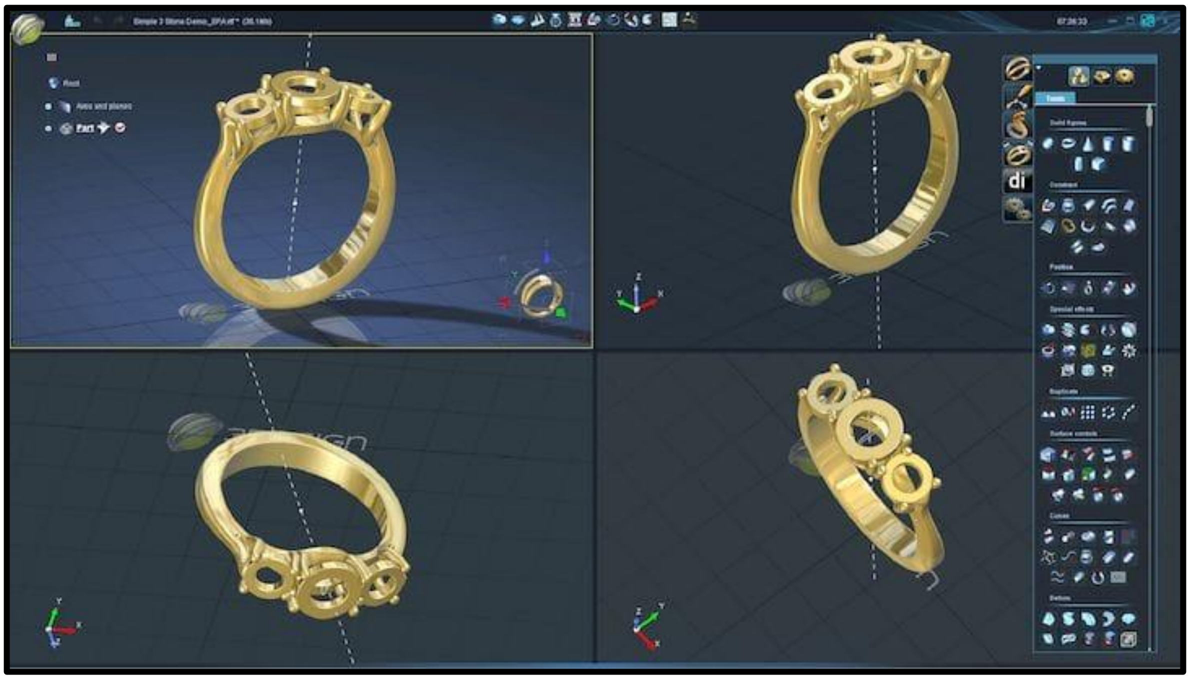
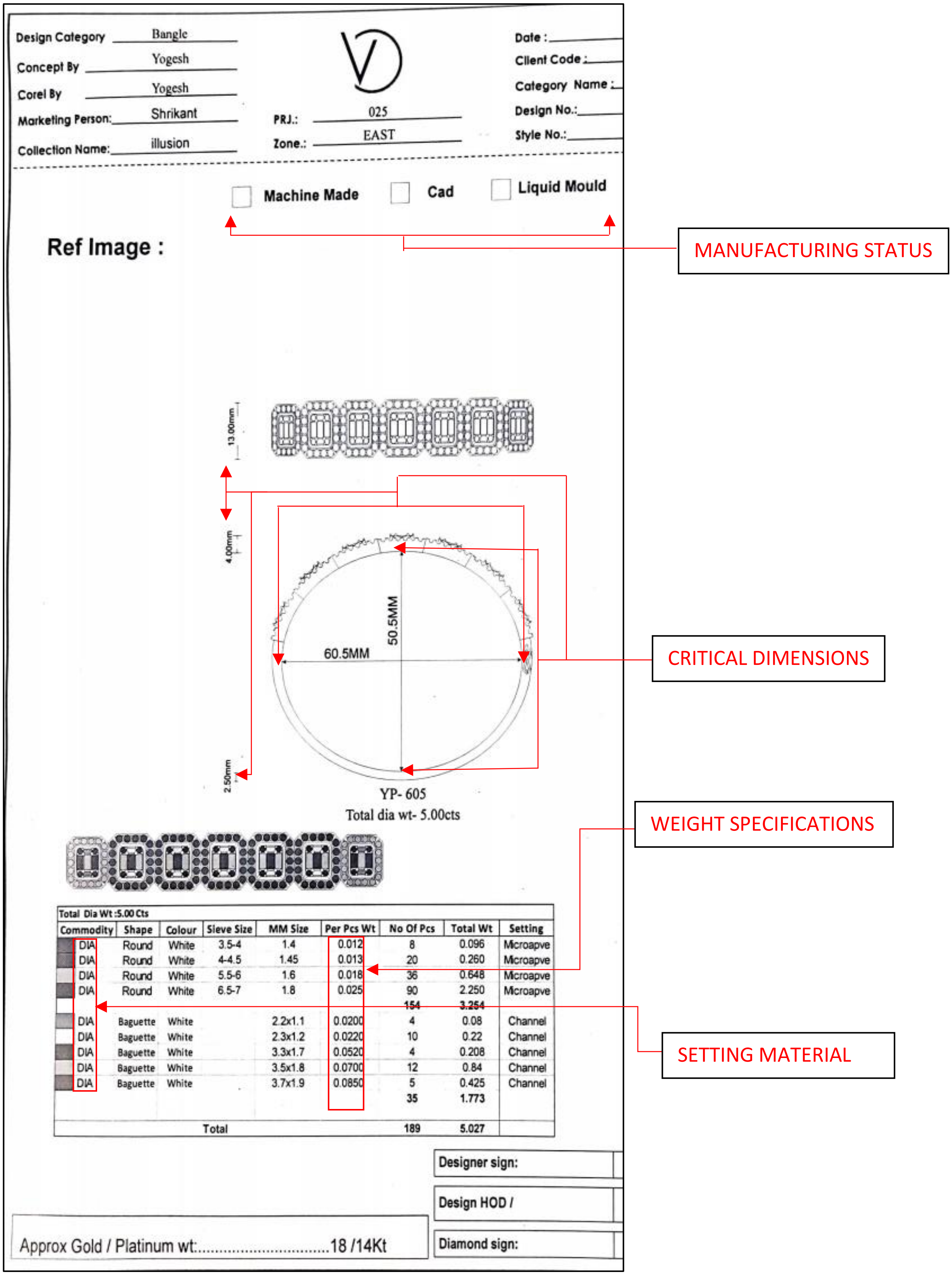


Fig.3 CAD Designing of Ring

Fig.4 Company Products



Design Category: Bangle
Concept By: Yogesh
Corel By: Yogesh
Marketing Person: Shrikant
Collection Name: illusion

PRJ.: 025
Zone.: EAST

Date :
Client Code :
Category Name :
Design No.:
Style No.:

Machine Made | Cad | Liquid Mould

MANUFACTURING STATUS

Ref Image :

13.00mm
4.00mm
2.50mm
60.5MM
50.5MM

CRITICAL DIMENSIONS

YP- 605
Total dia wt- 5.00cts

WEIGHT SPECIFICATIONS

SETTING MATERIAL

Total Dia Wt :5.00 Cts

Commodity	Shape	Colour	Sieve Size	MM Size	Per Pcs Wt	No Of Pcs	Total Wt	Setting
DIA	Round	White	3.5-4	1.4	0.012	8	0.096	Microapve
DIA	Round	White	4-4.5	1.45	0.013	20	0.260	Microapve
DIA	Round	White	5.5-6	1.6	0.018	36	0.648	Microapve
DIA	Round	White	6.5-7	1.8	0.025	90	2.250	Microapve
						154	3.254	
DIA	Baguette	White		2.2x1.1	0.0200	4	0.08	Channel
DIA	Baguette	White		2.3x1.2	0.0220	10	0.22	Channel
DIA	Baguette	White		3.3x1.7	0.0520	4	0.208	Channel
DIA	Baguette	White		3.5x1.8	0.0700	12	0.84	Channel
DIA	Baguette	White		3.7x1.9	0.0850	5	0.425	Channel
						35	1.773	
Total						189	5.027	

Designer sign:
Design HOD /
Diamond sign:

Approx Gold / Platinum wt:...............................18 /14Kt

Fig. 5 Process Sheet for Ring

2.2. Wax Casting Department:

After the 3D printed Master Model is obtained from the RPT department, it is used to create the mould for creating multiple copies of the master model. There are two methods which are used to create moulds:

a. Rubber Mould
b. Liquid Mould

2.2.1 Rubber Mould:

The rubber mould is prepared using fixture plates to provide the exterior structure of the mould as well as hold the master in correct position and orientation. The fixture plate is provided with four slots wherein rubber sheets (OEM) are layered together around the master model. The setup is such that there are three layers on top of the mould and two layers on the bottom (ref. fig.6).

At the same time, the vulcaniser is pre-heated to 150°C. The temperature is continuously monitored and once it is reached, the fixture plate assembly is placed over the baseplate of the vulcanizer and the top plate is pressed against it. As the temperature reduces, the upper plate of the vulcanizer is slightly lowered in gradual increments. The staggered increment is necessary because the pressure should increase gradually otherwise it may lead to cracks and defects in the rubber mould.

Fig. 6 Rubber Mould creation from 3D printed Master Model

2.2.2 Liquid Mould:

The liquid mould is prepared with a 10:1 mixture of Elastinol and Hardener. The 3D printed Master model is attached to a C-shaped metal frame sandwiched in between glass plates securely by a wax sprue.

The liquid mixture is then filled into the mould slowly to completely fill in the cavity and then placed in a vacuum machine to remove the air bubbles which would otherwise hinder with the finish of the product (ref. fig.7).

The liquid mould is then set aside to harden for 6 hours. The process can be sped up by providing additional heat by keeping it in front of an open furnace for 3 hours which accelerates the hardening process.

Fig. 7 Wax Injection Process

Fig. 8 Liquid Mould Injection Interface

2.2.3 Casting Process:

After the mould is ready, wax prototypes are made using the injection moulding technique. After the prototypes harden, they are attached to a wax tree in evenly spaced positions at oblique orientations. The wax tree is then placed on a cap-like structure and is positioned in between flasks. POP is poured into the flask with a composition of 1Kg of plaster powder and 40:38:39 water mixture. The POP is mixed in a cylindrical container and is placed in a vacuum chamber to remove any air bubbles present. This is performed in a 3 in 1 vacuum casting machine after which the POP is poured into the flask. The flask is then sealed with brown tape on all sides to ensure that the POP or wax does not pour out.

The flask is placed in the cylindrical vessel again for removal of air bubbles, which takes around 6 minutes to complete. The flask is then kept aside for 1 hour at room temperature to harden the POP. The tape and base camp are removed and is kept inside the furnace for 10 hours, 600 degree Celsius for wax and 700-720 degree Celsius for the handset.

During these 10 hours, the wax melts off and drains into the lower surface, forming a cavity inside the flask. It is then removed and put into the casting machine and alongside it, the metal (gold/silver) is melted along with their respective alloy elements (Nickel, Copper, etc. to make White/Yellow gold).

Now, the metal is poured into the flask which is kept inside the casting hole (ref. Fig.9). The excess metal is accumulated at the top ensuring that the metal has completely filled the cavity. The flask is removed and kept outside at the room temperature for 15 minutes.

Now it contains the required metal after which the flask is cooled by placing it in a bucket of water. POP is removed from the flask using a waterjet machine. The final metal tree is extracted after cleaning the tree which contains the required metal base pieces. These are cut off using clippers and the remaining metal tree is remelted for use in future pieces.

Fig. 9 Casting Machine

2.2.4 Setting Process:

Setting process is done in two ways – Wax Setting and Hand Setting (ref. Fig.10). For both the processes, firstly slits are made on the individual components. These are C-shaped to incorporate for the diamond shape which are usually square or trapezoidal as per the client specifications.

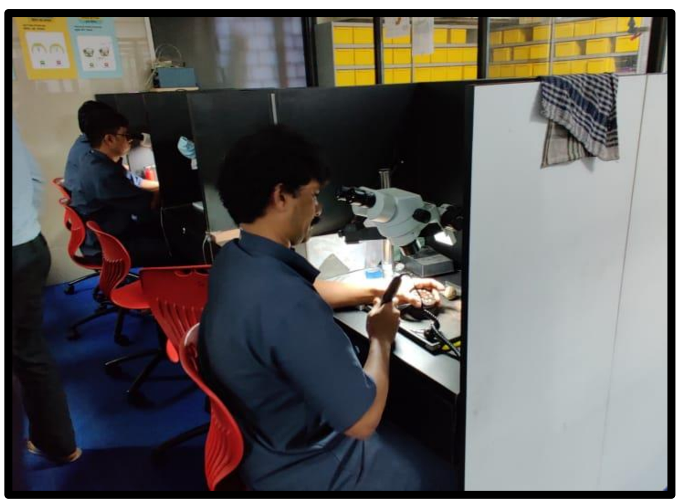


Fig. 10 Hand Setting Stations

The metal ends are given slits at the appropriate heights and the diamond pieces are placed there by pulling out a small metal covering from one side. After the diamond is placed, it is locked in place by pushing the deviated metal covering back in place. This is done using a compression hammer followed by a laser process used to fill in the material which gives a clean finish and is aesthetically superior. In prong setting, the diamonds are embedded between four protrusions which are cut at the level of the flat diamond surface. This is done to cater to the taper head of the diamond, the prongs are bent away from the mean position to adjust the setting of the diamond once it is embedded into the cavity (ref. Fig.11). Then, the prongs are bent towards the centre and into the diamond to fix it in place.

Fig. 11 Hand-setting of Diamonds on Earrings

2.3. Polishing Process:

After the hand setting process, the metal base is non-lustrous and requires additional finishing operations performed on it before it is used commercially. These operations are called polishing operations which involve the use of various tools to remove rough areas from the base and add a desirable lustrous finish to the product.

The various processes used in the polishing operations are usually named as per the name of the tool and is performed sequentially in a logical order based on the hardness of the tool. The processes are as follows (ref. Table 1):

Table 1: Polishing Sub-Processes

Sr. No.	TOOL NAME	FUNCTION	APPLICATION AREA	
1.	Cotton Thread	Removes surface impurities and adds lustre.	Inner Surface	
2.	3-Row Bristle Brush	Performed in the initial stage to remove larger nubs and produce the initial lustre.	Outer Surface	
3.	Soft Bristle Micro-Brush	Subsequent operation to apply lustre at localised patches, softens the metal.	Outer Surface	
4.	Hard Buff	Removes larger nubs and flattens the rough surfaces using harder bristles.	Outer Surface	
5.	Soft Buff	Final process which provides additional lustre by using finer bristles.	Outer Surface	

The polishing process is performed on multiple workstations in the polishing department (ref. Fig.12, 13, 14) where the workers are provided with the required tools and a vacuum suction base which extracts the metal powder that is generated in the polishing process. After Polishing, the workpieces are sent for Ultrasound cleaning to remove the microscopic impurities using high frequency vibrations. The resulting product is highly lustrous and ready to be sent to QC before shipping to the customer.

Fig. 12 Polishing Department

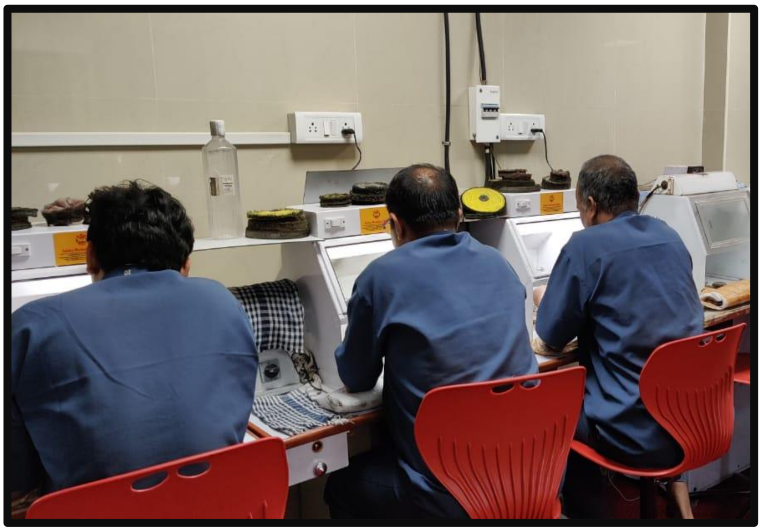


Fig. 13 Workers at Polishing Workstations

Fig. 14 Ultrasound Cleaning Machine

2.4. Laser Cutting and Quality Control (QC):

The Laser cutting department comprises of a *laser welding machine* as well as a *laser etching machine*. The laser welding machine (ref. Fig.15) is used to weld together joints in the metal base at strategic locations to *reinforce the product*, *rectify imperfections* as well as *provide welded attachments* for the setting materials (diamonds, rubies and other precious gems). Therefore, the laser welding machine has product inflow from multiple departments at the same time (welding, setting, polishing and QC) which leads to high wait times.

The laser etching machine is used to etch relevant product information on the metal base which may include an identification number, batch code and manufacturing information among other forms of identification. Additionally, some pieces may have customised etchings requested by the client, which are usually personalised messages and anagrams.

The *Quality Control department* is responsible for ensuring that the product meets the market standards and issues rectifications after proper inspection of the pieces coming from the polishing department. They may send these batches to the appropriate departments for rectification operations. They also issue clearance certificates for the products before sending them to shipping.

