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Improving efficiency and productivity of a production line using lean manufacturing and DMAIC

Mateen Omar Carrim[1], Kapil Gupta[2]
[1,2]*Department of Mechanical and Industrial Engineering Technology, University of Johannesburg, Johannesburg-2028, Republic of South Africa*
Corresponding email: kgupta@uj.ac.za

ABSTRACT

This study successfully employed lean manufacturing techniques in conjunction with the DMAIC methodology to enhance the efficiency of a sweet manufacturing production line. By using key performance indicators (KPIs) and value stream mapping, we were able to quantify the improvements achieved. A notable 36% increase in Overall Equipment Effectiveness (OEE) was realized, driven by a 19.4% improvement in performance and a 17.58% increase in quality. While availability experienced a minor decline, the overall gains in performance and quality outweighed this effect. Value stream mapping revealed a significant reduction in rework from 388 kg to 273 kg per production shift, representing a substantial 30% decrease. This reduction directly contributed to a 18.8% increase in production yield, from 612 kg to 727 kg. These improvements were facilitated by the implementation of a Poka-Yoke device and targeted bottleneck analysis. The achievement of the present work encourages to extend the implementation of lean and DMAIC combined methodology to other production lines of the company.

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INTRODUCTION

The manufacturing sector is constantly facing pressure to improve efficiency, reduce costs, and increase competitiveness in a rapidly changing global market. Lean manufacturing, one of the important and extensively used industrial technique, has emerged as a popular approach to address these challenges (Dubey & Gupta, 2023). The principle of elimination of waste, or "Muda," which refers to the nonvalue added activities for the customer, underpins the Lean manufacturing philosophy. By identifying and eliminating waste, lean manufacturing aims to optimize processes, reduce resource consumption, and ultimately create more value for customers. This approach has been widely adopted in various industries, including food production, to enhance performance (Pereira & Tortorella, 2018; Das & Das, 2023). The implementation of lean manufacturing tools can lead to significant improvements in production yield, line efficiency, and a reduction in product rework. By quantifying these improvements, businesses can make informed decisions based on economic benefits and identify areas for further optimization. DMAIC technique involves five phases i.e. *define*- defining the problem and causes, *measure*- measuring the factors responsible, *analyse*- analysing the results for problem-solving, *improve*- improving the processes using devices and implementing solutions, and *control*- controlling the deviations and procedure to obtain the desired outcomes (A-Rifai, 2024). DMAIC can easily be integrated with other tools and techniques to solve the problems in lean manufacturing and/or Six Sigma projects (Jirasukprasert et al., 2014; Adeodu et al., 2020). iLeanDMAIC, a unique technique, is a framework that has been validated by various studies (Fereira et al., 2019). iLeanDMAIC takes lean tools and implements it into the DMAIC cycle. Some of the benefits of implementing lean tools include a reduction in waste, cycle and transmission time, improvement in efficiency and quality, and cost reduction. As each phase of the DMAIC cycle has a different function, several lean tools are implemented and used to execute each function to solve the problem. There are five generic principles of lean which are essential for its implementation. These are to map value stream, to create flow, to establish pull system, and to pursue perfection (Solaimani et al., 2019; Kumar et al, 2022).

Some of the important tools inherent to these lean principles include the 5S, Poka-Yoke, OEE, Kaizen, Kanban, etc. Poka-Yoke, a quality control technique, is used to minimize human error by making alterations in the process designs (Lazarevic et al., 2019). It can pick-up the error immediately upon its occurrence and can also help to permanently remove errors. There are different types of Poka-Yoke devices, including physical, functional, and symbolic devices. Physical and functional devices are independent to the operator's interpretation. The former can block the flow of mass, energy, or information, whereas the latter can be activated or deactivated following an event. The symbolic devices, based upon the situation, may require an interpretation. The benefits of implementing Poka-Yoke devices include reduced setup time, reduced scrap, and improved quality (Kumar et al., 2021). The effectiveness and performance of manufacturing processes or systems are measured using Overall equipment effectiveness (OEE) (Jaqin et al., 2020). It is one of the leading factors for measuring performance and productivity of processes, plants, or systems.

