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The Implementation of Six Sigma and DMAIC Methodology To Increase Productivity and Meet Customer Requirements

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Abstract

The Lean Six Sigma approach has become a popular initiative which companies have embarked on to remain competitive, ensure growth within the global market and to establish customer satisfaction and loyalty. Six Sigma is at the top of the agenda for many companies that aim to reduce cost and improve a firm's productivity. This paper focuses on a production that was unable to meet the hourly target. Using the six-sigma approach and DMAIC methodology, the current problems on the line were studied and the root cause was established by using a fish bone diagram. Process improvement initiatives were characterised by the installation of a conveyor, synchronised with the takt time, and the production line was able to meet the daily output a. An Andon system was also installed to keep track of scoring, to ensure each process meets their required cycle time and process operation as well as to indicate to line management if there is an abnormality at any process or holistically.

Keywords
Hourly Target, Fish Bone Diagram and Conveyor.

1. Introduction
Manufacturing companies are struggling to keep up with fluctuating and an increase in volume at their production lines. Their primary goal is to meet customer demands, with the shortest lead time and with the highest quality (Rathilal, 2015). Efficient and low-cost production is the aim of any production process. Continuous process improvement is critical for organizations to stay in business and to stay competitive in the industry. A sewing component manufacturing company situated in South Africa faced challenges when they received an additional volume of components requested by the customer daily. This production line named Line X was not able to meet their hourly target and subsequently their daily score. This line is also a sub production line to the final assembly line before the product eventually reaches the customer. The daily available time per day is 455min with a volume of 168 units per shift. Their takt time calculated is 2.70min for each unit. Their plan or quantity to be met hourly is 22 units per hour in an eight-hour shift. The Andon assists in the waste reduction of lean by lowering the response time to issues. The system is supposed to give a quick overview of production visually and attract the attention of supervisors. The aim of this study is to identify the root causes of inefficiency in the assembly Line labelled X. The fishbone diagram will be used to investigate potential causes of the line not meeting their hourly score. This paper will also focus on the use of the Six Sigma approach (DMAIC) to investigate and identify ways to ensure there is an improvement of hourly targets online X.

1.1 Objectives of study
This research paper objectives are:
- To identify constraints on a cell type process using a fishbone diagram.
- To implement a pacemaker to ensure hourly production score is met.

- To implement a production visualization system to track daily scores.

2. Literature Review

The organization's effectiveness and efficiency are based on its vision, how it takes on challenges, adopts to new opportunities and its ability to constantly change to keep c competitive advantage. (Knapp 2014). The lean principles and six sigma define, measure, analyze, improve, and control process (DMAIC) has been used for many improvements of decreasing cycle time and operations. This is one of the most modern strategies and well-established methodologies for improving speed and quality of manufacturing operations (Bhat and Jnanesh 2014).

According to Patel and Desai (2017), they define SS as a business strategy and a systematic methodology which aims to improve profitability through products/service quality, increase productivity and nit forgetting customer satisfaction. This research literature then goes on to compare different articles of different authors and their definition of SS, which can be summarized into one definition as follows: Six Sigma can be seen as a methodology that focuses on identifying and eliminating not only defects but continuously improving failures and mistakes in business processes to achieve customer satisfaction and a company's vision and goals.

Naicker (2008) mentions that the foundation of Six Sigma is built on the DMAIC concept which divides a process improvement task into smaller sublevel tasks. By dividing tasks, it becomes much easier to focus attention and tackle a problem based on a specific task at a time and thus reducing the time taken in the implementation of most process improvement projects. A brief overview of the DMAIC process as discussed by Naicker (2008) is shown in Figure 1.