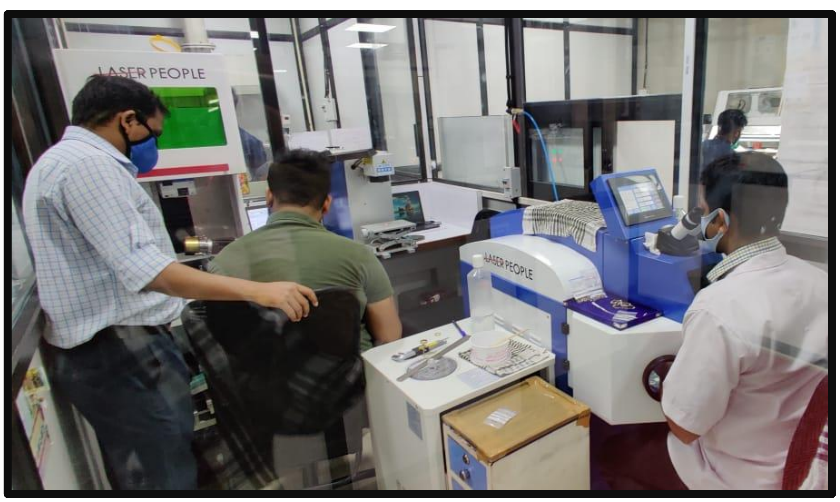


Fig. 15 Laser Cutting Department

2.5 Summary:

There are many processes involved in the manufacturing of jewellery items, ranging from initial conception to design, casting, setting and polishing. These processes are constantly being improved as technology progresses overtime. One notable improvement which is being used widespread in the industry is the utilization of 3D printers to create the master model which replaced the traditionally used clay sculpting method involving separate sculptors and artisans who created the master model by hand.

Below is a brief summary of all the processes discussed above (ref. Fig.16).

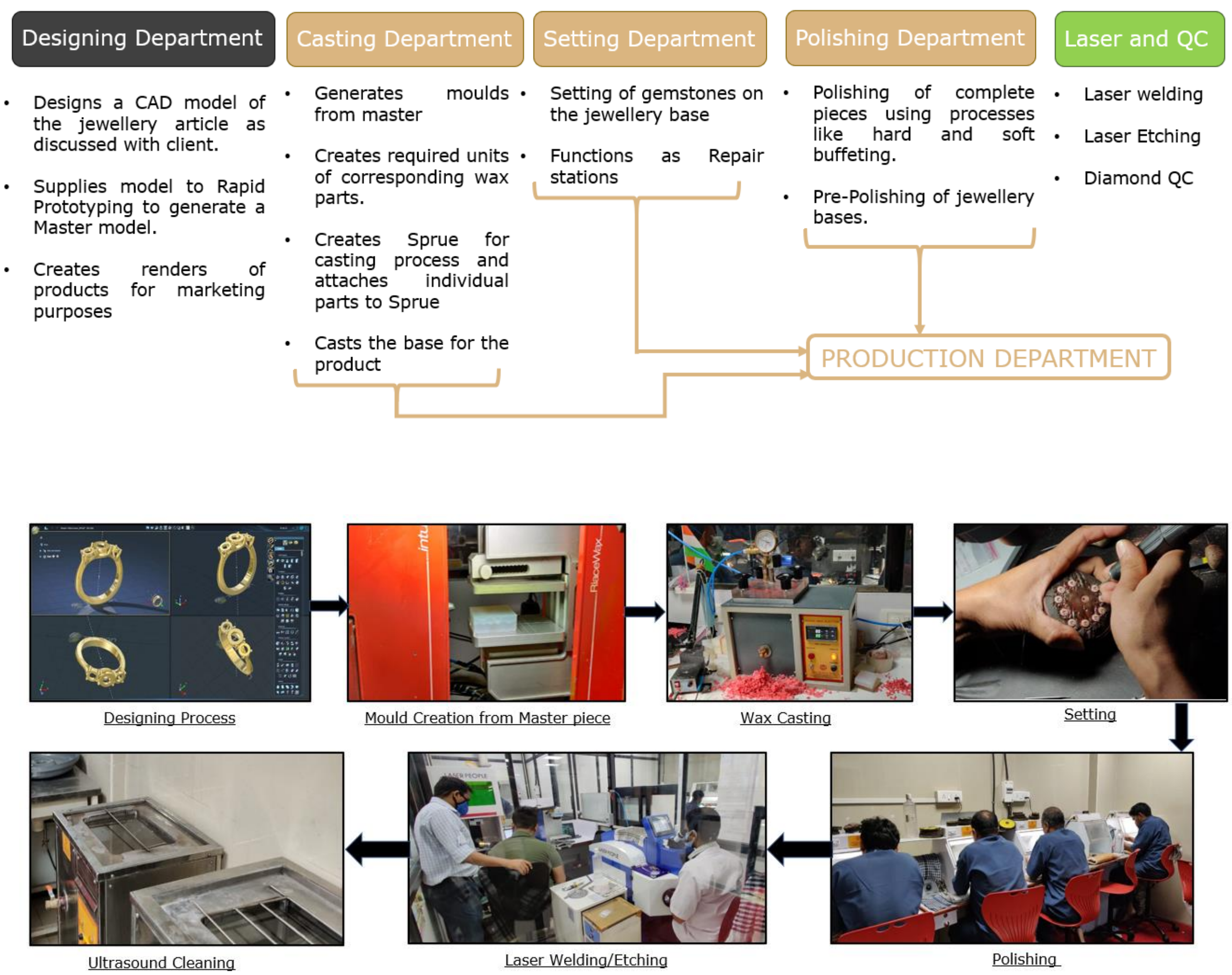


Fig. 16 Summary of Manufacturing Process Sequence

Chapter 3: Lean Manufacturing

3.1. About Lean Manufacturing

Lean manufacturing is a systematic method used to minimise waste in a manufacturing system while ensuring a neutral or positive change to productivity. This system was pioneered in the Toyota Production Systems (TPS) in Japan wherein the emphasis was put on minimizing waste within a manufacturing operation by identifying appropriate value generation streams.

Summarising the above, lean manufacturing can be construed as a management methodology which concerns itself with identifying components adding value to a product and reducing or eliminating irrelevant components, thereby creating a "lean" manufacturing methodology (ref. Fig.17).

Fig. 17 Summary of Lean Manufacturing Principles

Lean manufacturing aims to minimise the following types of wastes:

1. **Defects**: Scrap products or products that do not meet commercial specifications fall under the banner of defects. Defects lead to delivery delays and logistical complexities which reduce customer satisfaction in addition to additional resources utilised to correct the defects themselves. This amounts to significant wastage in both time and resources, and at the same time blemishes customer reputation.

2. **Overproduction**: Mass production is a cost-effective method to produce a similar kind of product. However, understanding the balance between mass production and the more selective batch production of varied sets of products is imperative to the success of the company. Overproduction leads to inventory cost increments due to excessive storage needs and may reduce the overall profit margins of the company.

3. **Waiting**: Waiting is caused by the culmination of many kinds of wastage in the company. Often in the manufacturing process, the succeeding steps may be ready for incoming load but there may be a delay in the previous step which may cause an overall delay in delivery. Most often, these are caused due to significant bottlenecks present in the manufacturing processes, both in terms of machinery and logistical inefficiencies. For example, machine downtime causing delays in packaging.

4. **Non-utilized talent**: Not utilizing the full potential of employees can be considered as a form of waste. Poor teamwork, minimal training, bad communication and unnecessary administrative tasks are common examples of non-utilized talent waste.

5. **Transportation**: In many manufacturing plants goods are transported from one place to another, for example, raw materials from China to a plant in Germany. As the process in itself adds no value to the end product and is more often than not adding additional overhead expenses to the end consumer, it is encouraged to establish the manufacturing plants as close to the raw materials as possible. For example, Toyota's manufacturing setup has most of their suppliers near the production plants.

6. **Inventory**: Inventory waste happens when a product is lying around in storage without being sold for a long time. Unlike overproduction, inventory has an associated storage cost owing to physical storage space requirements, though the former is one of the causes of the latter. Often demand falls short of expectations and higher inventory costs become unavoidable.

7. **Motion**: Motion wastage is caused due to the unnecessary movement of people, machinery and items around the factory floor. It is usually caused by improper layout design and ambiguous work protocols due to improper implementation of 5S principles. For example,

employees may waste significant time looking for materials or equipment in poorly designed workplaces.

8. **Extra Processing**: Extra Processing or over-processing refers to adding work that is not required as a value addition to the end product. Extra processing leads to increased material and equipment cost which add over time. It also makes processing less efficient because the employees performing the extra processing tasks may rather be working on more productive tasks instead.

Fig. 18 Summary of Lean Manufacturing Wastes

3.2. Lean Manufacturing Principles, Tools and Techniques

A variety of Lean Manufacturing techniques have been developed to minimize the wastes as discussed above. These techniques may be used either individually or as a composite of multiple tools as suited to the company needs (ref. [7]). The most widely used techniques are:

3.2.1 Kaizen:

Kaizen translates to "change for the better", with the concept of "continuous improvement" as the driving principle. It makes teams work together proactively and take responsibility for their areas within the company. Together, employees make incremental improvements in the manufacturing process. With kaizen, there is always room for improvement, and workers should constantly look to improve the workplace (ref. Table 2). This philosophy also emphasizes that each individual's ideas are important and that all employees should be involved in the process to better the company. An organization that practices kaizen welcomes and never criticizes suggestions for improvement at all levels. This helps to create an environment of mutual respect and open communication.

Table 2: Benefits of utilizing Kaizen Principles

Benefit	Description
1. Less Waste	Inventory and Employee's skills are used more efficiently.
2. Employee satisfaction and Commitment	Employees have a direct impact on how things are done which gives them a higher stake in the company, leading to a commitment to do a good job.
3. Improved Retention	Happy and engaged employees are more likely to stay with the company long term.
4. Customer Satisfaction	Engaged employees produce higher quality products which improve value to the customer.

3.2.2 5S System:

The 5S system is an organizational method stemming from five Japanese words: *"seiri", "seiton", "seiso", "seiketsu"* and *"shitsuke"*. These words translate to organize, tidiness, clean, standardize and sustain. They represent a five-step process meant to reduce waste and increase productivity and efficiency (ref. Table 3).

Table 3: Benefits of utilizing 5S Principles

Benefit	Description
1. Reduces cost through less storage space	Getting rid of unused materials, tools & equipment and organizing layout frees up a lot of space. This kind of cost-saving hits on not only storage rental costs but also heating and cooling, cleaning and the maintenance of the space.
2. Cleanliness	Cleanliness translates into improved maintenance and less downtime. If a machine is clean, spotting defects is easier and issues like oil spills become rarer. This allows preventative measures to be more efficient.
3. Safety	Cleanliness directly relates to improved safety. It removes clutter which can reveal electrical, chemical or machine hazards. Organizing tools and equipment in areas close to where they're needed minimizes movement and reduces injury.

A. **Seiri (ORGANIZE)**: The first step, Seiri, involves eliminating clutter and unnecessary items from the workspace.

B. **Seiton (ORDER)**: Next, the workers need to set an order by ensuring there is a logical place for everything.

C. **Seiso (CLEANLINESS)**: The next step involves cleaning the workplace and always keeping it well maintained.

D. **Seiketsu (STANDARDIZE)**: Standardization of all work processes and keeping a good consistency is vital to ensure that a worker can step in and perform a job as required.

E. **Shitsuke (SUSTAIN)**: The final step is to constantly maintain and reinforce the previous four steps.

3.2.3 Kanban:

Kanban is a system of eliminating inventory and unproductive waste by implementing a method for regulating the flow of goods inside and outside the factory. It translates to "visual signal" and relies on utilizing visual signals to help employees control inventory. Kanban cards can be placed in visible areas to signal when an inventory can be replenished. With this process, products are assembled only when there is demand from the consumer, thereby allowing companies to reduce wastage and minimize inventory costs. The Kanban method is highly responsive to customers because products can be manufactured by responding to customer needs in real time instead of having to rely on future predictions (ref. Table 4).

The Kanban system usually takes the form of columns denoting sequential stages of work progress; namely – *"To Do", "Doing", "Done"* and *"Under Review"* columns. The first step is to use colour coded notes to denote the "To Do" activities, which are then placed in the "Doing" and subsequent columns as the work progresses. This allows the other employees and the worker themselves to keep track of the status of the work. Columns can be labelled to match a particular project and there can be as many columns as needed.

Table 4: Benefits of utilizing Kanban Principles

Benefit	Description
1. **Flexibility**	With the Kanban Techniques, priorities are always being reassessed based on the most recent information.
2. **Continuous Delivery**	Kanban helps to deliver exactly what the customer wants by continuously delivering small batches of the product. This lets the team constantly update processes based on new business requirements.
3. **Waste Reduction**	Kanban improves your productivity and efficiency, reducing waste like over-production, unnecessary motion, defects and waiting.

3.2.4 Heijunka:

Heijunka is the Japanese word for “Levelling”. Level Scheduling is a type of production that purposely manufactures products in smaller batches by sequencing varying products in the same process (ref. Table 5).

In the context of the jewellery industry, we can take an example of bracelets and chains which are regularly ordered every week. Let us assume a weekly order of 500 bracelets coming in, with 200 orders on Monday, 50 orders on Tuesday, 100 on Wednesday, 50 on Thursday and 100 on Friday. Rather than trying to meet the order requirements in a sequential order every week, a set number of bracelets, say 100, can be made before the orders for Monday come in and then every day following another set of 100 bracelets are manufactured. That is, there are 100 bracelets in the inventory on Monday and 100 bracelets are produced every day of the week.

Implementing Heijunka allows the company to set the pace of manufacturing according to the “**Takt Time**”. The Takt Time is the rate at which the customer makes the purchase or the time it takes to finish a product to meet customer demands. In other words, the production rates are being matched to meet customer demands, thereby creating a level process.

Table 5: Benefits of utilizing Heijunka

Benefit	Description
1. Predictability	Levelling the production schedule enables predictability when it comes to producing goods.
2. Flexibility	Levelling the production schedule reduces the changeover time.
3. Stability	Levelling the production schedule allows balancing the use of labor and machines to predict demand.

3.2.5 Just-In-Time (JIT):

Just in Time is a management philosophy involving only producing a product when the customer wants it, in the amount the customer requested it and sent to where they want it without it being stuck in inventory. In other words, instead of making and stockpiling products in anticipation of what the customers might want, the company makes what customers order when they order it (ref. [2]). This lets the company allocate their resources (employees, machines, etc.) to only work on manufacturing the products as demand dictates. Just in Time helps improve inventory costs, reduce space, reduce lead time, increase productivity and more.

Just in Time lean manufacturing plays off of many other lean tools and techniques. Here's what is required to implement the Just-in-Time philosophy.

a. Reliable equipment is vital for JIT to work properly. Machinery cannot be constantly breaking down or producing low-quality products.

b. Well-designed workspaces are key for the JIT flow. Using the 5S system is a good strategy for improving workspace layout and flow to minimize inefficiencies.

c. Improve the quality of the workforce by setting up Kaizen teams, so employees take ownership of their own areas.

d. Defining standards for how each operation should be performed.

e. Since JIT lean manufacturing doesn't create inventory, it strives to produce only according to customer demand. Using the Kanban technique signals the previous process what needs to be made.

3.2.6 SMED:

Single Minute Exchange of Dies (SMED) is a process used to greatly reduce the time it takes to complete equipment changeovers. Officially developed by Japanese industrial engineer Shigeo Shingo, the SMED process led to an average reduction in changeover times of 94 percent across multiple industries. Implementing a SMED process has multiple benefits when it comes to going lean and minimizing waste (ref. [2]). These benefits include:

The SMED process involves a series of steps or "elements", which are categorized in two types: internal and external. Internal elements need to be completed while the equipment is stopped, while external elements can be completed while the equipment is running. The goal of SMED is to have as many external elements as possible while streamlining and simplifying all other elements.

Implementing the SMED system consists of five steps:

a. Decrease in manufacturing costs

b. The ability to produce smaller lot sizes

c. Improve schedule flexibility and responsiveness to customer demand

d. Lower inventory levels

e. Improved machine startups

f. Identifying a pilot area

g. Identifying elements

h. Separate external elements

i. Convert internal elements to externa elements

j. Streamline the remaining elements

3.2.7 **Poka-Yoke**:

Poka-Yoke – a Japanese term roughly translated to "mistake proofing" – is a technique used to make sure the lean process produces quality products. Its purpose is to minimize or eliminate defects by preventing, correcting, or bringing to light any human errors that are occurring.

In manufacturing, poka-yoke can be implemented at any step of the manufacturing process where human error can cause something to go wrong (ref. [2]). For example, a device holding pieces for processing might be modified to only allow pieces to be held in the correct orientation required for input. Another example would be a digital counter that counts the number of spot welds on each manufactured piece to ensure the welder makes the correct number of welds.

There are three types of poka-yoke for detecting errors in a manufacturing setting:

1. The **contact method** identifies defects by testing the product's shape, size, color and physical makeup.

2. The **fixed-value method** (constant number) sends out an alert to the operator if a predetermined number of movements are not executed.

3. The **motion-step method** (sequence) makes sure the predetermined number of steps for a particular process have been followed.

Generally, the operator is alerted when a mistake is impending (known as a warning poka-yoke) or the poka-yoke device prevents the mistake from being made itself (known as a control poka-yoke). Benefits of implementing poka-yoke include less money spent training operators; elimination of certain quality control operations; lessening the number of repetitive operations; a reduction in the number of product rejects; built-in quality control; preventing defected products from reaching your customers and more.

3.3 Benefit of Lean Manufacturing in Jewellery Industry

Nearly 60 percent of all manufacturing activities around the world are classified as waste. Every industry has some degree of waste generation and thereby significant room for improvement, including the jewellery industry.

Whenever a company starts implementing lean manufacturing technologies, a significant time for gestation is required to correctly establish these systems within all levels of the company (ref. [7]). The team needs to decide whether to implement one technique at a time or a composite of various techniques together as suited to the real time needs of the company. Correctly using these tools, the company may be able to reduce one or more types of wastes as discussed previously.

In the Jewellery industry which involves a significant amount of varied batch orders including niche custom products as well as auxiliary retail products, lean philosophies like JIT play a crucial role to maintain favorable profit margins. Significant wastage of expensive raw materials as scraps in the wax casting and polishing processes and the need to recycle these scraps involves the inclusion of 5S techniques to minimize material wastage. Maintaining the processing and delivery timelines of all these products requires the management teams to accurately keep track of the status of the product in each tier of the process cycle wherein they may utilize Kanban methodologies to be more efficient

Before implementing Lean Manufacturing principles, the company needs to keep the lean manufacturing cycle in mind. There are five steps in the lean manufacturing cycle:

1. **Identify value**: This means thinking about the end customer and what they define valuable.
2. **Map the *Value Stream***: Layout all the steps within the processes and eliminate those that do not add value.
3. **Create flow**: Figure out ways to make the valuable steps more streamlined in a tight sequence to provide the end customer with as much value as possible.