Some of the important past attempts utilizing the tools and techniques introduced, are discussed below. This is proven through a study that implemented DMAIC in a company that manufactures furnaces, whereby the company observed a sigma level increase from 3.31 to 3.67 (Srinivasan et al., 2016). It has also been used to improve the supply chain (Dosou & Dedeban, 2017), and to analyse the root causes of circuit breaker failure in a distribution system (Popov et al., 2018). A case study on the implementation of Poka-Yoke systems in a punching machine shop of a service provider to an automobile company, found it very effective with securing no defective unit and elimination of rework time towards achieving improved productivity and profit (Tak and Wagh, 2015). A zero-defect achievement was also claimed by other researchers after implementing Poka-Yoke in an assembly line of a company manufactures starters (Rajendra et al., 2013). OEE was found effective in a variety of manufacturing industries i.e. from automotive to paper industries (Jaqin et al., 2020; Sayuti et al., 2019). In combination with other industrial engineering tools, researchers could successfully increase the effectiveness of the plant machinery using OEE. Garcia et al., (2019) achieved 9% increment in OEE after employing lean techniques in a food industry. In a casting industry, lean-DMAIC implementation with an effective use of Poka-Yoke, successfully saved cost at 24.63% and component rejection rate at 90% (Khan et al., 2022). Lean-DMAIC approach was found greatly beneficial to fabricate quality weld parts in a transport equipment manufacturing company (Awanis & Vikaliana, 2023). In a potato chips manufacturing company, DMAIC was used with six-sigma and causes of defects were successfully found for a possible eradication (Arifin et al., 2021).

The review of important past attempts on employing lean, DMIC, and other tools and techniques, summarizes that these techniques are effective indeed and their implementation to food industry, especially sweet manufacturing, requires further attempts to establish the field.

As consumer demands shift and market competition intensifies, it is crucial for the company to continually evaluate and improve its production processes. The ABC sweet manufacturing company which is in focus in the present work was facing some challenges. This report focuses on analysing the current state of the production line and identifying opportunities for improvement using lean manufacturing tools. Despite ABC Sweets' efforts to maintain a competitive edge, inefficiencies within the production line were hindering overall productivity, leading to increased costs and reduced customer satisfaction. To remain competitive, it is necessary to identify and address these inefficiencies by applying lean manufacturing principles and techniques. This study aimed to investigate the efficiency of the caramel production line at ABC Sweets and to develop a set of recommendations for improvement using lean manufacturing tools to increase the productivity and efficiency of the production line.

The main objectives of this work are as follows:

- To successfully implement the DMAIC methodology in combination with Lean manufacturing.
- To decrease rework of the production line.
- To improve key performance indicators (KPIs).
- To remove identified inefficiencies to finally improve overall equipment effectiveness of the selected production line and to improve its yield.

The important aspects i.e. lean manufacturing, DMAIC, and relevant tools and techniques have been introduced, and review of some important relevant past work has been done, followed by stating problem and laying the foundation of this case study with aim and objectives. Further, the article structure includes explaining the overall methodology for implementing lean and DMAIC, analysing the results to evaluate the implementation effectiveness, and drawing conclusions with possible future research avenues.

METHODOLOGY

Based upon the implementation effectiveness in past work, joint Lean and DMAIC approach has been adopted to carry out the present work. This case study makes use of different lean manufacturing tools at each phase of the DMAIC cycle to investigate and solve the caramel production line problem. By combining the rigor of DMAIC with the practical tools of lean manufacturing, this work attempts to achieve significant gains in efficiency and productivity in the selected caramel production line of the ABC sweet manufacturing company. Figure 1 presents the overall methodology adopted in the present work. This overall methodology stepwise is discussed here as under.

Study Setting

The study setting was in a manufacturing plant that is interested in improving its efficiency and productivity. The research was undertaken in the plant's production area, where we observed the production process and collected data on the flow of materials and information. A detailed discussion with the plant employees was also done to get their insights on the current state of the production process and how it could be improved. The status quo of the case study is that the plant is currently operating inefficiently and is not producing at its full potential. It was expected that by implementing lean manufacturing principles, the plant can improve its efficiency and productivity, which will lead to the increased profits.