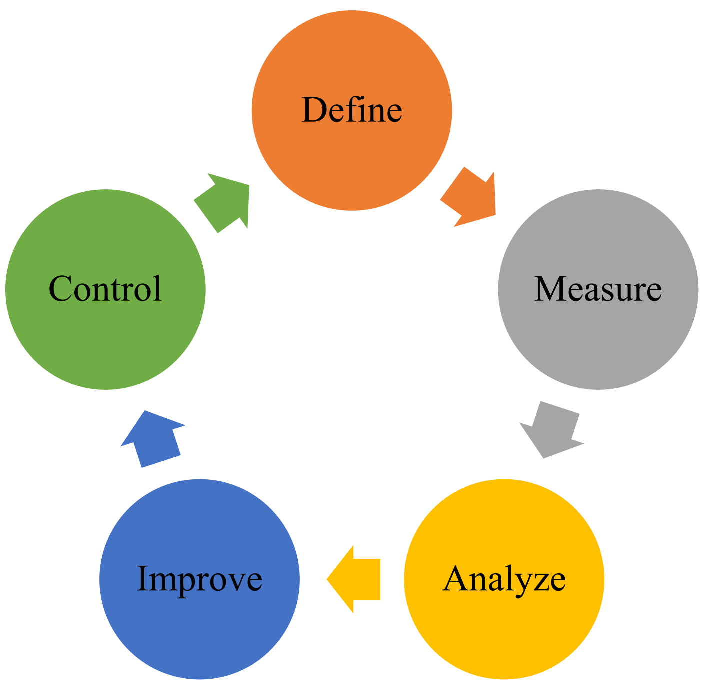

Figure 1. DMAIC Process

- D – Define: This stage uses several methods such as a development of a project charter, statement of the problems at hand and opportunities that can arise from the process improvement project being worked on. All of these methods are used to identify the problem and in continuing the project what are the possible improvements that will be achieved.
- M – Measure: At this stage data is collected and by the thought process of how to achieve the end process improvement before the collection of the required data.
- A– Analyze – Different statistical tools can be used, such as cause and effect analysis, Pareto analysis and motion and time analysis, to analyze and interpret the data to identify the core problems within the process.
- I –Improve – Process improvement ideas are generated here by brainstorming with everyone involved on how to address the problems uncovered.

- C– Control – This stage of the process aims to ensure the improvements implemented during the improve stage are maintained and the process does not lag behind by reverting into the previous method. At this stage, the improvements are documented, checklists are implemented for lower-level personnel to follow and constant checks in the form of audits after a period of time are conducted to monitor and sustain the process improvement.

The benefits of six sigma include, assists in viewing data in a statistical viewpoint and business viewpoint, assists in root cause analysis, process control planning, project management and knowledge discovery (Kwak and Anbari, 2004). Defect tracking and prevention, organizational planning, mapping and improvement, simulations and experiments are also some of the activities associated with six sigma (Flannery *et al*. 2010). Increased market share, business profitability, improved customer satisfaction is some of the many business benefits as a whole (Anthony, 2006). Six sigma implementation requires a good vision and direction from top management, practical and hands on training, effective co-ordination and a teamwork attitude from managers. (Moosa and Sajid 2010).

Belt conveyors are durable and reliable components use in industries for transporting material. Conveyors producing a single type of component at a time generally monitor and control a single type of object. Conveyors are fixed in their position and locations and the conveyor belts move according to their synchronized speeds. Many manufacturing industries, including the food and beverage companies are opting for this option (Kara *et al*, 2005). The fishbone diagram, also known as the Ishikawa diagram, has become a key diagnostic tool for analyzing and illustrating problems through root cause analysis. This is also a useful diagnostic tool for improvement (Phillips and Simmonds, 2013). Fishbone analysis begins with a problem. This diagram provides a template to separate and categorize the causes of the major problems in a process (Jayswal et al. 2011). Phillips and Simmonds (2013) further go on to state that because this method allows problems to be analyzed, if it is used with colleagues, it gives everybody an insight into the problem so that solutions can be developed collaboratively. This tool can also assist groups or individuals to identify the root causes of problems to understand the reasons behind the failures, and to determine a progression of actions and consequences to prevent another failure from occurring (Mahto and Kumar 2008).

3. Methodology

Using the DMAIC methodology, we identify further possible causes for the manufacturing line not meeting their score as well as in what ways we can improve and ensure line productivity.

3.1 Define

A production line of assembly components was not meeting their hourly score (Table 1) and subsequently their daily target and OA% and was failing to meet customer requirements.