4. **Establish Pull**: Create more demand from your end customers, so they are looking for the product rather than the industry having to push the product to the customer.
5. **Strive for Perfection**: Continuous improvement is key in Lean Manufacturing. The goal is to always be thinking of ways to eliminate waste and document and standardize the processes to generate success.

Finally, it's important to always respect the human elements when talking about going lean and implementing lean principles. This means striving to keep employees happy and engaged with their work by making this goal a core principle. Without a respect for employees and the people within your organization, people tend to disengage and not perform at a consistently high level. It's a relatively easy principle to put into practice as there are only a few elements to keep in mind, but each element tends to become difficult to manage since you're dealing with humans and not machines.

Chapter 4: Using Lean Manufacturing Tools to Increase Time Efficiency

4.1 Introduction

In the increasingly dynamic and competitive world of Jewelry manufacturing, a continuous and steady improvement in process efficiency and flexibility is needed to ensure the consistent growth of a company. The employment of Lean Manufacturing processes has proved to be an indispensable tool for companies to continuously improve production processes and thereby increase quality and customer satisfaction.

One of the major tasks for a company are to eliminate the scope of different types of wastes, especially time, using Lean Manufacturing principles. The purpose of this study is to analyze and improve production and management processes, specifically by utilizing the Kaizen, Kanban, 5S, JIT (Just-In-Time) and other Lean Manufacturing processes. The sequential operational processes were studied over the last two months and various Lean Manufacturing principles were incorporated in the following three phases:

1. **Design Stage**: Developing streamlined methods to minimise errors at the design stage is indispensable to successive operations working efficiently.

2. **Planning Stage**: Creating precise project plans, scheduling and inventory management is beneficial for the operations to perform smoothly at the shop floor.

3. **Operations Stage**: Elimination of wastes during the sequential processing cycles and removal of redundancies allows greater utilization of resources and higher overall profits.

4.2 Problem Statement

Since VD Jewels and Artisons Pvt. Ltd. is a relatively young company, a variety of the major bottlenecks in the production process arise due to limitations in working capital which limits the redundancies of machines, thereby creating possible chokeholds on the production cycle.

1. A recurring problem during the process cycle is the demand for the laser welding machine from multiple departments such as setting, repair and QC. Since there is only one operational laser welding machine at the shop floor, and complete batches are kept on hold until the particular defective unit(s) from that batch is repaired, an unprecedented bottleneck is occasionally created which is the primary contributor to delayed service to the customer.

2. As for the initial activity of generating the SO; the marketing and sales department primarily creates the service order without the supervision of the PM. The SO generated lacks certain critical technical information such as core dimensions, target weight and material requirement & compositions which are retroactively added by the design team. This results in delayed reception of the SO to the PM and PPC head which results in production delays.

3. Since a majority of the workers are contractually hired rather than being full time employees, often the shop floor is staffed according to the expected order flow. This sometimes leads to workers having to leave their own stations to personally deliver to or operate on another workstation, often leading to unexpectedly high idle times.

4. Non-standardized working practices which lead to miscommunication between teams regarding order status and completion and thereby causing manufacturing delays.

5. Inadequate implementation of visual management tools at the setting and repairing departments keeps worker efficiency limited.

6. Limitations on knowledge of order status in the intradepartmental level creates confusion in order tracking and may cause delays in service times.

4.3 Objective

The purpose of this project is to utilize various Lean Manufacturing tools like 5S, JIT, KAIZEN and KANBAN to increase the time-efficiency of the production processes by reducing the overall idle time of operation.

4.4 Methodology

The team started their research with an overview of the various departments and company hierarchy. Every student followed the entire production process in a logical sequence - starting from the Design department, followed by the Wax, Casting, Hand setting, Polishing, Quality Control, Laser and Ultrasound Cleaning departments wherein batch production of wide-ranging items such as rings, earrings and bracelets are produced from raw materials. The management hierarchy starts with the Chief Executive Officer (CEO) at the head under whom is the Production Manager (PM) who establishes the weekly scheduling, inventory requirement and project scopes as per the Service Order (SO). The PM collaborates with the head of the Production Process and Control Department (PPC) to initiate a production request as per the SO. The PPC head utilizes an MES software - Jemysoft to assist in traceability and manage scheduling. This information is added to the SO and provided to the various departmental heads. The MES software is used to record information on batch orders, namely the design specifications, material requirements, target weights, delivery schedules, etc. which facilitate the company's traceability apparatus.

4.5 Implementation of Lean Tools

Lean Manufacturing philosophies can radically change how a company operates at all levels. The universality of this philosophy allows it to be translated to tasks of all nature, ranging from purely managerial to purely technical and among all levels of the company hierarchy.

Lean Manufacturing methods emphasise ownership, accountability and engagement among all the workers in the company and enables them to solve problems at the micro-level without the oversight of their supervisors. This philosophy also emphasises both systemic and micro-level changes within the company processes such as saving a few seconds in each individual process to reach a significant cumulative increase in overall efficiency. To this effect, techniques like

KANBAN, KAIZEN and 5S methodologies are at the forefront of LM implementation in companies. Below are solutions to some of the major problems which were affecting the company.

4.5.1 Kanban and Visual Management systems:

One of the most elegant tools used in "lean" philosophy is Kanban. At its core, it is a workflow management system used for defining, managing and improving services that focus on the elimination of various kinds of wastes including over-production, faulty products, over-stocking, under-utilisation of employees, unnecessary transportation and prolonged wait times. The following is how KANBAN will help this company to reduce the idle time wastage:

a. **The SO generation Problem**: As discussed above, the team has noticed a recurring miscommunication between the Sales Department and the Production Manager regarding the Service Orders (SO). A change in the current system has been suggested which integrates the SO generation system to allow orders to be initiated by the Sales Department under the supervision of the PM and subsequently plans and sorts how and when these orders are converted to Service Orders and sent to the required departments through the existing MES software.

b. **Visual Management System**: Currently, the various departments work independently and communicate to each other through the company's ERP system. Although there is no inherent flaw in this system, it keeps these departments quite opaque and sometimes hard to keep track of. Often, the team has seen discrepancies in order status between departments which leads to confusion and additional time is wasted in trying to figure out where the status has been misreported.
Incorporating visual management systems to aid each department in keeping track of the status of the products is an excellent way to steer this company towards a "lean" philosophy. One of the most effective implementations are KANBAN boards, as described below:
    - **Physical Boards**: Utilization of a physical white board with colour coded notepads comprising of task information. This is best suited for more personalised tasks at the employee level.

- **KANBAN Software**: A variety of open-sourced software like JIRA, TRELLO, etc. (ref. Fig.19) can be used at no additional cost to the company. These KANBAN software allow departments to communicate within and in-between themselves in a very effective way. The concept functions within four separate phases – *"To Do", "In Progress", "In Review"* and *"Completed"* wherein the orders (written on virtual colour coded cards) are shifted between these project phases as per their completion status. The "In Review" column exists to indicate that the particular order batch is currently on hold due to machine unavailability or QC issues. As the order card moves between the phases by a simple "drag and drop" method, a different colour is assigned to signify its level of completion, with editable columns in the "To Do" section to increase or decrease the resolution of production processes within the departments.

This system allows for a higher level of transparency to the Production Manager to keep track of the status of all service orders and makes identifying possible problems in the assembly line. The versatility of Kanban Boards allows it to be utilized by almost anyone in the company irrespective of departmental constraints and therefore will prove to be an indispensable tool for organization at the micro and macro levels.

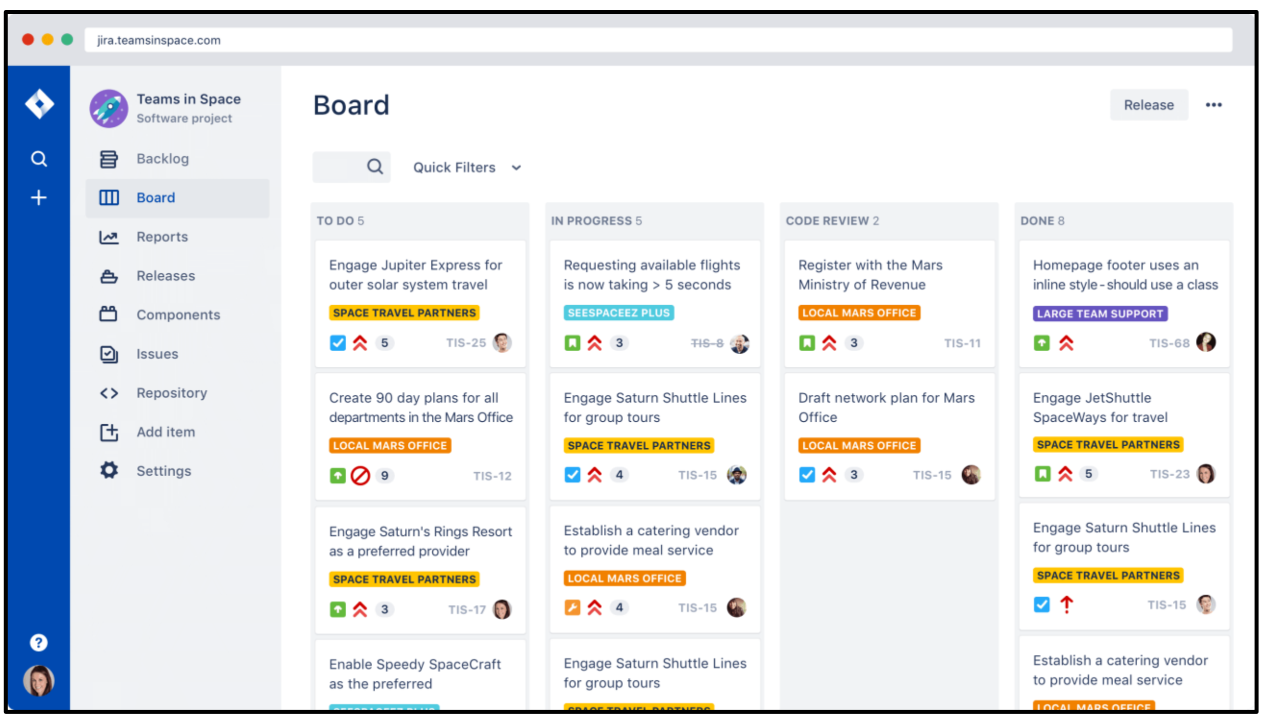


Fig. 19 User Interface of JIRA software

DETAILS	DESCRIPTION
Order Number:	-
Quantity (No. of Units):	-
Product Weight (Per Item in Grams):	-
IN:	DD/MM/YYYY – 24:00
OUT:	DD/MM/YYYY – 24:00
Observations:	-

Fig. 20 Designed Order Card

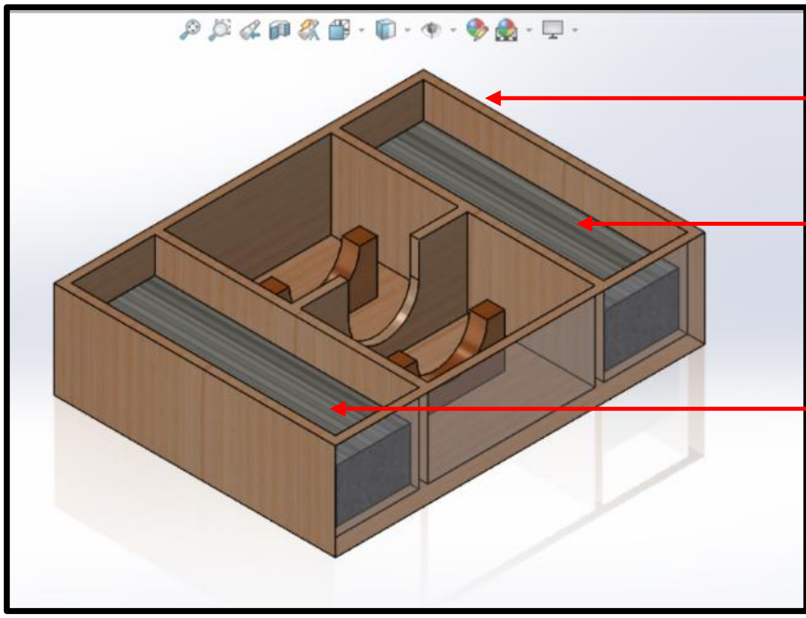
4.5.2 5S System:

Various 5S systems were implemented along with KANBAN principles to facilitate efficient storage and accessibility for the workers who are handling various tools during the production process.

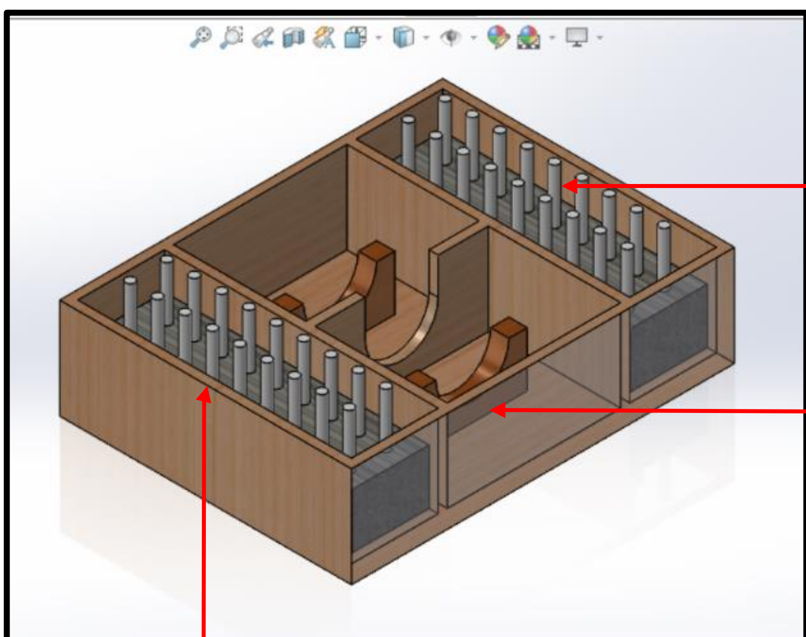
Initially, I surveyed the hand-setting and repair departments where I noticed a disorganization in tool storage from workstation to workstation. Considering that most of these employees are contractual and often change workstations, adjusting to disorganized workspaces can cause additional confusion which is an avoidable time wastage.

Therefore, the workstations required a regulated storage system. 5S principles were used to design a sorting tray in which the toolsets would be stored in colour-coded compartments. The *toolbox* (ref. Fig.21) itself will be constructed from MDF boards which are cheap and commonly available, with rectangular high-density XPS foam slabs placed in smaller compartments to hold the thinner tool-bits. A separate section for the Dremel tool and smaller subsections for other tools will create a compact storage space which will be portable enough. Additional shelves and handles to carry the box can be attached if required. The toolbox design has been presented to the project in-charge and deliberations about its utilizations are being conducted as of April 2021.

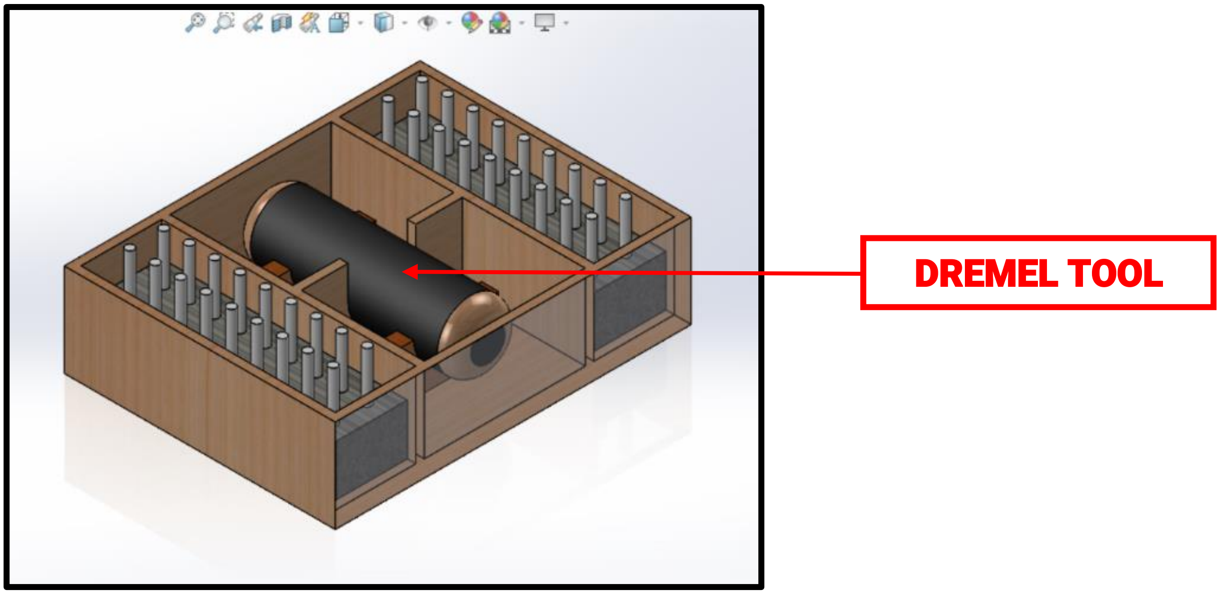
The Toolbox has been designed in Solidworks CAD Software and has a base dimension of *20cmx15cm* with *height 7cm*. It has three compartments – <u>one compartment for storage of Dremel tool and two compartments for storage of tool-bits</u>. The Dremel compartment contains MDF holders which follow the contour of the tool surface, while the tool-bit compartments have XPS foam slabs for attachment. Identifiers can be placed in the two compartments for tool-bit identification. A hinged lid is also provided for enclosure.