Sampling Methods and Data Collection

Systematic sampling was used to collect data as it is the most appropriate way to collect data from a production line that produces high volumes. The units were selected at regular intervals and the data was stored and captured on data sheets, scorecards and excel. The data collected was used to identify and confirm problems within the production line, analyse rework and non-conformities. The quality team was also approached to understand and define the already known problems faced and understand the impact of the said problems.

Data analysis falls under the Define, Measure, and Analyse phases of the DMAIC ideology. We started with the production line layout and a Value Stream Map (VSM) to visualize the process, and we then moved over to the different Key Performance Indicators (KPI's) to measure the current state of the production line.

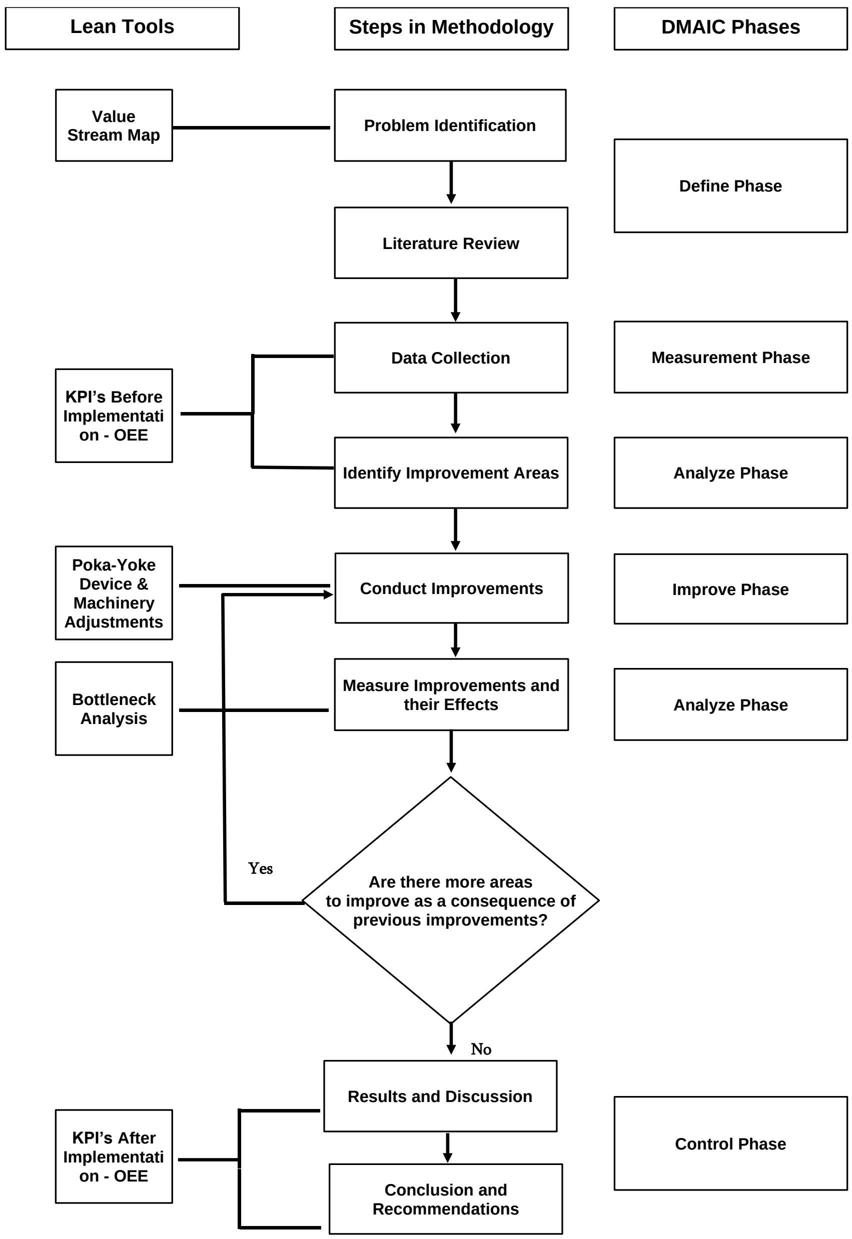


Fig. 1. Overall methodology adopted in the present work.

Figure 2 presents the flow of DMAIC phases. Figure 3 illustrates the sweet manufacturing process of the company under investigation in the present study.