Table 1. Hourly score to be met per hour

LINE X		
	Plan	Target (hourly)
07:00 - 08:00	22	22
08:00 - 09:00	22	44
09:00 - 09:30	11	55
09:30 - 09:50	Tea Break	
09:50 - 10:00	3	58
10:00 - 11:00	22	80
11:00 - 12:00	22	102
12:00 - 12:30	11	113
12:30 - 13:00	Lunch	
13:00 - 14:00	22	135
14:00 - 15:00	22	157
15:00 - 15:30	11	168

Calculation for their hourly target is shown below:

Total amount of hours in a shift: 7.5Hours/455min/27300sec

Volume target per day: 168 units

Hourly target: $\frac{168\ units}{7.5\ hours}$

: 22.4 units per hour

Cycle time per process: $\frac{27300secs}{168\ units}$

: 162.5 secs per unit
: 2.70*min per cycle*

The production line is shown below in Figure 2. This is a cell type manufacturing layout, where after each process is assembled, it is passed onto the next process manually for the next process to complete their cycle.

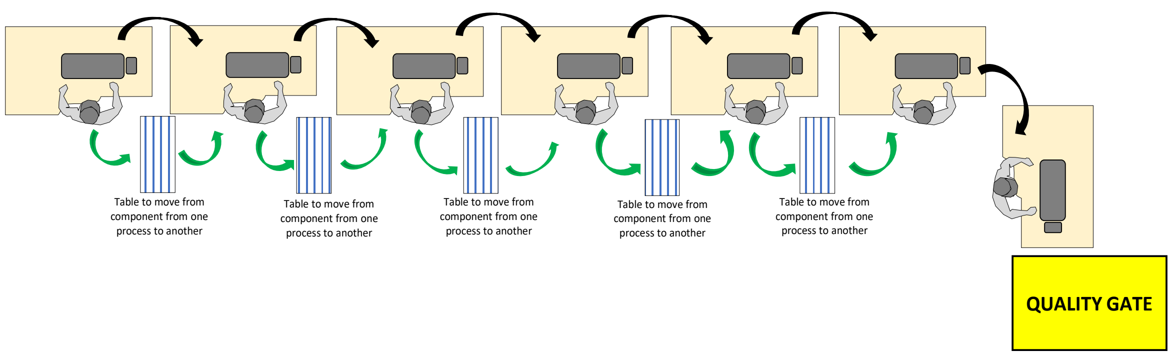

Figure 2. Cell type manufacturing line

When the hourly production line daily scoresheet was checked, the following plan versus actual score was noted. A random day of scores is shown in Table 2.

Table 2. Production Scores of a random day

LINE X					
	Plan	Actual	Target (hourly)	Cumulative Target	% OA
07:00 - 08:00	22	13	22	13	59
08:00 - 09:00	22	14	44	27	61
09:00 - 09:30	11	4	55	31	56
09:30 - 09:50			Tea Break		
09:50 - 10:00	3	1	58	32	55
10:00 - 11:00	22	14	80	46	58
11:00 - 12:00	22	15	102	61	60
12:00 - 12:30	11	13	113	74	65
12:30 - 13:00			Lunch		
13:00 - 14:00	22	14	135	88	65
14:00 - 15:00	22	14	157	102	65
15:00 - 15:30	11	5	168	107	64

3.2 Measure

The above table shows you the hourly target of units needed to be manufactured and the Operational Availability (OA %) is shown against every hour. "Operational availability" (OA) can be described as the percentage of time that the equipment or assembly line can operate properly when it is needed for production. The target OA of this particular line hourly was set at 95%, while the actual OA was between 55% and 65%. An overall of week production targets in units is shown to validate the lines performance of it was an abnormal condition on that particular day. The results are as follows in Figure 3.