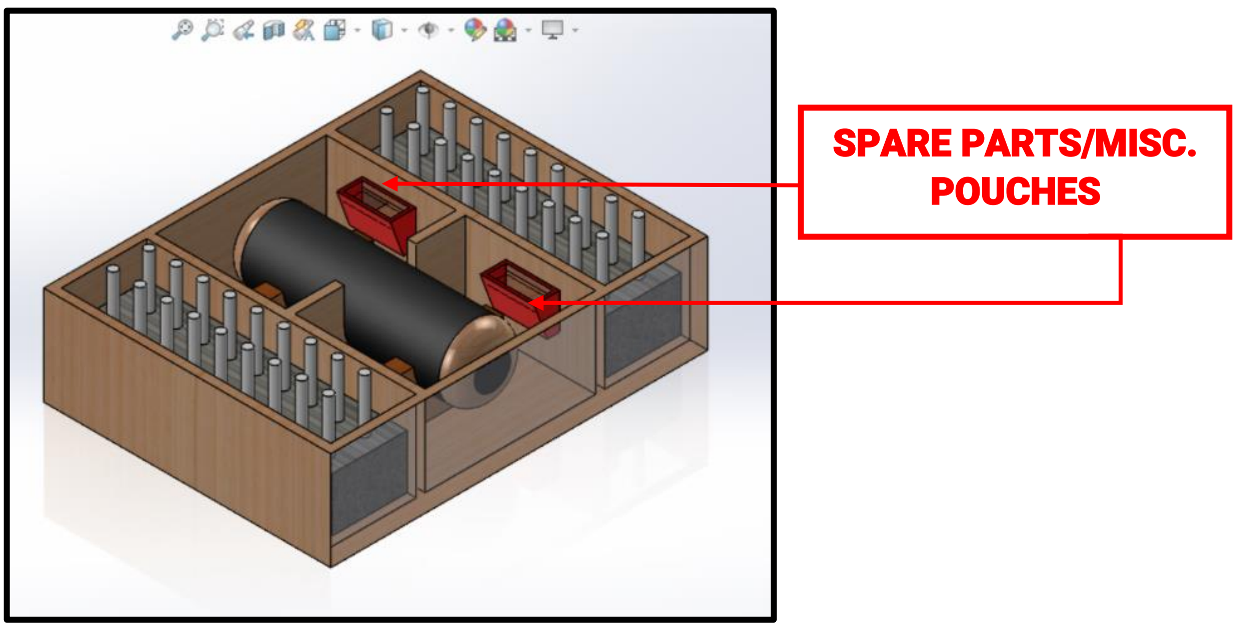
TOOLBOX STAGE-I



TOOLBOX STAGE-II



TOOLBOX STAGE-III



TOOLBOX STAGE-IV

Fig. 21 Toolbox Design

In the jewellery industry, it is a standard practice to operate on jewellery units in the form of batches which are usually kept in zip-lock bags (ref. Fig. 22). This prevents the individual pieces from moving too far away from the main batch and reduces the risk of losing track of these pieces.

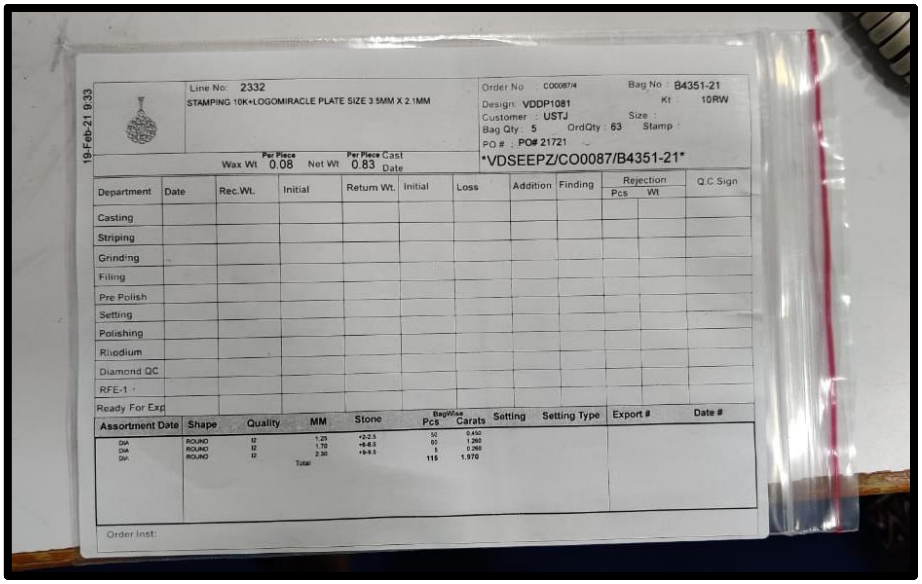


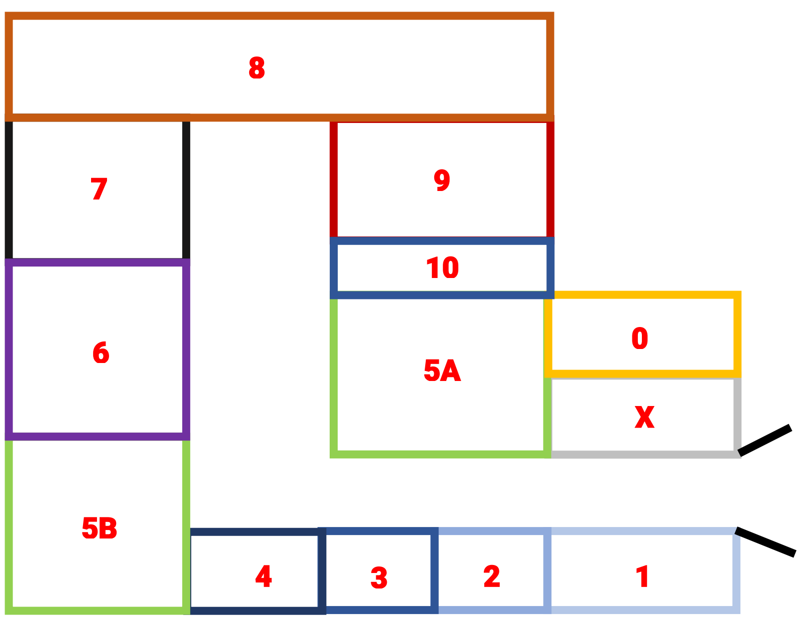
Fig. 22 Ziplock Batch Bags

These bags also have relevant product information which is used to co-ordinate with the MES software in filling out the order status. Currently, the management of products within the bags is highly unregulated and depends on the oversight of the workers themselves. This can be improved by utilizing the 5S principles for which a **bag sorting system** similar to the toolbox was proposed to allow for a more systematic way to organize the bags. Four compartments would be created with colour coded identifiers which would each denote in sequence the “To Do”, “Doing”, “In Review” and “Done” columns similar to the KANBAN system. This system negates the possibility of In-Review bags intermixing with completed bags which was a recurring problem in the repair and hand setting departments. Additionally, it allows the floor managers and everyone in the workstation array to quickly identify the progress of the batches.

Additional identifiers may be used for different product categories, possibly with layered trays for each specific product category. A basic version of this is being experimented with (as of April, 2021) to ensure its efficacy, it employs simple cardboard divisions right on the workbench which are labelled as per the four columns to denote progress. So far, speaking anecdotally, the concept has yielded easier workflow and has encouraged workers to be more organized. Giving the workers themselves the autonomy and instrumentation to make changes in the company is one of the driving forces of the lean philosophy, wherein the workers themselves can feel empowered to address problems and present solutions. The 5S philosophy aims to achieve just that.

One of the more serious problems in the shop floor (ref. Fig.23) was the recurring need for workers to move away from their workstations to operate on a separate workstation or deliver workpieces themselves, thereby leaving all the remaining batches idle. This was observed during our time studies conducted that during such situations, jobs would be completed at an average of **250-300%** of their usual time, which is a significant wastage of time.

Even though this glaring wastage can be compensated by hiring more workers, often it is counter-intuitive to do so especially during the slow months where the company can afford to delay product completion as long as it ships in time, owing to lower order volume. However, this does not exempt the other situation when the worker has to physically deliver the product(s) themselves. **In this case, the team observed an average 150% increase in completion times, with 50% idle time which translates to 2-5 minutes accounting for separate product categories.**



- **0: Wax/Casting Department**
- **1: Project Manager's Office**
- **2: Production Control Department**
- **3: Quality Analysis Room**
- **4: Laser Department**
- **5A/5B: Setting & Repairing Departments**
- **6: Quality Control Room**
- **7: Abrasive Cleaners**
- **8: Polishing Department**
- **9: Secondary Polishing Department**
- **10: Ultrasound Cleaning Department**
- **X: Storage/Misc. Room**

ITEM FLOW:

0->5A->3->4/8->7->9->10->6

Fig. 23 Shop-floor Layout

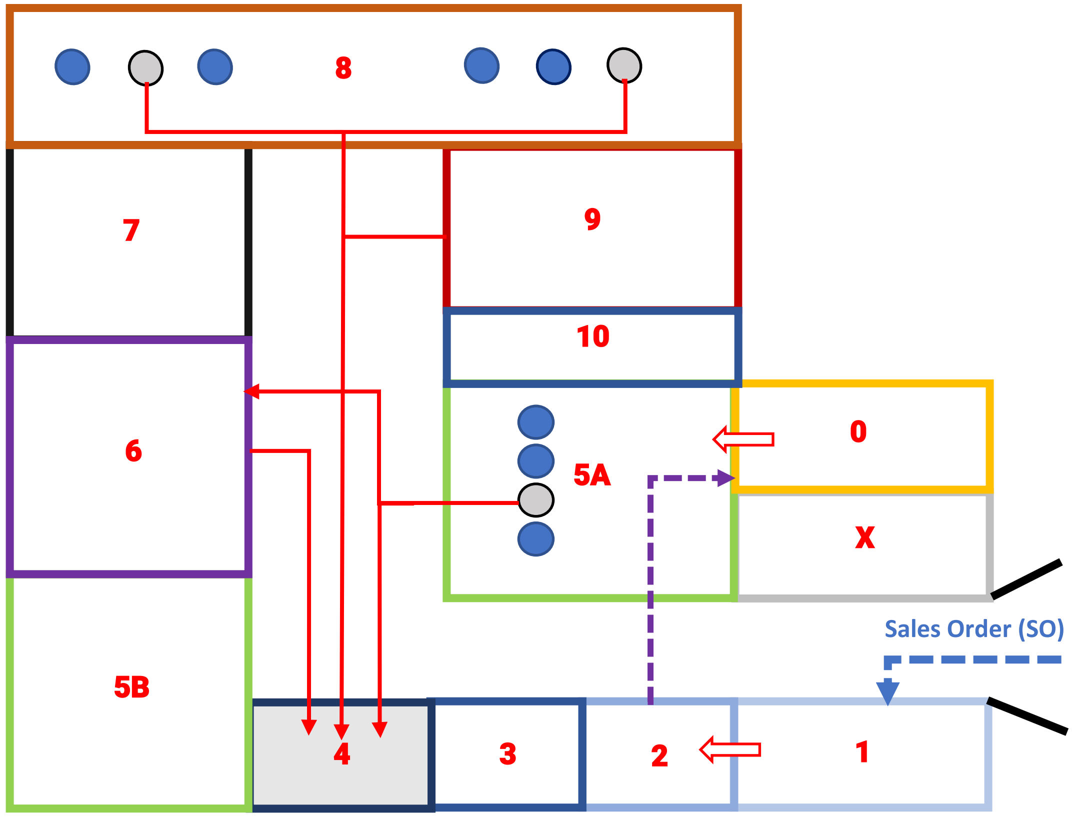


Fig. 24 Shop-floor Layout with Product Flow Lines

The red lines (ref. Fig.24) denote the usual product flow within the company, as you can see, room no. 4 which is the Laser Department has the highest inflow at any given time, with items coming in from almost all the departments simultaneously. This causes a long queue and immensely contributes to idle time, thereby becoming a major bottleneck within the company. Of course, the most direct solution to this issue is to order another laser welding machine or repair the secondary laser machine which has been non-operational for a long time. Both of these solutions will require significant capital investment; however, I have devised a solution which can alleviate these problems in the meantime.

A Runner System can be established where each worker is provided with a two-sided stand, with one coloured GREEN and the other coloured RED to signify the QC and Laser Departments respectively. These are the two most frequently visited areas where high numbers of batches pass continuously. An independent "runner" will be hired to deliver these batches to the required department, as signalled by the worker at the repair/setting workstation.

Once the worker pulls up the stand (which is hinged on the side wall of the workstation cubicle and facing towards the door), the runner collects the batches and updates the batch status in a “Tasks” software or app similar to Google Tasks. They then bring it to the required department as per the colour of the flag. At the same time, the worker can keep working on the next batches rather than wait in line for access to the laser department. This is expected to *save an average of 2-4 minutes per batch and a cumulative of 1-1.5 hrs per worker daily*. A *weekly saving of 7-8 hrs* equates to one full day of productive work for each worker. Considering 20 workers at a time, this equates to *160 hrs of cumulative savings weekly*.

The Runner System has been proposed and trial runs have been conducted which corroborated the above findings. The workers themselves have responded positively to this idea and seem to be happier and more focused in their work. Physical exhaustion is minimised for the worker and they have shorter working hours at the end of the day. This suggests that hiring the extra worker is worth the time saved.

Over time, the system can be evolved to incorporate multiple departments, increase connectivity by using electronic tablets with shared networks and establishing electronic and sensor- controlled signals using IoT systems in the company.

4.5.3 **Pull System**:

A medium-scale jewellery manufacturing company normally produces the required products in specific batch quantities as per the orders received weekly. The raw materials utilized for these products, such as various types of gold (yellow gold, white gold, etc.), silver, copper, and various other precious metals and gemstones carry a very high holding cost and material cost which fluctuates daily. Therefore, keeping large amounts of these materials in stock is counter-productive, which encourages the implementation of a Pull system.

This implies that most orders (especially seasonal orders) are only produced as and when the orders are received from the customer. The production is initiated on receiving the order and only the required quantities are manufactured. For less seasonal and predictable products like rings and bracelets, the company utilizes a mixed Pull system. In this system, a reserve number of units are kept manufactured before receiving the actual order to serve as back-up stock for upcoming orders which reduces the probability of delivery delays to the customer.

Identifying the *Economic Order Quantity (EOQ)* and order times for the above systems will reduce the current inventory costs while ensuring adequate redundancies for on time delivery to the customer which in turn will allow higher profit margins for said items along with greater customer satisfaction and trust (ref. Table 6).

Table 6: Proposals and Results

Proposals	Implementation State
Adoption of Lean Manufacturing tools:	1. **Kanban Board Software** – Jira was suggested along with physical boards being used currently
	2. **Visual Management tools** using MES software suggested to aid in Flow Manufacturing
	3. **5S improvements** in existing workbench structures, incl. sorting and Kanban methodology
	4. Addition of "**runner**" system to aid in material handling
	5. Using **EOQ** in mixed pull systems (company declined to provide client list, which is a necessary requirement for EOQ calculation so I have suggested project guide to utilize the same)
	6. **Standardization** of working practices among workers and greater transparency to head of production
Integration of MES-ERP Software:	A two-layered approach has been proposed which includes an ERP top layer for orders, bills of materials, inventory control and then an interface to an MES layer which focuses on operations on the floor such as electronic batch records, scheduling, material consumption tracking and reorder procedures. (Discussion Later)

Predicting the EOQ can be done by counting incoming orders, predicting future orders and establishing connection b/w the production and sales departments using a layered ERP-MES system which will be discussed later.

4.6 Analysis of Results:

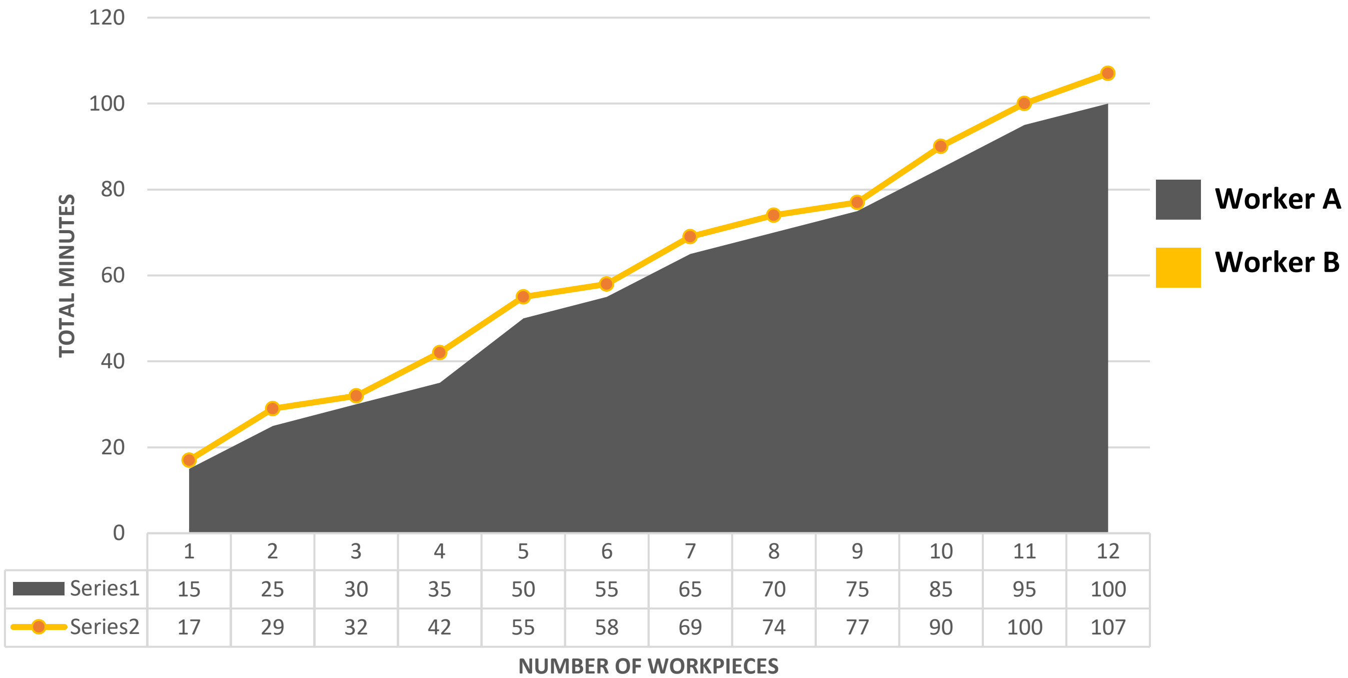


Fig. 25 Time Study – Setting and Repair Department

A dry run was conducted with the previously discussed improvements to evaluate their efficacy. For this purpose, I selected a day in which a similar kind of ring was ordered in bulk so that there would be enough units for the workers to operate on in independent workstations at the same time.