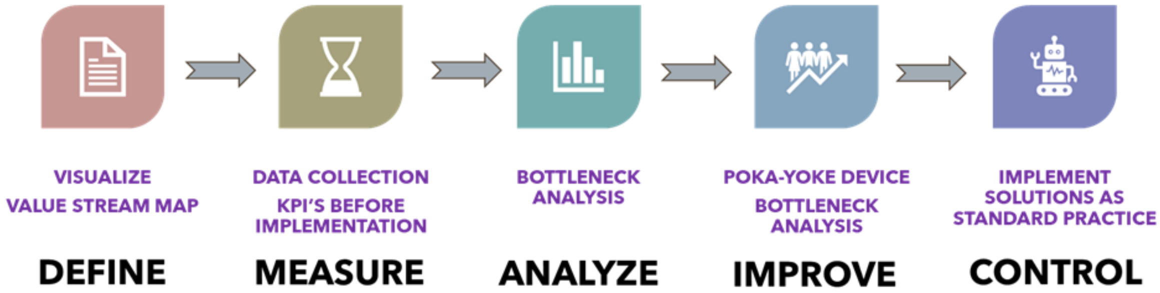


Fig. 2. DMAIC methodology adopted in the present study.

Fig. 3. Sequence of sweet manufacturing processes and tasks in the present case.

Results and Discussion

In our methodology, under the first step i.e. define, with the help of value stream mapping, we carried out production layout visualization. Figure 4 shows the value stream map of the production setup under focus. Moving on from the define phase, we moved over to the measurement phase, where data is collected and recorded accordingly. According to the factory's specifications, the overall plant production rate was 4600 sweets per minute against the plant capacity 12200 sweets per minute. The caramel production, which is the focus of this project, used to account for roughly 72% of production. There were three production lines for caramels, all of which were the same. The OEE analysis was taken from a single shift on a single production line and thereafter applied to all of them. Operators take shift breaks rotationally therefore there was no impact on production time from operators' breaks.

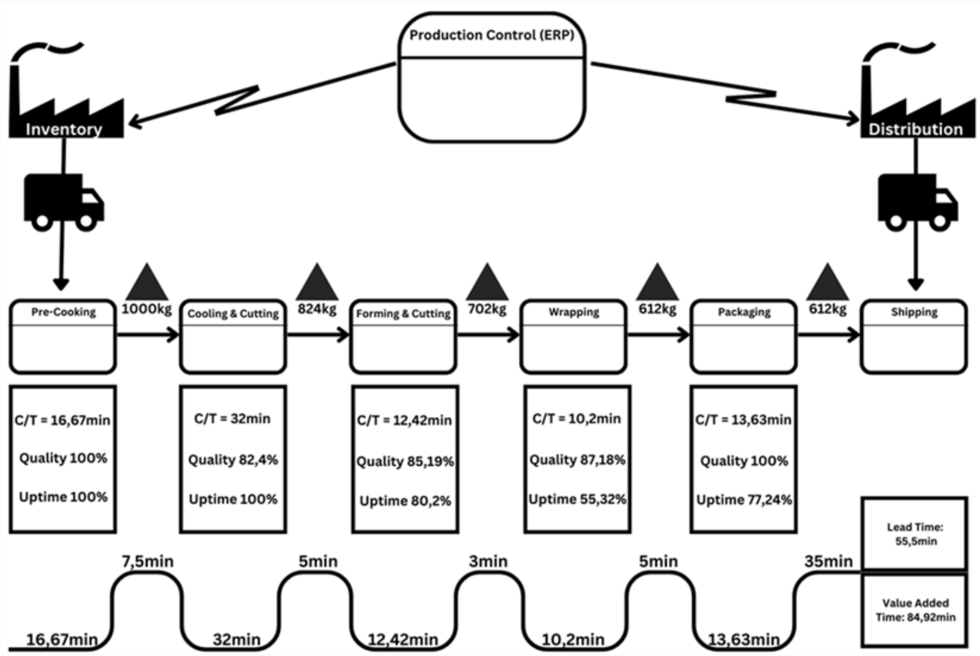


Fig. 4. Value stream map of the existing conventional process setup.

Key performance indicators (KPI), namely, availability, quality, and performance, measurement before implementation was done to calculate the OEE eventually. Availability considers all processes and steps in the production line and is a measure of the true production time that takes place as opposed to how much production time is actually planned. The data related to availability in our case, is presented in Table 1. The calculation of availability was conducted using Equations 1 and 2.