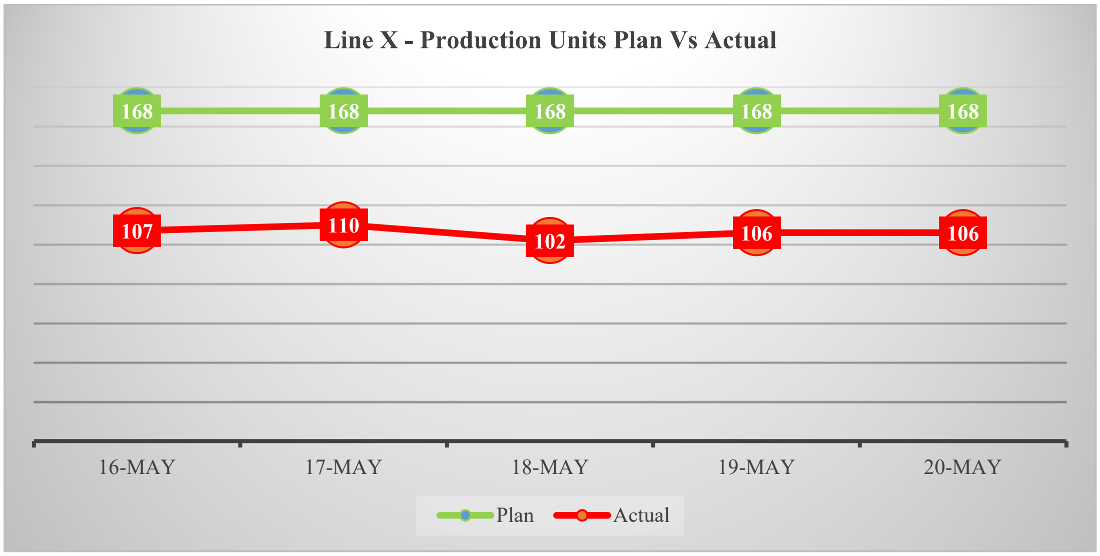

Figure 3. Plan versus actual for a week of production at Line X

Further to this, we then observed Line X and its manufacturing process and a downtime analysis study was conducted which showed the contributors to the poor performance of the process not meeting their hour score. The data is summarized and shown in the Table 3.

Table 3. Downtime analysis table of Line X

Item	%
Incorrect score between Quality and Manufacturing	20
Standardized work/ element per process not being followed	25
No material/part shortages	5
Member not at process	27
Line stoppages due to Tiolet breaks	7
Machine breakdowns	10
Delay with sewing	6
	100

The downtime analysis summary and the elements presented was then categorized into man, method, machine, and material (Table 4). It was found that the biggest contributor to downtime was man and method categories.

Table 4. Each element categorized between man, method, machine and material

Item	%	Category
Incorrect score between Quality and Manufacturing	20	***Man/Method***
Standardized work/ element per process not being followed	25	***Man/Method***
No material/part shortages	5	Material
Member not at process	27	***Man***
Line stoppages due to Tiolet breaks	7	***Man***
Machine breakdowns	10	Machine
Delay with sewing	6	***Man***
	100	

3.3 Analyze

A fishbone diagram assists in determining root causes of issues of line constraints and finding possible solutions to the problem areas. A fishbone diagram is broken up into six categories, Man, method, material, machine, and environment (Figure 4).