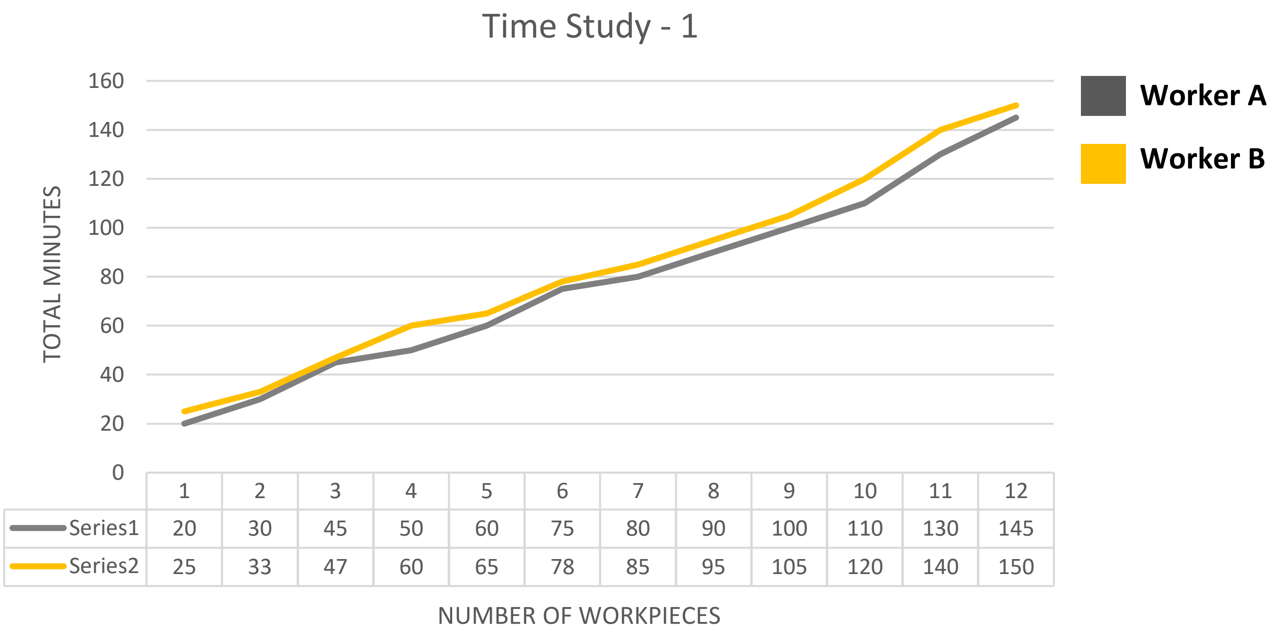
The workers were chosen at random in sets of two, and time study was conducted (ref. Fig.25) such that one worker was placed on the improved workstation and the other in the control workstation (which has not been changed from original). The trial was conducted three days after the workstations were improved so that the worker may be able to adjust to the new changes.

Both workers began with 12 unworked metal base pieces on which setting is to be conducted. One worker (*A*) is at the workbench with 5S improvements (GREY) and the other (*B*) is at an unchanged workbench (ORANGE).

We can notice the benefits of having the sorting system and other 5S principles at workbench A, as even at the very first piece, he saves 2 minutes on the whole operation as compared to worker B. Now, overtime, this number cumulates and *we can see that worker A finished with all 12 pieces 7 minutes earlier than worker B.*

However, this trial run by itself was insufficient to conclusively establish the benefits of the 5S system since there was no parameter to consider the variation in the efficiency of the workers themselves, or guarantee the conformity of every metal piece which may contribute to the adulteration of actual data.

The only way to understand the trend is to generate multiple trial runs using many worker pairs and also iterating between workers within those pairs. The time-study data was collected as shown below:

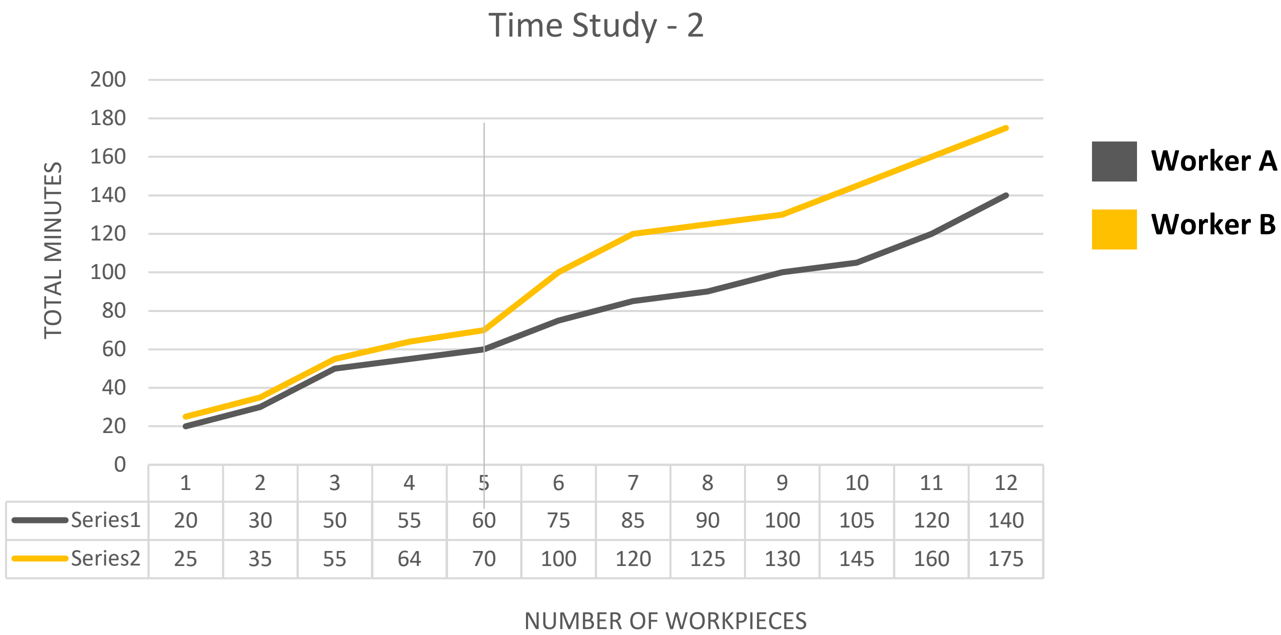


	1	2	3	4	5	6	7	8	9	10	11	12
Series1	20	30	45	50	60	75	80	90	100	110	130	145
Series2	25	33	47	60	65	78	85	95	105	120	140	150

Fig. 26 Time-Study 1 – Setting Department

Here also we can see a similar trend wherein worker at bench A completes the same set of workpieces faster than worker at station B (ref. Fig.26). Similar trends were obtained for three other pairs, however one trial was of particular significance as it establishes the necessity of the *runner system*.

The following graph (ref Fig.27) is the cumulative average of time-study data collected over 10 days at workstations where the “Runner” system was on trial. Data was collected using a stop watch and the runner motions were identified to locate high product flow workstations. This graph shows the comparative time-study of two workers, A and B with worker A provided with a runner and worker B is operating in original conditions.



<u>Fig. 27 Time-Study 2 – Setting Department</u>

Here again, we find a similar trend as the above two graphs. However, we can see that in this instance, the time saved by worker A is almost 35 minutes, which is very high. The reason for this was that both the workers were provided with one defective piece which required a laser welding operation. However, only worker "A" was provided with the runner, so when worker "B" reached the defective piece (no. 5), he had to physically leave his workstation and queue at the laser department whereas "A" had the service of a runner who did this task for him while he worked on the remaining units. So, by the time the runner returned with the piece around 30 minutes later, "A" was already finishing up with workpiece no. 7 and could smoothly change over to workpiece no. 5. At the same time, worker "B" returned after 30 minutes of having left the workstation and then resumed from workpiece no. 5 onward.

In the end, the runner system saved approximately 35 minutes for worker "A" which can be utilised to perform operations on two extra workpieces. Situations like this occur approximately 30% of the time during rush hours as per my observation, so a system like this may hypothetically save 50 minutes at maximum. *(Calculation = 0.3 * 35 min * 8 hrs * 60 mins / (Approx. 100 min cycles) = 50 minutes/day saved) The above evidence suggests that the Lean Manufacturing Principles, 5S improvements and the Runner system have proved beneficial to improving the time-efficiency in the company*

Chapter 5: Multi-Layered Enterprise Resource Planning Software Integration

5.1 Introduction to the MES System

A Manufacturing Execution System (MES), is an information system which monitors and tracks the process of producing manufactured goods on the factory floor. The overall goal of MES is to make certain that manufacturing operations are effectively executed to improve production output. That goal is achieved by tracking and gathering real-time and accurate data about a complete production lifecycle (ref. [8]).

MES is a comprehensive system that controls all the activities occurring on the shop floor. It begins with all the various orders from customers, the MRP system, the master schedule, and other planning sources; and then builds the products in the most effective, low cost, expedient, and high-quality way possible.

VD Jewels and Artisons Pvt. Ltd. currently utilizes a customized MES software called Jemysoft. This system is used to consolidate system critical information including inventory, sales, process times, etc. and co-ordinate between various departments in the factory floor to track and monitor each and every order batch from the casting stage to packaging and shipping stage.

Incorporating the customized MES system to co-ordinate between the sales team and the factory floor allows the project manager and all concerned employees to review the status of products, increasing the overall efficiency and ease of operation.

The major benefits of the MES system are mentioned below:

- Reduces manufacturing cycle time
- Reduces or eliminates data entry time
- Reduces work-in-process
- Reduces or eliminates paperwork between shifts
- Reduces lead times
- Improves Product qualities
- Eliminates lost paperwork
- Empowers power operations people
- Improves the planning process
- Improves customer service
- Reduces setup cost and wait time
- More reliable and precise sequence planning

Yet another critical characteristic of a Class A MES, is the ability to integrate with the systems surrounding it. Not only does this eliminate the mindless re-entry of mounds of data, it also allows the adjustments necessary to bring the surrounding systems closer to reality. For example, critical information from the shop floor is needed to update other elements of the manufacturing ERP system such as Inventory, Costing, and Procurement. Setup times may be improved with new techniques used on the shop floor, and need to be fed to the ERP system for future use. This will provide better information when advising customers of projected delivery dates on new orders, or will provide improved costing information when making pricing decisions. The shop floor information provides the reality to make the adjustments necessary to continually update the other business systems. This is called *Closed Loop Integration*.

A good MES system also provides the latest tools for controlling the scheduling requirements in the shop floor. The shop floor is a complex, highly entropic environment where various related and unrelated products are manufactured at the same time. Scheduling is therefore a critical avenue for process improvement.

The MES system has the following scheduling systems:

1. **Finite Scheduling**
2. **Minimum Operation Priorities**
3. **Queue Compression**
4. **Finite Slotting**
5. **Visual Scheduler**

The MES scheduling methods are:

1. F = Forward
2. R = Repetitive
3. B = Backward
4. O = Overlap
5. M = Manual
6. P = Parallel

5.2 Functions of MES System

The MES system possess all the critical functions performed on the shop floor. These are the basic functionalities of the MES system:

- Resource Allocation and Status
- Operation/Detail Scheduling
- Dispatching Production Unit
- Document Control
- Data Collection
- Labour Management
- Quality Management
- Process Management
- Exception Management
- Maintenance
- Management
- Product Tracking and Genealogy
- Performance Analysis, including Work-In-Progress (WIP) overviews

5.3 Core functions of MES system

The MES software has certain core functionalities which are essential to the functioning of the shop floor, these are:

- Planning System Interface
- Visual scheduler
- eProduction/Dispatching
- Shop Floor Control
- Inventory Tracking and Management
- Material Movement Managing
- Exception Management
- Support functions of MES
- Maintenance Management
- Time and Attendance
- Payroll
- Human Resources
- Job Cost
- Quality
- Statistical Process Control
- Performance Management
- Document Management
- Product Data Management
- Genealogy/Product Traceability
- Product Configurator
- Bill of Material
- Engineering Change Control
- Supply Chain Management

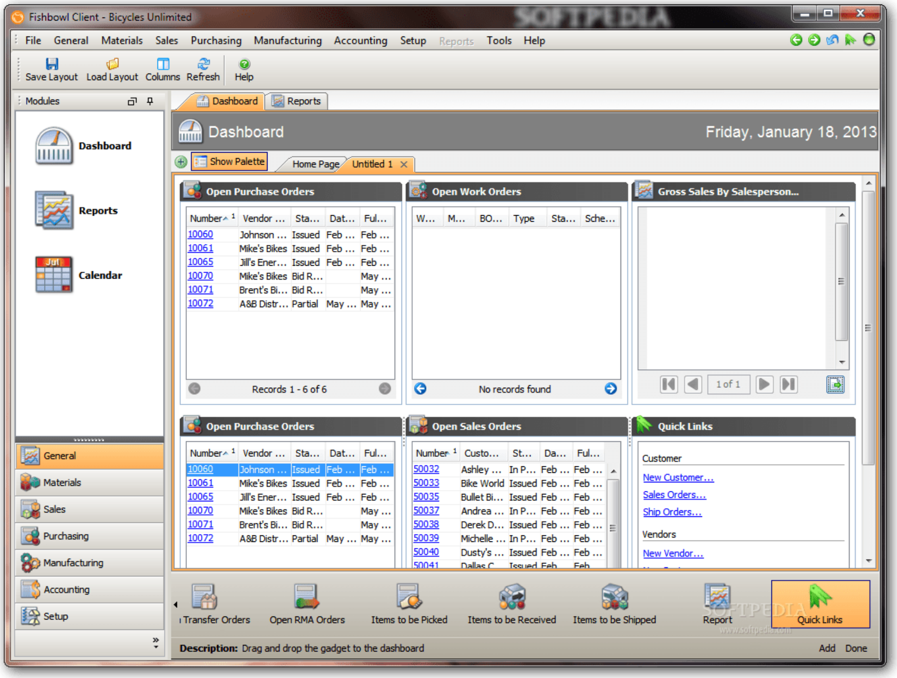


Fig. 28 MES Software Dashboard

The MES system (ref. fig.28) consists of a customisable dashboard which comprises of information relating to Purchase Orders, Sales Orders, Manufacturing Information among others.

The dashboard is customised as per the requirement of the PPC head so as to best integrate information between the sales department and the shop floor.

This is used to coordinate information flow between the clients to the shop floor via the sales department.

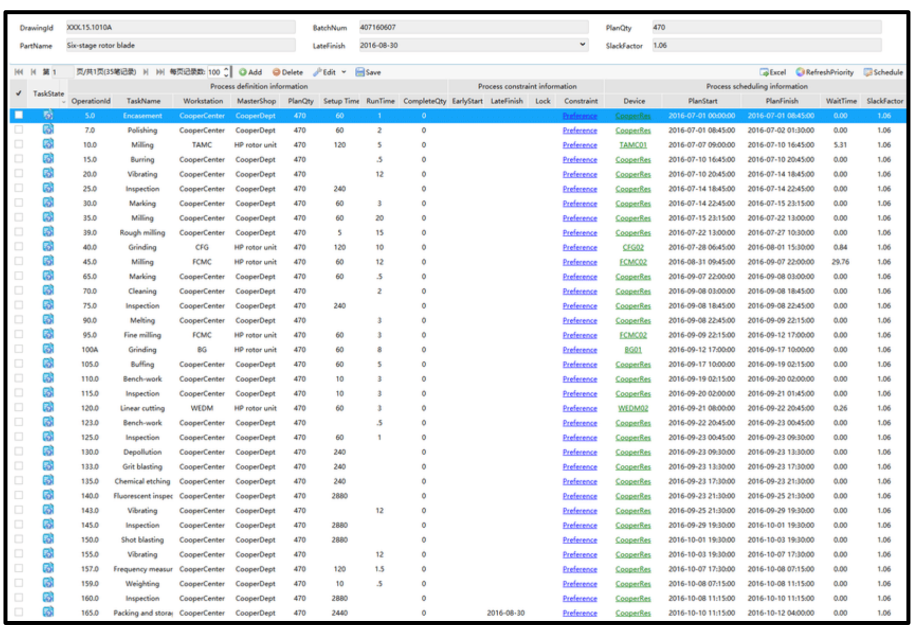


Fig. 29 MES Software UI For Part Task

The MES system is highly beneficial for part task scheduling (ref. Fig.29). It displays relevant information including the task name, workstation/department, machine no., wait times and the project completion timeline.

This allows the PPC head to track the real time status of batches in the factory floor and provides an overview of the expected completion time of the particular operation.

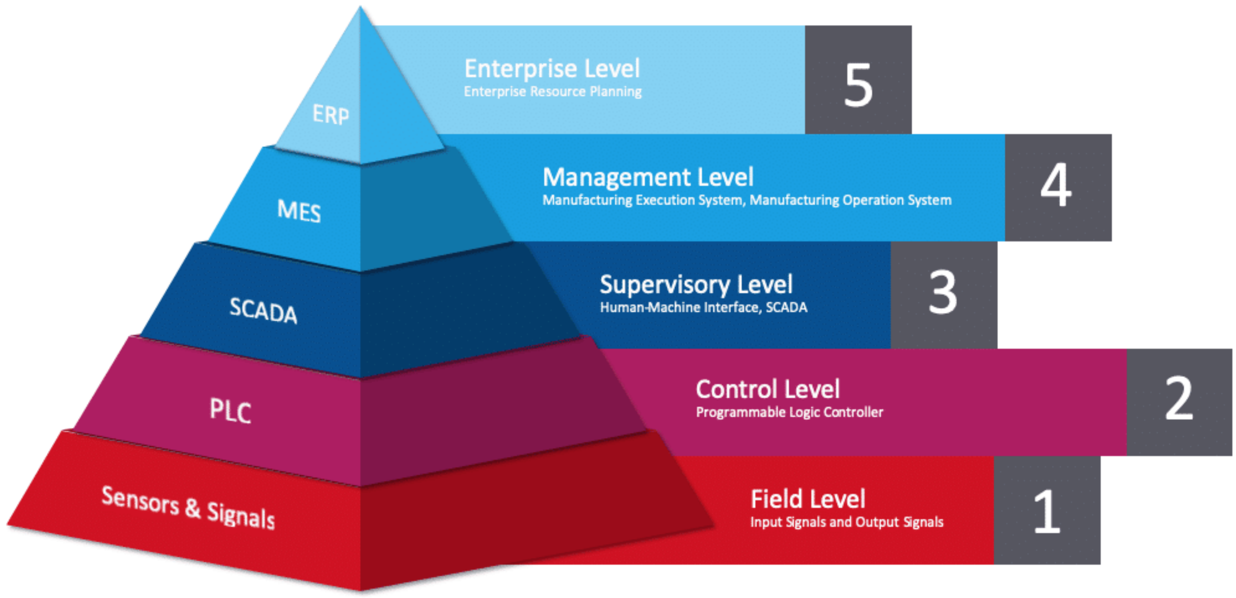


Fig. 30 Enterprise Control System Hierarchy

Integration of the existing MES system – **Jemysoft**, with an ERP software such as SAP system or Tally ERP has been proposed to consolidate Production Control and Sales Department. Unlike the MES system which is based on individual process events, an ERP system works on the basis of financial transactions and its economic substructure.