Table 1. Availability data pre implementation

Total Time Scheduled		570
Planned Downtime		
Cleaning	-45	
Quality Inspection	-25	
Total Planned Downtime		-70
Planned Production Time		500
Setup Time		
Pre-cooking	-40	
Equipment Calibration	-22	
Total Setup Time		-62
		438
Breakdowns		

Malfunctions	-36	
Breakdowns Requiring Maintenance	-132	
Total Breakdown Time		-168
Total Operating Time		270

$$\text{Availability} = \frac{\text{actual production time}}{\text{planned production time}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{Availability} = \frac{\text{total time scheduled} - \text{planned downtime} - \text{setup time} - \text{breakdowns}}{\text{total time scheduled} - \text{planned downtime}} \ldots\ldots(2)$$

$$Availability = \frac{570min - 70min - 62min - 168min}{570min - 70min}$$

$$Availability = 54\%$$

For quality calculation, defects were collected and bagged from each process step during the cleaning downtime scheduled at the end of the production shift. Weighing the rework at the end of a production, shift yielded the total rework collected per shift. This is compared to the weight of the pallets of the final boxed products (final step of the production line) at the end of the production shift. Equation 3 was used to calculate quality. The vertical packaging machine was taken into consideration for performance measurement. Performance is a measure of how the machine actually performs according to its full capacity. As per the original capacity of the machine, it could box 1000kg per hour, however the performance was set to bag 680 kg per hour. That indicated an inefficiency in the performance. Equation 4 was used for performance calculation. Using Equation 5, the calculated value of the overall equipment effectiveness was 28.11%.

$$Quality = \frac{total\ products - rework}{total\ products} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3)$$

$$Quality = \frac{8000kg - 1876kg}{8000kg}$$

$$Quality = 76.55\%$$

$$Performance = \frac{Actual\ Production}{Production\ Capacity} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$Performance = \frac{680\frac{kg}{hr}}{1000\frac{kg}{hr}}$$

$$Performance = 68\%$$

$$OEE = Availability \times Performance \times Quality \ldots\ldots\ldots\ldots(5)$$

$$OEE = 54\% \times 68\% \times 76{,}55\%$$

$$OEE = 28.11\%$$

In summary, our analysis shows that the caramel production line was operating at 54% of its planned production time, 76.55% of products were getting completed, and 23.45% was the rework. The vertical packaging machine was operating at 68% of its capacity. The production line was performing at very low OEE i.e. 28.11% of its capacity.

In the analysis phase itself, after some brainstorming and investigation, an inefficiency has been identified during the cooling process in the production line. The product was to be cooled for 25 min on the cooling table, but the timing was being ensured manually by an operator, this caused there to be an inconsistency in the timing of the cooling process due to operator error.

When the product is not cooled properly it causes there to be a lack in consistency between the hardness of the product. If the product is too hard, this causes there to be breakage during cutting process and therefore an increase in rework.

In improve phase, to address this, a Poka-Yoke strategy has been adopted. As discussed before, a Poka-Yoke is a quality control technique to minimize human error by making changes in the physical process design. The devices used under Poka-Yoke technique were to ensure the eradication of the issues related to production line operation. These devices were a buzzer, a pushbutton, and the PLC (Fig. 5).

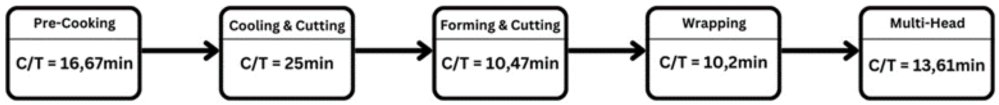
(a) PLC *(b) Push button* *(c) Buzzer*

Fig. 5. Devices used under Poka-Yoke.