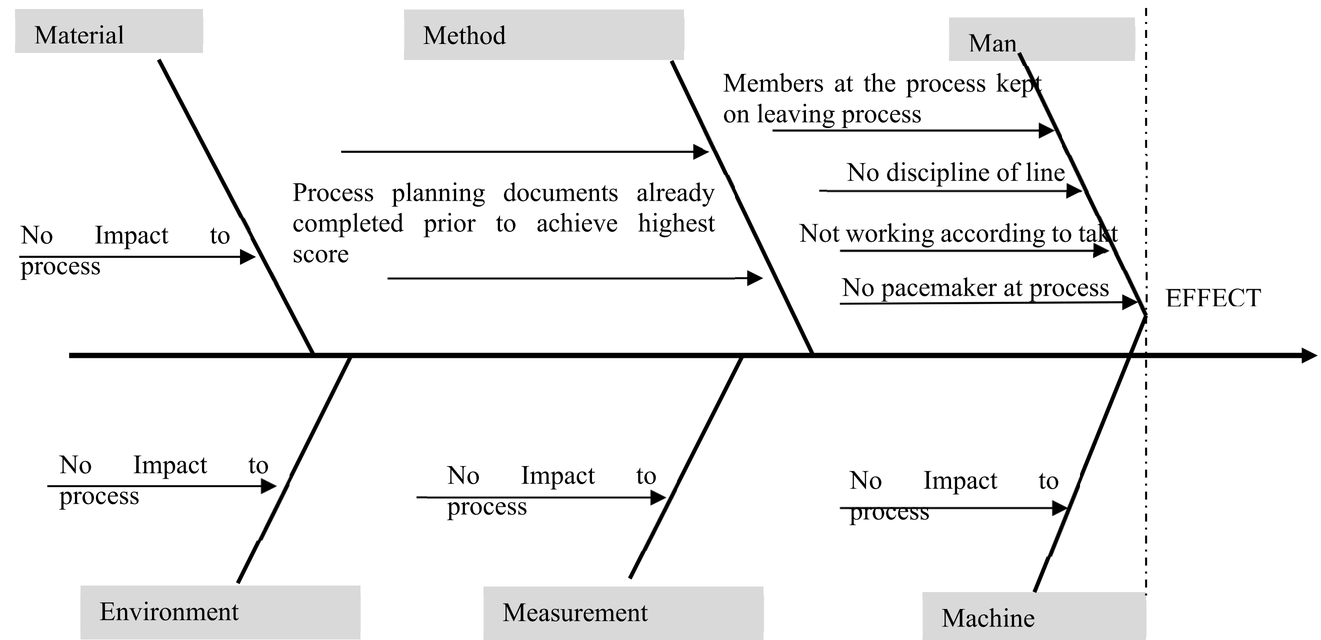

Figure 4. Fishbone diagram for manufacturing line X not meeting the hourly score.

3.4 Improve

To improve and keep track of scores, we saw that there was no confirmation of takt per process or confirmation that there are any delays at the process. There was no pacemaker for the line to run against. A pacemaker process simplifies production oversight.it allows the schedule to be given to one point on the value stream and that process then controls the flow of production.

A conveyor system was put in place where the process runs on a specific takt time, particularly set to the takt of the line. Each process will take components from the conveyor, assemble, and conduct the process requirements at that station and place back onto the conveyor. Each pitch (linear velocity of circular gear from one point to the next in which a certain time passes) is at the speed of the takt time. At the start of each pitch (white line) till the end of the next white line, is equivalent of the time taken to assemble a component at that station. Each process will have the same takt and will be able to complete their process for each pitch.

Each member will work at the speed of the conveyor which is set to the takt calculated for the process, based on the required volume (Figure 5).

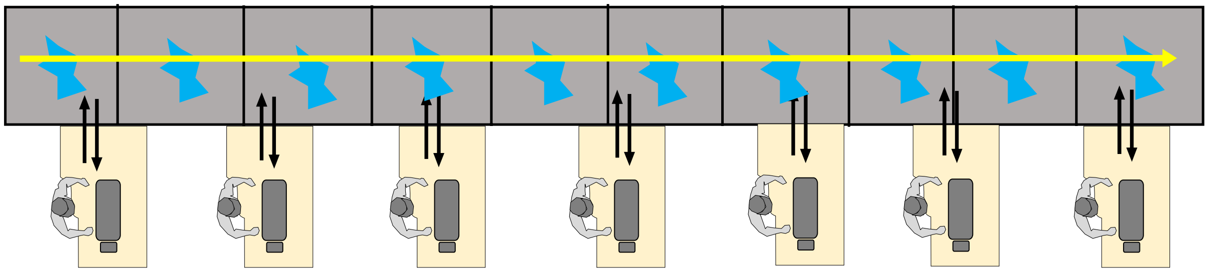

Figure 5. Conveyor installed with each process

3.5 Control

A production visualization system or commonly known as an Andon system was also installed at the process. An andon cord or button is used to generate alerts. Here at each process, there is a push button for "CALL TEAM LEADER" and "WORK COMPLETE" (Figure 6). The call team leader button is for the member to call the Team leader without moving from their station if there are any abnormalities or breakdowns (Figure 7,9). The WORK COMPLETE button is pressed after each cycle done by a member (Figure 8, 10). So, every 2.70 min, ideally it should be pressed to confirm each member at each process has completed their work cycle. If this is not the case, the Work complete starts flashing to indicate to the member at the process that she is running behind. This is also displayed on the screen showing which process is now delaying the overall line. This screen is displayed at the end of the line or at any point that is visible to line management or management walking by. While this is being shown, a melody is also played for the line management to draw attention to the screen to visually see which processes are behind schedule and takt time.