A two-layered approach (ref. Fig. 30) has been proposed which includes an ERP top layer for orders, bills of materials, inventory control and then an interface to an MES layer which focuses on operations on the floor such as electronic batch records, scheduling, material consumption tracking and reorder procedures. An ERP software like **Tally ERP** is a popular choice for most medium-scale industries. It has an efficient user-interface with a Front Office enabling data collection from the shop floor and a comprehensive Back Office to ensure full traceability of the production data.

This integrated system aids in creating a Lean Manufacturing approach for the entire production process in real time which can be accessed by all levels of the managerial hierarchy at any time. Although the system benefits from automated data collection in all levels in the assembly line, in the scope of this company where a majority of the processes are manual, data entries have to be manually recorded in the software by the department head or a subsidiary.

Over time, data collection can be automated using the following techniques:

- Using **sensors** to log unit quantities in batches. This will help in identifying any missing pieces in a batch even before it reaches the QC for approval, thereby saving a lot of time.

- Data can also be logged by the workers themselves using **electronic tablets** in the shop floor directly rather than having to log all the batches at the same time at the port of exit. This will make the data logging process more streamlined with lower risk of human error.

- A **barcode system** can be used to greatly increase product traceability which is essential during the packaging and shipping operations. This will also allow all batch information to be stored in the barcode and eliminate the need for larger batch bags.

- Added **telemetry** at the outlet of each production line will automate internalized process tracking and minimize human involvement.

- Utilizing **cloud-based task software** will allow different departments on the same shared network to locate the status of individual product batches.

Therefore, A two-layered approach has been proposed which includes an ERP top layer for orders, bills of materials, inventory control and then an interface to an MES layer which focuses on operations on the floor such as electronic batch records, scheduling, material consumption tracking and reorder procedures (ref. Fig.31).

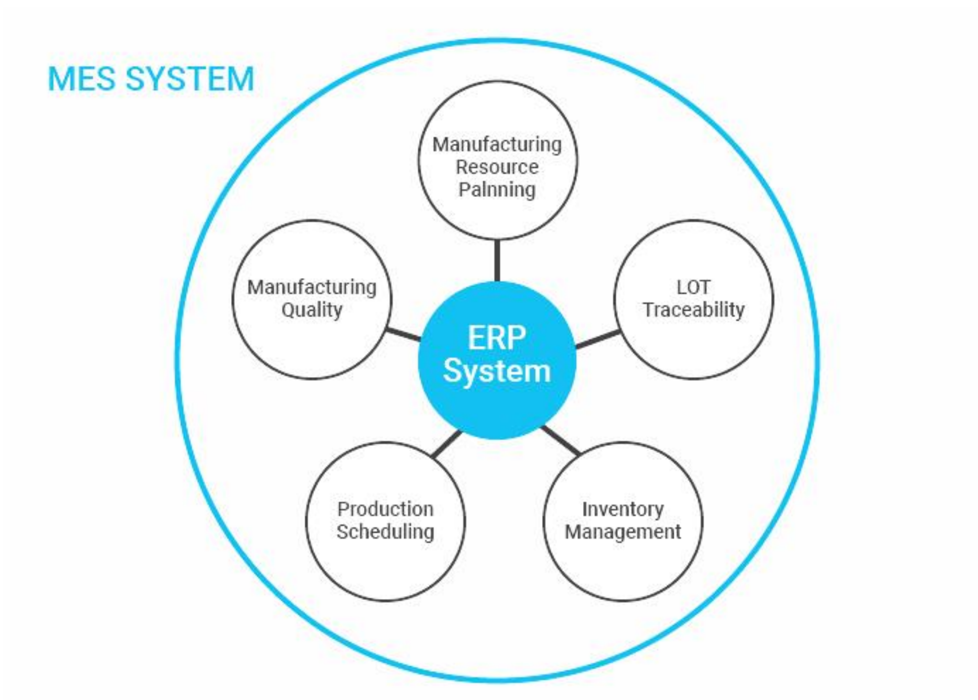


Fig. 31 MES-ERP Integration Overview

Chapter 6: DMAIC Method to Increase Productivity

6.1 DMAIC Method

The DMAIC method is one of the most widely used methodologies to achieve six-sigma. Over the past few decades, six-sigma has been adopted by many companies with a majority having yielded success after its implementation (ref. [5].

The Six-Sigma process can also be used to improve operational performance in order to increase the customer satisfaction with better products and services. Although there are many ways to achieve Six-Sigma, including Net Cost Savings, Capacity and Customer Satisfaction, Cost of Poor Quality and other methods, it has been identified that Six-Sigma works best when it is tied to a definite business priority with reasonable scope.

The DMAIC method is therefore highly beneficial because it ties the business priority to the core of the Six-Sigma technique. DMAIC stands for the following:

- **D**EFINE
- **M**EASURE
- **A**NALYSE
- **I**MPROVE
- **C**ONTROL

To identify the productivity of a company, we need to define the concept of Total Productivity. The total productivity of a company is defined as the ratio of its total output to its total input. This productivity type is the most important indicator of a company's performance because it considers the cumulative efficiency of the total inputs to the company.

Another important concept to identify within a company is the Key Performance Indicator (KPI). A company can be considered to be performing well in case of the following:

- High quality operations do not require any excess time or waste additional resources.
- Rapid operations reduce the level of inventory Work-In-Progress (WIP).
- Reliable operations can be expected within the company.
- Flexible operations which are compatible and can adapt to changing scenarios.

An example of a commonly used measurement of productivity in the manufacturing industry is OEE. The original definition of OEE developed by Nakajima, consists of six large losses which are divided into three categories such as inventory, performance and quality. **OEE** is the abbreviation for **Overall Equipment Effectiveness**, instead of Overall Equipment Efficiency. However, the real purpose of OEE measurement is to measure the efficiency of internal rather than external effectiveness, therefore, a more precise definition is Overall Equipment Efficiency.

6.2 Problem Statement

This project aims to increase the overall productivity focusing on the polishing process, by identifying key performance indicators and key contributors to machine idle time using the six sigma DMAIC methodology.

6.3 Methodology

The methodology followed (ref. Table 7) for this technique was collecting the primary and secondary data to be processed on the DMAIC method as discussed in the table below –

Table 7: DMAIC Methodology

DMAIC	Method Used	Explanation
Define	- SIPOC Diagram	Using the SIPOC Diagram, the initial problem can be identified.
Measure	- Histogram	Using the histogram allows us to find the trends or source of the problems based on quantitative data.
Analyse	- TOPSIS-AHP - Decision Tree	TOPSIS-AHP is used to analyse the level of importance of existing alternatives. Decision tree method is used to select the best alternative.
Improve	- Based on the Analyse method	Analyse the data and identify improvements which are practical and can be implemented easily.
Control	- Performance Measure (KPI)	The selection of KPIs will be adapted acc. to alternative chosen.

6.4 Steps in DMAIC Method

STEP 1: DEFINE

The first step of defining the business problem, goal, potential resources, project scope and high-level project timeline (ref. Fig.32). This information is critical for the set-up of the DMAIC procedure. In this stage, it is important to define the business problem, the SIPOC (Supplies, Inputs, Process, Outputs and Customers) and the critical process outputs (ref. [3]).

An efficient method to identify critical process outputs is to generate a value stream map (VSM) of a complete process.

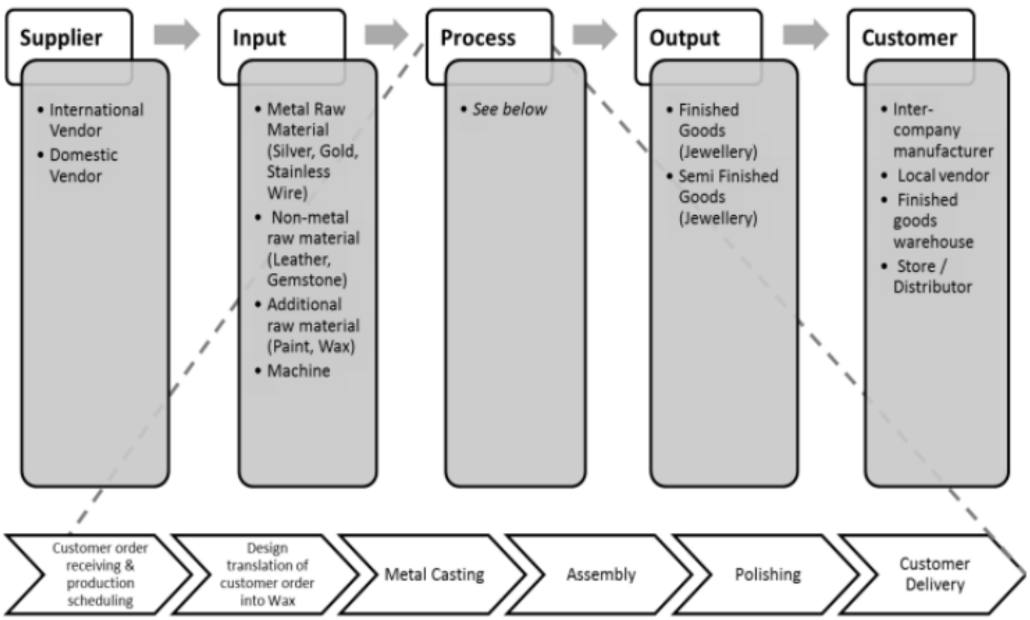


Fig. 32 SIPOC Diagram of Business Process Flow

STEP 2: MEASURE

The purpose of this step is to measure the specification of problem/goal. This is a data collection step, the purpose of which is to establish process performance baselines. The performance metric baseline(s) from the Measure phase will be compared to the performance metric at the conclusion of the project to determine objectively whether significant improvement has been made. The team decides on what should be measured and how to measure it. It is usual for teams to invest a lot of effort into assessing the suitability of the proposed measurement systems. At this stage, we develop the data collection methods, recognize input and output indicators and outline the failure modes (ref. Fig.33).

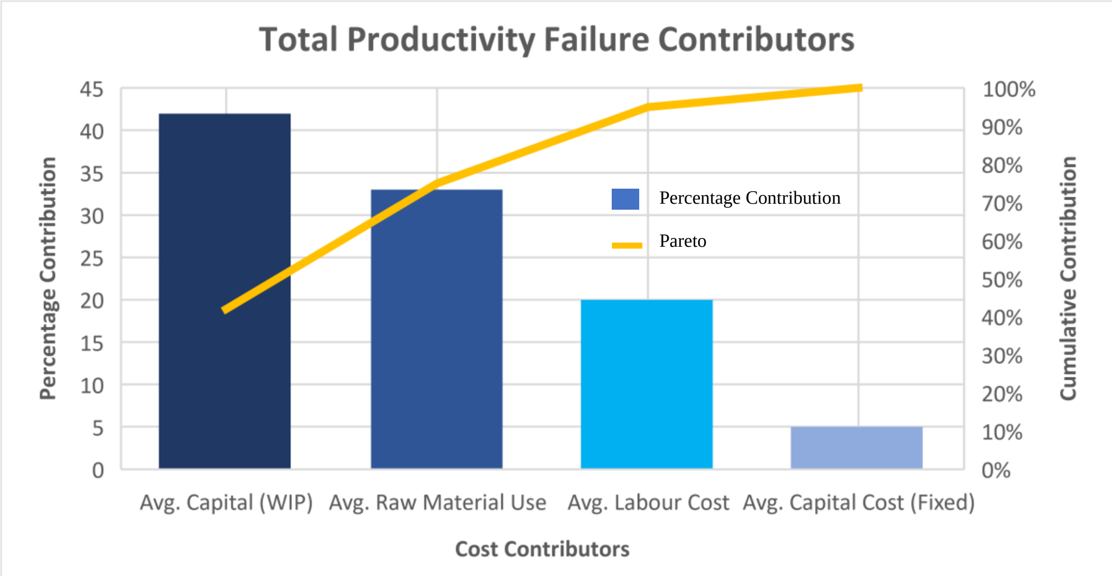


Fig. 33 Total Productivity Failure Contribution

Through the following Pareto Chart, we can see that the largest contributors in terms of value is the Cost of Work-In-Progress (inventory) and followed by Raw Material Cost, Employee Costs (labor) and Fixed Capital Costs. Here, we can identify that Labour Cost is a major contributor which can be optimized using DMAIC principles.

STEP 3: ANALYSE

The purpose of this step is to identify, validate and select root cause for elimination. A large number of potential root causes (process inputs, X) of the project problem are identified via **Root Cause Analysis** (for example a fishbone diagram). The top 3-4 potential root causes are selected using multi-voting or other consensus tool for further validation. A data collection plan is created and data are collected to establish the relative contribution of each root causes to the project metric, Y. This process is repeated until "valid" root causes can be identified. Within Six Sigma, often complex analysis tools are used. However, it is acceptable to use basic tools if these are appropriate. Of the "validated" root causes, all or some can be.

- List and prioritize potential causes of the problem.
- Prioritize the root causes (key process inputs) to pursue in the Improve step.
- Identify how the process inputs (Xs) affect the process outputs (Ys). Data are analyzed to understand the magnitude of contribution of root cause, X, to the project metric, Y.

- Statistical tests using p-values accompanied by Histograms, Pareto charts, and line plots are often used to do this.
- Detailed process maps can be created to help pin-point where in the process the root causes reside, and what might be contributing to the occurrence.
- Performing Failure Mode and Effect Analysis (FMEA) to identify problem points.

STEP 4: IMPROVE

The purpose of this step is to identify, test and implement a solution to the problem; in part or in free of all whole. This depends on the situation. Identify creative solutions to eliminate the key root causes in order to fix and prevent process problems. Use brainstorming or techniques like Six Thinking Hats and Random Word. Some projects can utilize complex analysis tools like DOE (Design of Experiments), but try to focus on obvious solutions if these are apparent. However, the purpose of this step can also be to find solutions without implementing them.

- Create
- Focus on the simplest and easiest solutions
- Test solutions using Plan-Do-Check-Act (PDCA) cycle
- Based on PDCA results, attempt to anticipate any avoidable risks associated with the "improvement" using the Failure mode and effects analysis (FMEA)
- Create a detailed implementation plan
- Deploy improvements

Discussions were conducted with the PM regarding the factors affecting productivity in the company. As a result of these discussions, it was established that the major contributors to productivity in this company are – Labour Productivity, Material Productivity and Capital Productivity. The following points were discussed with the PM as possible solutions:

1. Creation of a high-level vision for the company, based on customer value at the forefront.
2. Design a Productivity Improvement framework.
3. Implementation of Priority Management System.
4. Implementation of Daily Planning System for all employees.
5. Implementation of Integrated Operational Planning Information System (ERP/MES).

6.4.1 AHP Method

The **AHP** (Analytical Hierarchy Process) method is used to assign weighted priorities to different productivity improvements. It is performed on specialised software (XLSTAT-Excel, etc.) to assign weights ranging from 0->1 which provides clarity on which factors have the highest priority based on the assigned weight. For example, the weights were calculated as following - Labour Productivity: 0.449, Material Productivity: 0.294 and Capital Productivity: 0.257, we can see that the order of preference is labour-material-capital. Now, improvements can be made according to the priority hierarchy to emphasise maximum effect on the bottom line (ref. [11]).

In summary, The AHP method looks at the problem in three parts. The first part is the issue that needs to be resolved, the second part are the alternate solutions that are available to solve the problem. The third and the most important part as far as the AHP method is concerned is the criteria used to evaluate the alternative solutions.

6.4.2 Steps in the AHP Method

Step 1: Define Alternatives

The AHP process begins by defining the alternatives that need to be evaluated. These alternatives could be the different criteria that solutions must be evaluated against. They could also be the different features of a product that need to be weighted to better understand the customers perception. At the end of step 1, a comprehensive list of all the available alternatives must be ready.

Step 2: Define the Problem and Criteria

The next step is to model the problem. According to AHP methodology, a problem is a related set of sub problems. The AHP method therefore relies on breaking the problem into a hierarchy of smaller problems. In the process of breaking down the sub-problem, criteria to evaluate the solutions emerge. However, like root cause analysis, a person can go on and on to deeper levels within the problem. When to stop breaking the problem into smaller sub problems is a subjective judgement.

Example: A firm needs to decide on the best investment option amongst stocks, bonds, real estate and gold. If the AHP method is used, the problem of best investment will be broken down into smaller problems like protection from downfall, maximum chance of appreciation, liquidity in the market and so on. Each of these sub problems can then be broken into smaller problems till the management feels that the appropriate criteria have been reached.

Step 3: Establish Priority amongst Criteria Using Pairwise Comparison

The AHP method uses pairwise comparison to create a matrix. For example, the firm will be asked to weigh the relative importance of protection from downfall vs. liquidity. Then in the next matrix, there will be a pairwise comparison between liquidity and chance of appreciation and so on. The managers will be expected to fill this data as per the expectations of the end consumer or the people who are going to use the process.

Step 4: Check Consistency

This step is inbuilt in most software tools that help solve AHP problems. For instance, if the liquidity is twice as important as protection from downfall and in the next matrix, it can be said that protection from downfall is half as important as chance of appreciation, then the following situation emerges:

Liquidity = 2 (Protection from downfall)

Protection from downfall = ½ (Chance of appreciation)

Therefore, Liquidity must equal chance of appreciation.

However, if in the pairwise comparison of liquidity and chance of appreciation, if I have given a weight of more or less than 1, then my data is inconsistent.