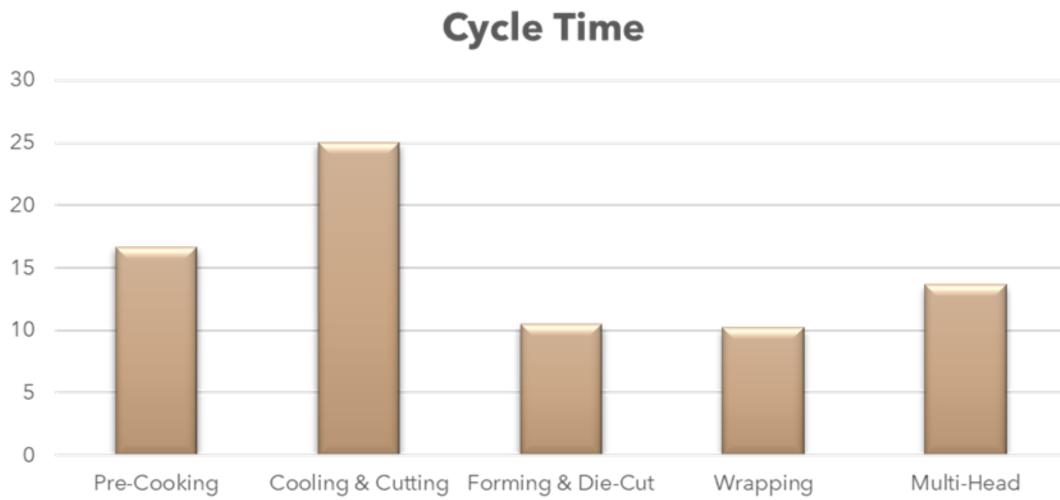
During the cooling process, the operator who was responsible for the smoothing and evening out the product on the cooling table, pushed the pushbutton, the PLC then started an ON-DELAY timer which was programmed using ladder logic language in the CX-Programmer software. The timer lasted for the required cooling time of 25 minutes and thereafter a short, intermitted sound was emitted from the buzzer to notify the operator to move on to the next step of the process which was cutting the now cooled product. We now ensured that there has to be no human error in the timing of the cooling process, ensuring a reduced, more consistent, and accurate cycle time. The post Poka-Yoke cycle time at various stages is shown in Fig. 6. Table 2 presents the difference in rework collection before and after Poka-yoke implementation.

Again, under analyse phase, a bottleneck analysis was done. Through visual inspection, it was found that after implementation of the Poka-Yoke based devices, there were less defects left on the cutting table and the floor. It was then caught through visual inspection that the hopper of the multi-head at the end of the production line was overflowing. That is why a proper bottleneck analysis was required to be done to understand what was causing line imbalance and how we can treat that.

As evident from Table 2, the rework has been reduced significantly at the cooling table and thus more product started producing and being pushed through the production line until the multi-head. As depicted in Fig. 6, the multi-head bagging machines' cycle time is still high, this again indicated towards a bottleneck.



(a)



(b)

Fig. 6. Cycle Time Per Process Post Poka-Yoke Implementation.

Table 2. Rework collected before and after Poka-Yoke implementation

Location	Rework before Poka-Yoke	Rework after Poka-Yoke
Cooling table	176 kg	98 kg
Forming and die cut	122 kg	93 kg
Wrapping machine	90 kg	82 kg
Total	388 kg	273 kg

The vertical packaging machine was set to run at a production speed of 680 kg per hour. The actual capacity according to the machine specifications was 1000kg per hour. That's why the performance was 68%.

Taking into account that the production line is now producing more products than before due to the successful implementation of the Poka-Yoke device, it follows that the line should be balanced to this increase in rate. This explains why overflowing was observed. To accommodate for the increase in production, we need to increase the production speed of the multi-head. The multi-head should be increased from 68% to just enough to ensure that there will no overflowing. The reason for not increasing the machine's speed to its maximum capacity was responsible for mechanical failure and malfunctions and failing to accommodate variations in quantity of products in the hopper. Increasing the speed to its maximum capacity will require an increase in power consumption as well as increase in temperature of the machine and its components, and finally also an increase in air pressure. These factors need to be controlled to ensure no mechanical failure. By inspecting the multi-head specification, we will need to improve the vertical packaging machine's speed to match the production output of the wrapping machine. This production is approximately 812kg per hour as measured on the wrapping machine control panel. Thus, we need to increase the multi- head to accommodate for the same production capacity that comes through while also accommodating for variation. We thus increased the packaging machines' production rate to

812kg per hour. Due to the fact that there is inevitably rework from the wrapping machine we do not risk overflowing the hopper of the packaging machine as production capacity will also be less than the 812kg of planned production. All these improvements are illustrated in Fig. 7.