This was required as manufacturing confirms how many units they produced and so does quality. The reason as to why this is separated, and quality final counts are displayed on the andon is specifically because quality does the final count and are the last to touch the product before final shipment. For example, manufacturing can state that they manufactured 20 products and hour, and quality only counts 18 units. The variance of the 2 components can either be rework or units scrap. The andon system was also set up to account for any delays at each station. The line overall data can also be shown if requested as andon systems record daily data.

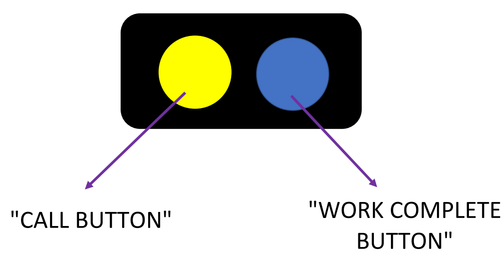

Figure 6. Andon button at each process

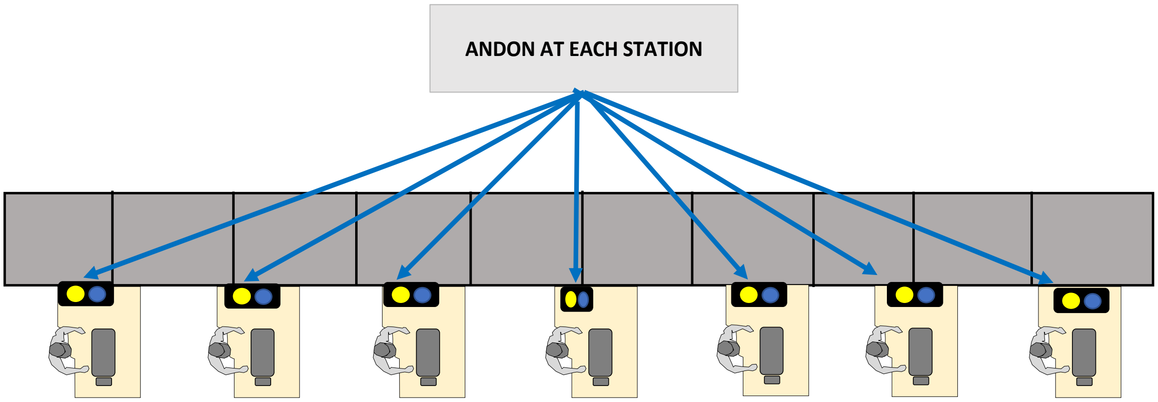

Figure 7. Andon at each process

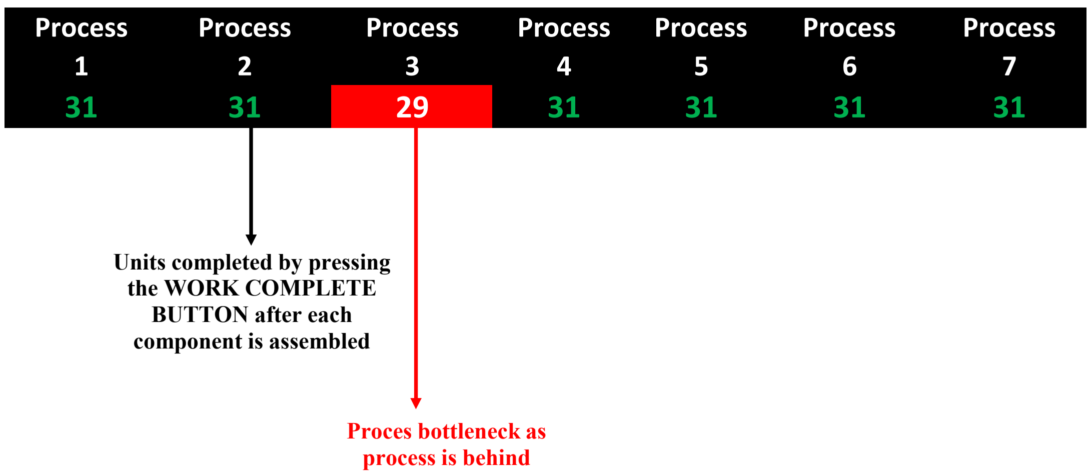

Figure 8. Process scores displayed by each process when the "WORK COMPLETE" button is pressed