Step 5: Get the Relative Weights

The software tool will run the mathematical calculation based on the data and assign relative weights to the criteria. Once the equation is ready with weighted criteria, one can evaluate the alternatives to get the best solution that matches their needs.

6.4.3 TOPSIS Method:

The **TOPSIS** (Technique for Order of Preference by Similarity to Ideal Solution) method can be used to achieve maximum productivity for future analyses (ref. [10]). It calculates the farthest distance from the ideal negative solution in the productivity graph (ref. Fig. 35) to point to the regions of maximum productivity. The TOPSIS algorithm is as follows (ref. Fig. 34):

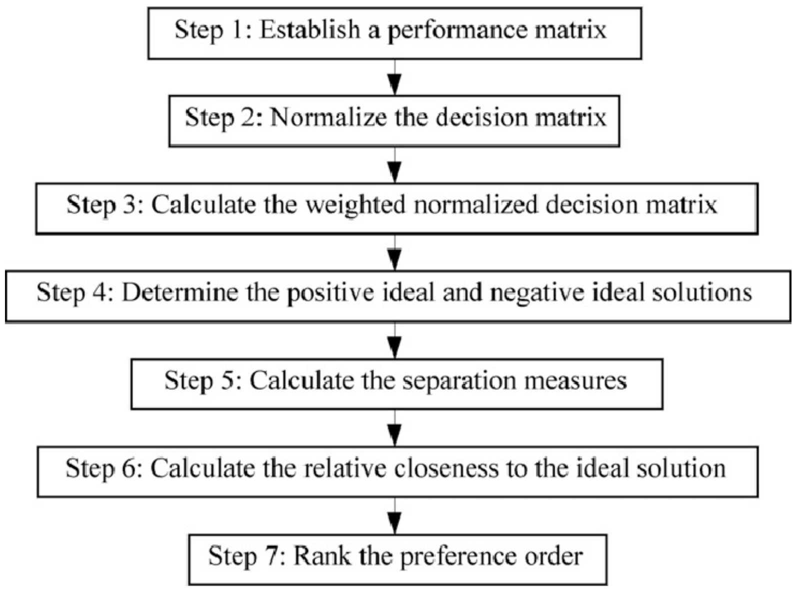


Fig. 34 TOPSIS Algorithm

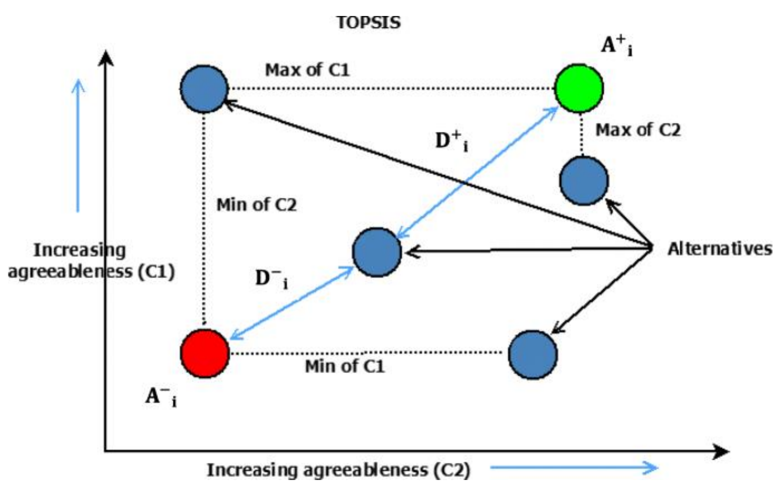


Fig. 35 TOPSIS Graph

STEP 5: CONTROL

The purpose of this step is to embed the changes and ensure sustainability, this is sometimes referred to as making the change 'stick'. Control is the final stage within the DMAIC improvement method. In this step; Amend ways of working; Quantify and sign-off benefits; Track improvement; Officially close the project; Gain approval to release resources.

- A **Control chart** can be useful during the Control stage to assess the stability of the improvements over time by serving as a guide to continue monitoring the process and provide a response plan for each of the measures being monitored in case the process becomes unstable.
- **Standard operating procedures** (SOP's) and Standard work
- **Process confirmation**
- **Development plans**
- **Transition plans**
- **Control plan**
- **Benefit delivery**

To monitor the overall performance of the company, the characteristics of an enterprise performance management system should be established based on the company's strategy related to the business target and financial condition of the company. By doing a benchmark with the similar character of labor-intensive industry, such as the Construction Industry or Small and Medium Enterprises Industry, the main focus of human productivity needs to be improved.

6.5 Future Scope

Key improvements to be made in the company based on the above discussed performance indicators are as follows:

- Designing an appropriate flow of business processes, which also pay attention to mapping the skills and abilities of each worker.
- Improve and develop the existing ERP system which should be adapted to business processes and other supporting data, such as the mapping of the skills and abilities of each worker.

- Creating a notification system, in the form Health check Notification system, due to lack minimum automation within the production process.
- Designing a new tool of performance indicators, such as supporting tools to process data that can be created using Excel, to then be designed to be made automation integrated in the ERP system.

6.6 Conclusion

The result of this research is the design of company productivity improvement for Jewellery Manufacturing Industry, using DMAIC method. The design of productivity improvement is based on the selected alternative which has been chosen out of the 3 criteria and 9 alternatives to increase productivity. The weighted priorities (reference [9], Annexure-1) of Labour Productivity is 44.9%, Capital Productivity is 25.7% and Material Productivity is 29.4%. **Therefore, the most important criteria to increase productivity is Labour Productivity**. Thus, it becomes imperative for a company in Jewellery Manufacturing to focus on the area of Labour Productivity Improvement.

6.7 Implementation of DMAIC in Polishing Process

As we see above, DMAIC is beneficial to make more systemic changes in the company. Additionally, DMAIC can be appropriated to improve individual production processes along with larger, systemic changes.

The polishing process comprises of many sub-processes which can be improved to cumulatively save time on the bottom line. We will follow the same procedure for DMAIC using its Define, Measure, Analyse, Improve and Control phases.

Phase 1: Define

On inspection of the entire polishing process, I narrowed down the primary criteria for improvement as the reduction of elemental processing times and thereby increasing the time efficiency of the overall process.

The polishing process involves the use of various tools to soften the metal surface and impart a desirable lustre to the jewellery pieces. These tools are used in sequential phases as the metal surface softens further and further, such that the heavy-duty polishing equipment like hard buffs are used first followed by finer grade polishing equipment like soft buffs.

The various tools used in the polishing process are as follows:

- Cotton String
- 3-Row Bristle Brush
- Stiff Bristle Micro Brush
- Hard Buff
- Soft Buff
- Tapered Felt Inside Ring Buff

A Value Stream Map (VSM) mapped for the entire process (ref. Fig.36) shows that in addition to useful time utilization (time spent to actually operate on the workpiece), there is a significant wastage of time whenever the worker has to find and change the tool-bits.

Improving this idle time using the DMAIC methodology is the scope of this activity.

Phase 2: Measure

Time-study was conducted (ref. Table 8) in the polishing department to find the individual process completion times. A stopwatch was used to measure the processing times of 10 workpieces over 5 days selected such that the workers were operating on similar kind of rings. The data presented below is the average value of 5 days of recordings (ref. Annexure-2), erratic data has been removed to more closely resemble the general trends in the company.

<u>Table 8: Time-Study Data for Polishing Process</u>

	SUBPROCESSES **(Time in seconds)**								
Sr. No.	Cotton String	3-Row Bristle Brush	Micro Bristle Brush	Hard Buff	Felt-Inside Buff	Soft Buff	Total Idle Time	Total Completion Time	
1	28	35	42	27	32	52	63	280	
2	35	40	49	27	33	55	60	301	**Above Average**
3	32	39	43	30	30	50	62	289	
4	30	41	49	28	35	48	64	299	
5	29	36	42	29	33	49	60	283	
6	30	35	43	33	30	47	59	283	
7	35	40	50	32	29	52	62	307	
8	33	39	44	28	29	50	58	289	
9	35	38	44	27	33	51	60	297	
10	29	35	45	27	35	46	60	287	
AVG	31.6	37.8	45.1	28.8	31.9	50	60.8	291.5	

We can see that the total time taken to polish every ring is approximately 292 seconds, or close to **5 minutes**. Additionally, we recorded a total idle time (time for tool change, etc.) as 61 seconds on average.

Therefore, the idle time per process is 61 seconds / (No. of tool change intervals) = **12 seconds**

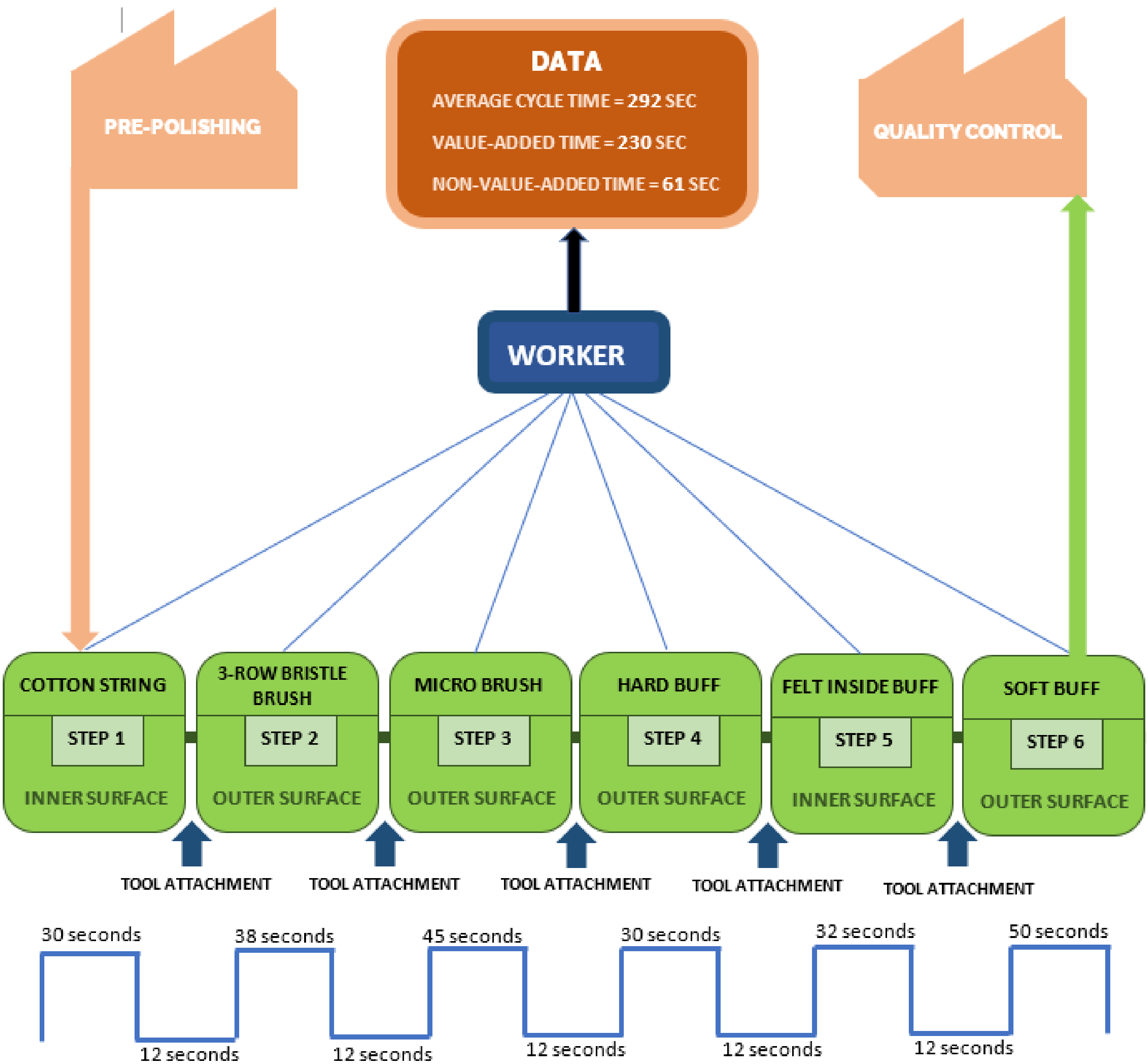


Fig. 36 Value Stream Map of Polishing Process

Phase 3: Analyse

The Value Stream Map is created and analysed for possible bottlenecks. By inspection of the above diagram, we can see that the overall idle time is around **20.8%** of the total processing time.

6.7.1 Root Cause Analysis

Root cause analysis (RCA) is the process of discovering the **root causes** of problems in order to identify appropriate solutions (ref. Fig.37).

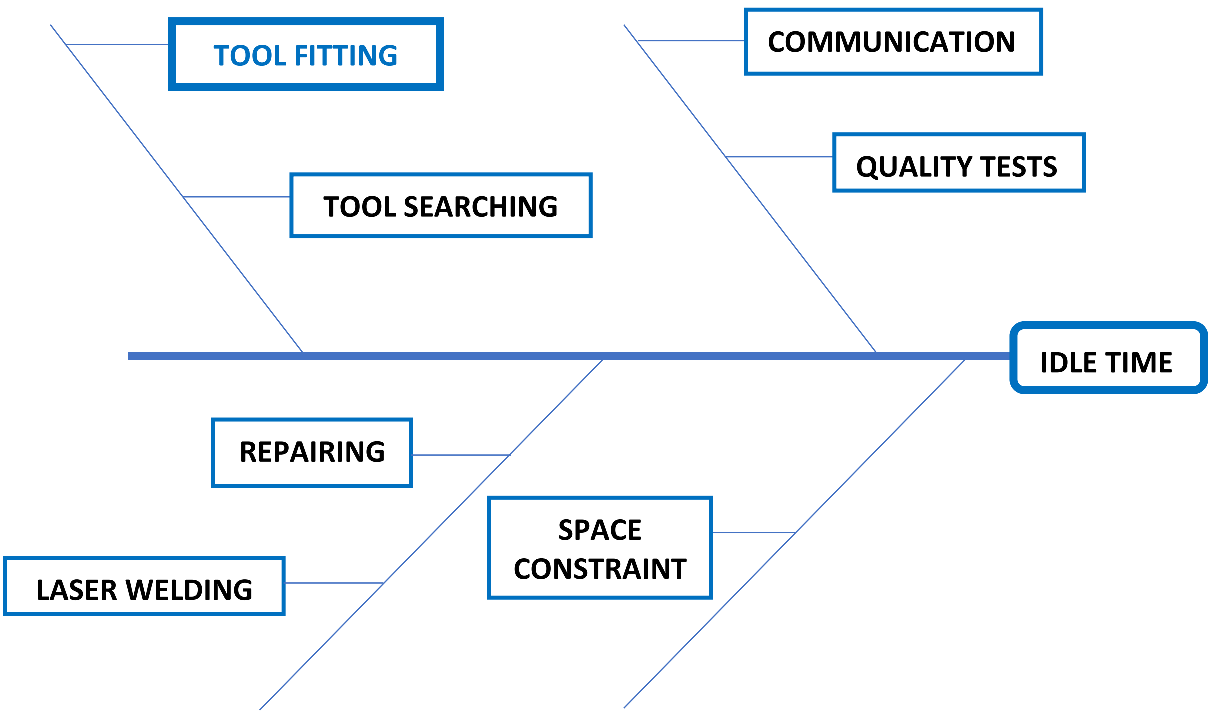


Fig. 37 Ishikawa Diagram of Idle Time Contribution

The major contributor to the idle time is the action of having to change the tool-bits after every sub-process. This is unavoidable under the current hardware because of the availability of only a single tool port, besides the lathe needs to completely slow down before they can remove the tool-bit.

The other reason why the tool change process takes so long is the fact that a significant amount of time is used to find the tool-bits themselves since they are usually kept scattered on the workstation base, near the outlet vent.

Phase 4: Improve

Keeping in mind the analysis above, the next step is to suggest improvements to reduce the overall idle time.

The following solutions were suggested to improve the idle time:

- The implementation of a 5S style **tool storage system** (ref. toolbox for repairing station, Fig. 21) mounted on the side walls of the workstation cubicle. This may contain sorted compartments of tools and other auxiliary parts.

- Utilisation of a **pneumatic brake system** in the lathe spool, which may be pneumatically triggered by a foot pedal. This can be made using rubber gaskets, similar to car wheel brakes. A brake like this will allow the lathe to slow down faster.

- A **manual braking system** may comprise of a lever with hard rubber stopper on one side and the other an arm pedal (similar to manual brakes on a fitness cycling machine). This may be anchored to the table and press against the lathe shaft on activating the pedal. This is a simpler and cheaper method but may require additional force by the worker due to the absence of force multipliers as could be provided with the above pneumatic brake.

- Another possible solution for storage is to design **diagonally aligned tool-boxes** like knife holders. This creates a suitable angle for the worker to simply detach the tool-bit from its holder as they are operating on the workpiece. The toolbox may be hinged against the lower wall, near the worker's knee length. The hinge will allow it to securely retract out and lock in place when in use and back in after work is done to save space.

- Creating specialised **process blocks** within the polishing department will help reducing the total number of tool changes required per workstation. This is similar to an assembly line where each worker has their own specialised task.

Among the solutions suggested above, we can test how much idle time is saved hypothetically after using the 5S toolbox system and the process block system. It is important to note that all the processes need to be performed on the workpiece in that specific sequence so it might not be possible to arrive at the highest efficiency since each process takes different processing times. A staggered approach may compensate for the time differences in completing various subprocesses.

Considering the toolbox improvements in the repair department, we could see a clear trend that for *every 100 minutes of work, at least 5-10 minutes were saved* due to 5S improvements. In extreme cases, the runner system also saved upwards of 30 minutes.

Assuming the same trend for the polishing department, we can assume a median improvement of a base value of **9%***, bringing the overall idle time down to 0.91*61 = **55.5 seconds**

So, the total time saved would be at least 5.5 seconds per piece.

Now, 1 piece takes 230 value added seconds + 55.5 idle time seconds = **285.5 seconds**

Now, by proportionality, 285.5 (time for one piece) /5.5 (time saved per piece) = 51.81 = 52 pieces

So, for **every 52 pieces**, after 5S improvements, **at least 1 extra piece** can be polished per worker.