By making these changes, we have now not only balanced the line ensuring the bottleneck has been addressed, but we have also improved OEE by increasing the performance of the vertical packaging machine, as evident from Table 3 and Equations 6-9.

Post improvement value stream mapping is shown in Fig. 8. It represents decrease in value added time, increase in production yield, increase quality in cooling and cutting, more consistent cooling-cutting cycle with the desired cycle time.

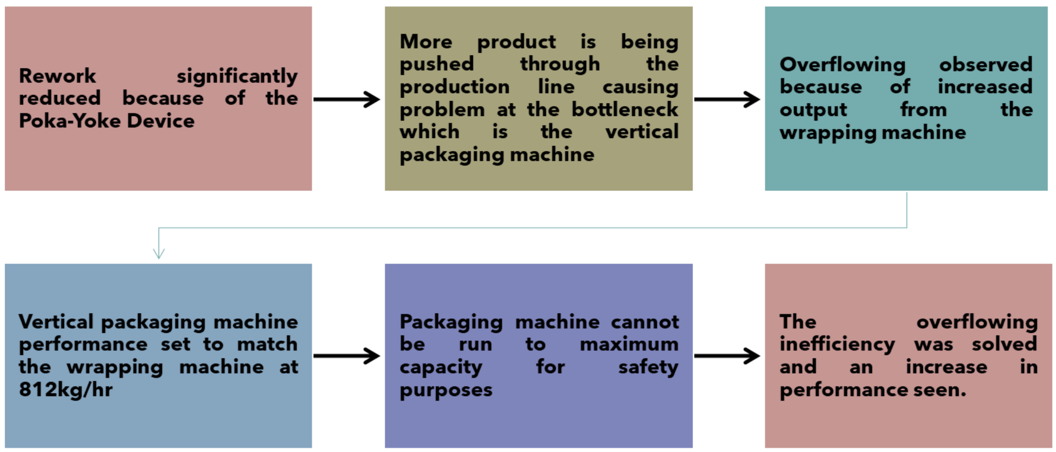


Fig. 7. Production improvements.

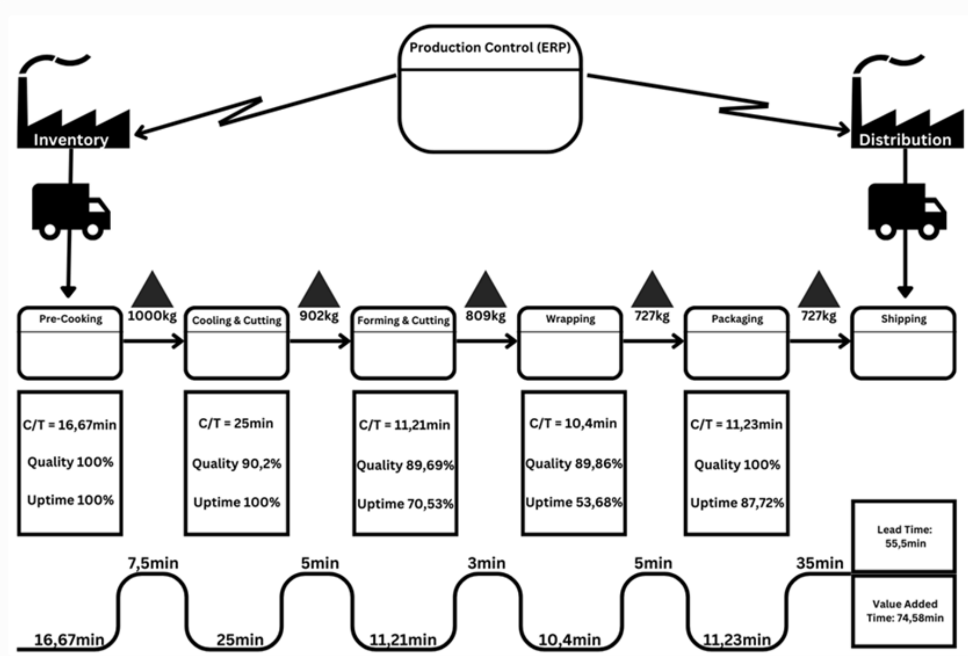


Fig. 8. Value stream map after DMAIC.