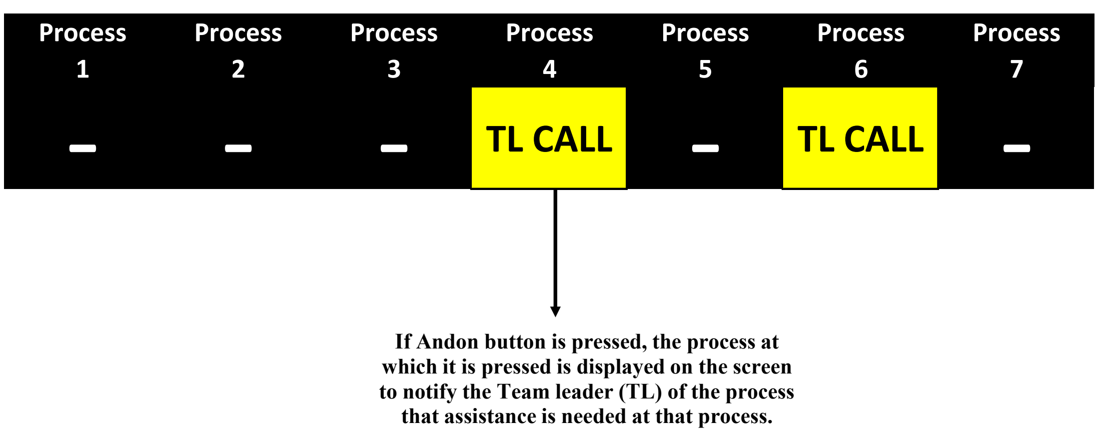

Figure 9. Display when the "CALL" button is pressed

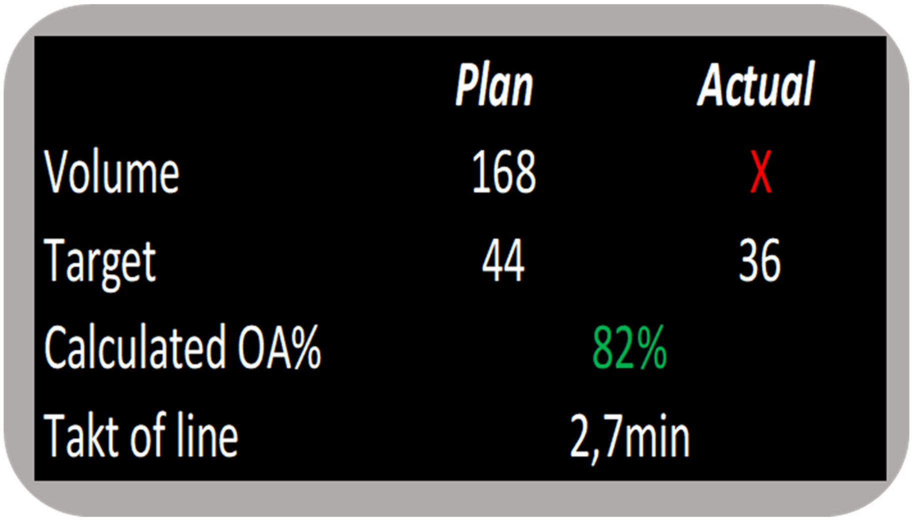

Figure 10. Display at the end of the process of the Andon screen

4. Results and Discussion

In a study conducted by Van der Merwe (2016), the involvement of employees in the continuous improvement is just as important as the implementation of a project or principle. He understood that there was no point in implementing a change if employees were not committed to making and embracing change and if this is the case, any transformation will fail. It is apparent that the real success of a lean transformation lies substantially in the hands of the employees who are responsible for implementing and sustaining any change. Once the conveyor was installed and the machines were set up, the new process set up, struggles and benefits were then explained to the members of the process. Given a daily target: 168 units a day, the weekly scores are summarized and shown below in Figure 11.