Or, another way to look at it is considering a 7hr workday, earlier with 292 seconds (4.87 minutes) per piece, every worker would generate a total of *86 polished pieces* by the end of the day, whereas with 5S improvements and reduction in idle time to 55.5 seconds, it is expected to reduce the total polishing time to 285.5 seconds (4.76 minutes) which allows the worker to make *88 polished pieces* at the end of the day.

So, just the 5S improvements alone *will increase productivity by at least 3%* per worker.

*(A base value of 9% was taken from the results of the time study for idle time reduction made in the repair department to analyze the efficacy of the 5S and other LM improvements which was collected on-site, pre-COVID lockdown in the repair and setting departments. Although, in reality this value ranges from 7.5-9% in the repair department, the higher value was considered because in case of the polishing department, the tool change operation is longer and the improvements suggested for improving the same should significantly reduce the major contributor – waiting for axle to stop rotating using braking systems.

It must be considered that due to COVID lockdown imposed from 2nd April, 2021 the team was unable to implement and perform the necessary time-studies to practically analyze the improvements and corroborate these assumptions.)

The new Value Stream Map will look like this (ref. Fig.38):

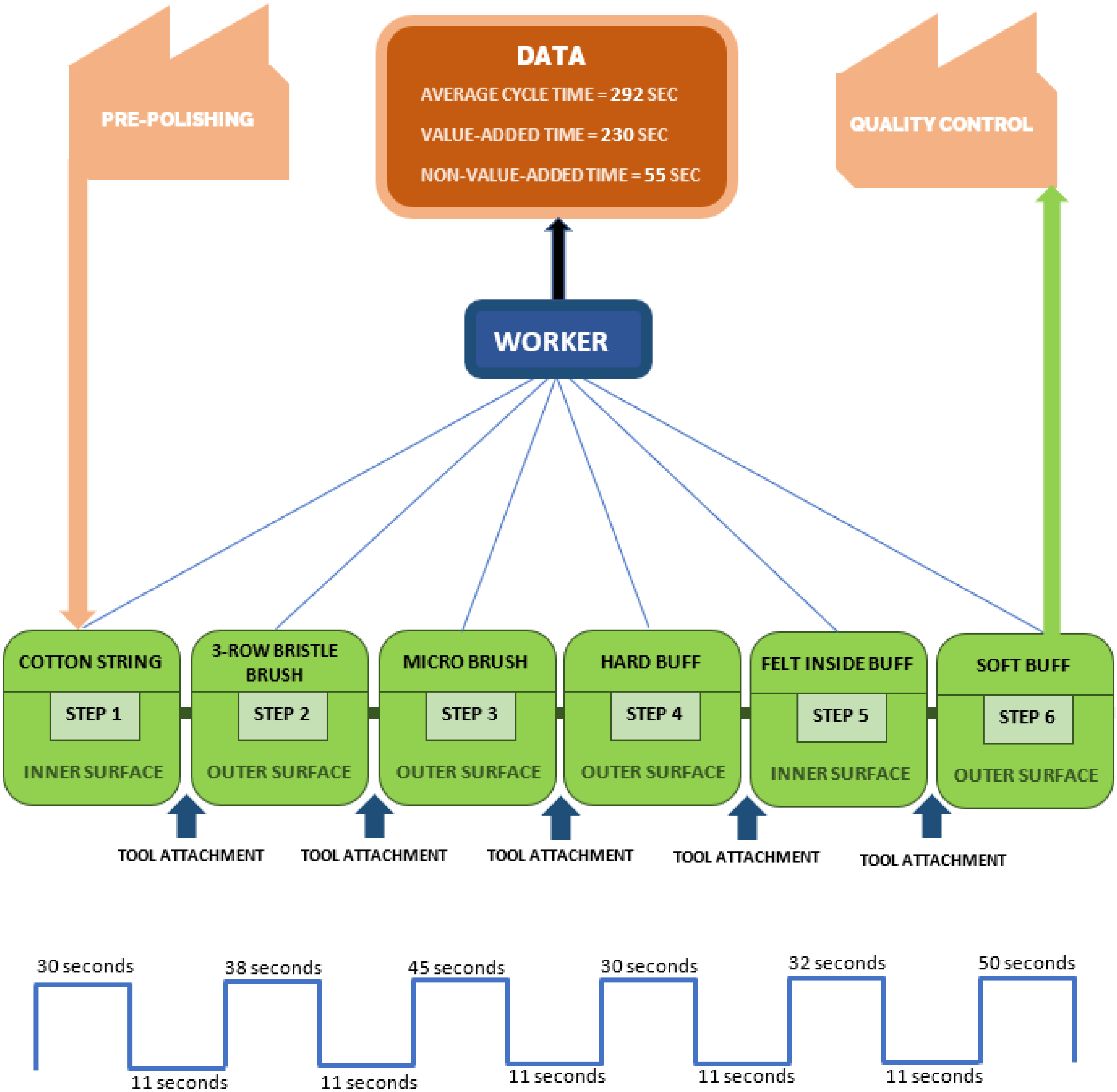


Fig. 38 Value Stream Map of Polishing Process w/5S Improvements

Phase 5: Control

The final phase for the DMAIC Process is to establish ownership and accountability of the tasks to the employees themselves and provide them with tools to communicate, keep track of and solve problems at the microscopic level without having to involve higher level managers. In the jewellery industry, there should be a philosophy of continuous improvement followed by everyone working in the company. Constantly updating methodologies, production processes and maintaining the existing improvements and established systems is indispensable for the company as a whole.

6.8 Results

The following results were obtained as a result of the changes made above:

- DMAIC Methodology was used to address systemic drawbacks and suggest changes
- Weighted priorities were identified and improvements were suggested for the same
- DMAIC methodology was used to identify improvements in polishing process
- Tool Storage system and 5S principles utilised in repair department were suggested
- Idle time reduction by **7.5-9%** is expected to be achieved
- Increased expected manufacturing productivity by **3%**

Chapter 7: Results and Conclusion

As discussed in previous chapters, over the course of the last six months, a significant number of ideas have been implemented and some ideas have been proposed to the upper management for possible future implementations. The following is a summary of the various ideas implemented, the methodology followed and inferences obtained throughout the course of the entire project "Increasing Productivity and Time-Efficiency using Lean Manufacturing Principles" (ref. table 9).

Table 9: Overall Results

SR. NO.	IMPLEMENTATION	METHODOLOGY	INFERENCE
1.	Improvement in Service Order (SO) generation System	SO-integration b/w sales department and PM	Less confusion at the shop floor
2.	KANBAN Boards	KANBAN	Easier order tracking
3.	KANBAN Software Integration	KANBAN	Open-Source JIRA software being used by company, greater shop-floor tracing
4.	Tool-Box	5S	Tool-box constructed made tool sorting more efficient.
5.	Bag-Sorting System	5S/KANBAN	Better tracking of batch bags, lesser chance of misplacing
6.	Runner System	5S	Improved time-efficiency, saves time between 2-4 minutes per batch, weekly savings of 7-8 hrs.
7.	Pull System	JIT	Pull system suggested with EOQ calculations based on demand
8.	Standardization	5S	Established proper worker practices, scheduling and maintenance
	Overall (1-8)	Lean Manufacturing Principles	As per detailed time-study conducted on site, the repair department recorded an

			average of **50 minutes saved/worker daily** after the implementation of ideas 1-8
9.	Tiered MES-ERP System	Enterprise Control	A two-layered approach proposed for ERP-MES software integration with ERP top layer for orders, bills of material, inventory control with interface to MES layer for batch records, scheduling, material consumption tracking and reorder procedures.
10.	Six-Sigma for process improvement	DMAIC Method with Value Stream Mapping (VSM)	Located primary productivity contributors and Key Performance Indices (KPI) for increasing overall profitability.
11.	Weighted productivity priorities	AHP Method	Identified highest priority productivity to allow for targeted improvements
12.	Root cause Analysis	Ishikawa Method	Identified root causes for understanding contributions to idle time
13.	Polishing Process Optimization	DMAIC Method and 5S	Reduced tool-change idle time, devised tool storage mechanisms for polishing process.
	Overall (10-13)	Six-Sigma/DMAIC Methodology	Overall idle time reduction by **7.5-9%** and increased manufacturing productivity by **3%**

As we can see, the implementations made during the 6-month internship period have had significantly positive results which has brought the company closer to its “lean” goal. Some ideas were suggested but could not be implemented because of COVID-19 restrictions within the state, however, it is expected that these ideas will be tried as and when it shall be possible to do so. Therefore, as shown in the table, we can see that the goal of this project – **“Increasing Productivity and Time-Efficiency using Lean Manufacturing Principles”** has been satisfied.

Conclusion

At VD Jewels and Artisons Pvt. Ltd., I have received first-hand knowledge of how a shop floor operates in the industry. The knowledge gained here shall benefit me for all my future endeavours.

A significant amount of work experience has developed over the past six months, where I was exposed to a real-life factory setting for the first time. Researching and implementing ideas during my project "Increasing Productivity and Time-Efficiency using Lean Manufacturing Principles", I understood the importance of having a "Lean" philosophy of manufacturing and the various intricacies of achieving the same.

Owing to the implementations made during the first phase of my project - "Increasing Time Efficiency using Lean Manufacturing Principles", I have been able to save on average 50 minutes daily and 7-8 hours weekly due to the various 5S improvements made in the workbench, namely the 5S toolbox apparatus and runner system which have demonstrated proven benefits to the company.

The ideas presented during the second phase of my project – "Increasing Productivity using Six Sigma DMAIC Principles", I have been able to isolate the highest priority criteria for improvement as Labour Productivity using the AHP method and suggest improvements on the same using the DMAIC technique with various 5S improvements on the polishing assembly line. The various improvements suggested are expected to reduce the overall idle time by 7.5-9% and increase productivity by around 3%.

The ideas implemented in the company have conclusively proved the benefit of Lean Manufacturing and has impacted both at the micro-level as well as on the systemic level of the organization. Many ideas still remain to be tested in the near future which will surely improve the organization's overall work ethic and profitability.

Overall, the purpose of my projects "Increasing Time Efficiency Using Lean Manufacturing Principles" and "Productivity Optimization using Six Sigma – DMAIC Principles" was successful in improving the efficiency and increasing the overall productivity of the company.

Chapter 8: Future Scope

VD Jewels and Artisons Pvt. Ltd. is a relatively new company with tremendous scope for improvement. Along the course of my internship, I have observed various areas in which the company can improve on both on the systemic level and on the micro-level inside the departments themselves. Additionally, there is scope for further streamlining the manufacturing pipeline by trimming off non-value-added times and reduce/recycle the various wastes and by-products resulting from the manufacturing processes. Some suggestions for the company to implement in the future are as follows:

- Designing an appropriate flow of business processes, which also pay attention to mapping the skills and abilities of each worker.
- Improve and develop the existing ERP system which should be adapted to business processes and other supporting data, such as the mapping of the skills and abilities of each worker.
- Creating a notification system, in the form of Health Check Notification system (COVID specific), due to lack of automation within the production processes.
- Designing a new tool for identifying performance indicators, such as supporting tools to process data that can be created using Excel, which can be integrated in the ERP system.
- Reuse the wax utilized during the casting process to make candles and other wax products as a high turnover side business.
- Resell the gold and silver dust by-product directly to the paint industry where gold dust is used as a primary material in high-end edible paints.
- Gold dust is also used in the hospitality industry, namely high-end bakers and chocolatiers who use the dust directly over the edible items for decorations since gold is an inert material which is edible.
- Utilizing a barcode system on product batches to ensure traceability from producer to end customer.
- Experimenting with electroplating using thiourea in the polishing department.
- Increasing machine redundancy, especially the laser welding machine to control product flow traffic on the shop floor.
- Performing TOPSIS analysis of all departments to find ideal solution with given alternatives.

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Annexure – I

AHP Calculations:

After discussions with PM, the following criteria were identified for productivity:

K1: Labour Productivity

K2: Material Productivity

K3: Capital Productivity

And the alternatives considered from research were as follows:

A1: Create a compelling high-level vision and strategic theme for the Company (based on Customer Value)

A2: Develop strong strategies and cultures in each Division/Team based on the respective requirement

A3: Develop the strong Strategic and Continuous Improvement Thinking for Division/Team Leaders, through Training

A4: Design a Productivity Improvement Framework through third party Expert Judgement/External Consultant. (Best practice approach)

A5: Design a Productivity Improvement Framework through Internal Expert Judgement or Division/Team Leaders. (Internal requirement approach)

A6: Design a Productivity Improvement Framework through employee character/divisional or team culture adjustments

A7: Implementation of Priority Management System

A8: Implementation of Daily Planning System (Daily Activity Planning) for all Employee

A9: Implementation of Integrated Operational Planning Information System (e.g., ERP)

After considering 3 criteria and 9 alternatives, an online AHP calculator (ref. [9]) was used as follows:

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	◉ L	○ M	○ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ◉ 8 ○ 9
2	○ L	◉ C	○ 1	○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
3	◉ M	○ C	○ 1	○ 2 ○ 3 ○ 4 ○ 5 ◉ 6 ○ 7 ○ 8 ○ 9

CR = 358.2% Adjust highlighted judgments to improve consistency

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AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Results:

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	L	44.9%	1	56.8%	56.8%
2	M	29.4%	2	37.2%	37.2%
3	C	25.7%	3	32.5%	32.5%

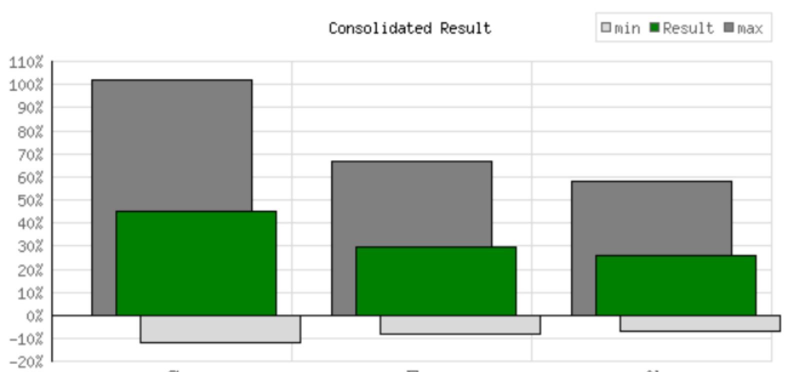
Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3
1	1	8.00	0.33
2	0.12	1	6.00
3	3.00	0.17	1

Number of comparisons = 3
Consistency Ratio CR = 358.2%

Principal eigen value = 6.433
Eigenvector solution: 20 iterations, delta = 7.4E-7



Annexure-II

Time Study data for Polishing process:

Table i: Time study - 1

Sr. No.	Cotton String	3-Row Bristle Brush	Micro Bristle Brush	Hard Buff	Felt-Inside Buff	Soft Buff	Total Idle Time	Total Completion Time
1	30	35	42	27	32	52	63	281
2	37	40	49	27	33	55	60	301
3	34	39	43	30	30	50	62	288
4	32	41	49	28	35	48	64	297
5	31	36	42	29	33	49	60	280
6	32	35	43	33	30	47	59	279
7	37	40	50	32	29	52	63	303
8	35	39	44	28	29	50	59	284
9	37	38	44	27	33	51	61	291
10	31	35	45	27	35	46	61	280
AVG	33.6	37.8	45.1	28.8	31.9	50	61.2	292

Table ii: Time study - 2

Sr. No.	Cotton String	3-Row Bristle Brush	Micro Bristle Brush	Hard Buff	Felt-Inside Buff	Soft Buff	Total Idle Time	Total Completion Time
1	25	31	41	26	29	54	66	272
2	32	36	48	26	30	57	63	292
3	29	35	42	29	27	52	65	279
4	27	37	48	27	32	50	67	288
5	26	32	41	28	30	51	63	271
6	27	31	42	32	27	49	62	270
7	32	36	49	31	26	54	66	294
8	30	35	43	27	26	52	62	275
9	32	34	43	26	30	53	64	282
10	26	31	44	26	32	48	64	271
AVG	28.6	33.8	44.1	27.8	28.9	52	64.2	283

Table iii: Time study - 3

Sr. No.	Cotton String	3-Row Bristle Brush	Micro Bristle Brush	Hard Buff	Felt-Inside Buff	Soft Buff	Total Idle Time	Total Completion Time
1	26	38	44	28	35	49	64	284
2	33	43	51	28	36	52	61	304
3	29	42	45	31	33	47	63	290
4	28	44	51	29	38	45	65	300
5	27	39	44	30	36	46	61	283
6	28	38	45	34	33	44	60	282
7	33	43	52	33	32	49	64	306
8	31	42	46	29	32	47	60	287
9	33	41	46	28	36	48	62	294
10	27	38	47	28	38	43	62	283
AVG	29.5	40.8	47.1	29.8	34.9	47	62.2	290.9

Table iv: Time study – 4

Sr. No.	Cotton String	3-Row Bristle Brush	Micro Bristle Brush	Hard Buff	Felt-Inside Buff	Soft Buff	Total Idle Time	Total Completion Time
1	26	39	43	29	30	50	62	279
2	33	44	50	29	31	53	59	299
3	30	43	44	32	28	48	61	286
4	28	45	50	30	33	46	63	295
5	27	40	43	31	31	47	59	278
6	28	39	44	35	28	45	58	277
7	33	44	51	34	27	50	62	301
8	31	43	45	30	27	48	58	282
9	33	42	45	29	31	49	60	289
10	27	39	46	29	33	44	60	278
AVG	29.6	41.8	46.1	30.8	29.9	48	60.2	290

Table v: Time study – 5

Sr. No.	Cotton String	3-Row Bristle Brush	Micro Bristle Brush	Hard Buff	Felt-Inside Buff	Soft Buff	Total Idle Time	Total Completion Time
1	33	32	44	25	34	55	62	285
2	40	38	51	25	35	58	59	306
3	37	37	45	28	32	53	61	293
4	35	39	51	26	37	51	63	302
5	34	34	44	27	35	52	59	285
6	35	33	45	31	32	50	58	284
7	40	38	52	30	31	55	62	308
8	38	37	46	26	31	53	58	289
9	40	36	46	25	35	54	60	296
10	34	33	47	25	37	49	60	285
AVG	36.6	35.7	47.1	26.8	33.9	53	60.2	296.9