Table 3. Availability data post implementation

Total Time Scheduled		570
Planned Downtime		
Cleaning	-45	
Quality Inspection	-25	
Total Planned Downtime		-70
Planned Production Time		500
Setup Time		
Pre-cooking	-40	
Equipment Calibration	-22	
Total Setup Time		-62
		438
Breakdowns		
Malfunctions	-42	
Breakdowns Requiring Maintenance	-134	
Total Breakdown Time		-176
Total Operating Time		249

$$Availability = \frac{570min - 70min - 62min - 176min}{570min - 70min} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$Availability = 52.4\%$$

$$Quality = \frac{8000kg - 792kg}{8000kg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (7)$$

$$Quality = 90.01\%$$

$$Performance = \frac{812\frac{kg}{hr}}{1000\frac{kg}{hr}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (8)$$

$$Performance = 81.2\%$$

$$OEE = 52.4\% \times 81.2\% \times 90.01\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$OEE = 38.3\%$$

Using the DMAIC methodology in combination with lean manufacturing principles improved the efficiency of a production line.

DMAIC was implemented as follows:

- Define - Value Stream Map and Visuals of the production line grouped into steps.
- Measure - KPI's Before Implementation (Performance, Quality, Availability, OEE)
- Analyse - Bottleneck Analysis
- Improve – Poka-Yoke Device
- Control – Making the improvements standard practice in the production line.

By implementing a Poka-Yoke device the quality of the cooling process has greatly increased. This is due to improving the consistency of the timing of the cooling process by preventing operator error. This improved the consistency of the product itself by ensuring less defects from the product hardening which was causing breakage.

This improvement in quality reduced the rework per production shift from 176kg to 98kg as seen in Table 2 and from comparing the pre and post implementation value stream maps. That consequently increased the product yield from the production line. Increasing the product yield caused an imbalance in the production line as more products moved to the system and the machinery needed to accommodate. It was found that the hopper of the vertical packaging machine was overfilling. Conducting a bottleneck analysis led to the conclusion that the line was unbalanced and that the speed of the vertical packaging machine needed to be increased closer to its performance capacity in order to ensure that it can keep up with the increased production volume. This shows the importance of line balancing in a production line as changes and variation in production can greatly impact line efficiency. Implementation of the lean tools (Poka-Yoke Device and Bottleneck Analysis) Yielded the following results:

• Slight decrease in availability from 54% to 52.4%
• Increase in quality from 76.55% to 90.01%
• Increase in performance from 68% to 81.2%
• Increase in OEE from 28.11% to 38.3%

OEE is still very low, and this shows that improving the efficiency of the production line still has a long way to go and many more changes need to be undertaken to improve production efficiency. Focus should be put on availability for future improvement. As evident from Table 2, the cooling table is still responsible for more rework than the other processes and thus shows that a poke-yoke device assists and improves operational processes aiding in reducing rework but does not address all factors and variables that produce rework.

CONCLUSIONS

This case study has presented an improvement of efficiency and productivity for a caramel production line of a sweet manufacturing company using a combination of lean manufacturing and DMAIC. The following conclusions can be drawn:

-We achieved 36% improvement in overall equipment effectiveness, as it was 28.11 % before and 38.3% after lean and DMAIC implementation.
-We obtained a significant decrease of 30% in rework, as it was 388 kg before and 273 kg after Poka-Yoke implementation.
-Finally, as per our value stream mapping, we also achieved improvement in the yield of the production line from 612kg to 727kg of product per production shift, which is an 18.8% increase.

The achievements of the present work, highlight the importance and effectiveness of lean and DMAIC technique, which can be scaled up to the other sweet manufacturing industries for productivity and efficiency enhancement. Since the scope of this work was limited to the caramel production line only; therefore, after the success of this work, future attempts can be made to the following:

-Maintaining Lean and DMAIC implementation in the caramel production line for high efficiency and productivity. Further, extending it to the other departments and production lines of the company.
-Adopting an integrated lean and six-sigma approach for the other production lines of this company
-Identifying other type of wastes in overall production and minimizing via a hybrid lean and total quality management approach.

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