WEEK 1					
	18-Jul	19-Jul	20-Jul	21-Jul	22-Jul
Plan	168	168	168	168	168
Actual	108	107	109	115	120

WEEK 2					
	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul
Plan	168	168	168	168	168
Actual	120	122	123	125	127

WEEK 3					
	01-Aug	02-Aug	03-Aug	04-Aug	05-Aug
Plan	168	168	168	168	168
Actual	143	147	146	149	148

WEEK 4					
	08-Aug	09-Aug	10-Aug	11-Aug	12-Aug
Plan	168	168	168	168	168
Actual	165	[redacted]	167	166	167

WEEK 5					
	15-Aug	16-Aug	17-Aug	18-Aug	19-Aug
Plan	168	168	168	168	168
Actual	166	168	168	168	167

Figure 11. Summarised scores

As captured in week one, there was hardly no difference in the scores of the components being manufactured. This was commonly expected as the conveyor is still new and the employees were still getting used to working with a constant speed. The daily score eventually picked up and between week 2 and week 3 and then finally the desired output was achieved. In week 4 and week 5, we see that the daily target scores were achieved and now at a constant.

Data from the andon system was also extracted to give us an insight of the amount of work delays in minutes. The information is summarized and shown below in Figure 12.

WEEK 1 - DELAY (MIN)						
Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7
88,2	**87,2**	**89**	**85**	**83**	**80**	**72**

WEEK 2 - DELAY (MIN)						
Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7
60,3	**65,3**	**62**	**55,3**	**40**	**50**	**52**

WEEK 3 - DELAY (MIN)						
Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7
20,3	**21,5**	**26,2**	**10**	**15**	**14**	**18,2**

WEEK 4 - DELAY (MIN)						
Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7
5,3	**6,4**	**9,5**	**5,4**	**6**	**18**	**14,2**

WEEK 5 - DELAY (MIN)						
Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7
10,2	**8,45**	**5,2**	**7,8**	**5,2**	**4,2**	**9,7**

Figure 12. Delay per process captured by the Andon system

From the number of minutes captured for the delay at each process, we can see that at the start of week one, there was an average of 83.45min of delay which is equal to 1.39 hours of downtime. Whereas as the weeks went along and the member got aligned with their process and working with the conveyor, the delay decreased to an average of 7.25 min per process, 0.12hour of downtime. By this we can see that our objective was achieved by installing a pacemaker/ conveyor and the collection of data, in this case the downtime/delay time was captured with the Andon system installed.

5. Conclusion

The DMAIC Approach, is one of the fastest and most efficient way of defining the problem, measuring or collecting data, analyzing the data collected, propose ways to improve the current situation and lastly how to control and maintain the selected recommendation if carried out. In a nutshell, six sigma was proposed as a tool to improve the reliability & the quality of products by starting off at the manufacturing process to attain the end goal i.e. Reducing defects. The article further goes on to stay that even though Sis sigma was developed as an operational strategy due to globalization, it is now a "competitive corporate strategy used extensively throughout the corporate world" (Kumar et al 2007).

From the constraints mapped out on a fishbone diagram successfully and from this we were then able to deal with issues relating to man and method. A pacemaker in the form of a conveyor was successfully implemented and was set and running according to the takt of the line.

The production line X were now easily able to now meet their production score of an hourly target of 22 an hour and were not able to meet customer requirements. Standardized work is now being followed, production members and each process were now able to work according to their takt. There was no discipline of the lie. Members did not leave their processes unless there was a member to relief them.

The production visualization system or the Andon system was also successfully implemented at the line side. This assisted greatly at responding to issues at each process to ensure the line runs efficiently.

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Biography

Prenisha Govender is a process engineer at a well-known automotive manufacturer situated in Durban, South Africa. She is also a student at the Durban University of Technology and is currently completing her Masters in Industrial Engineering. Upon graduating with her BTECH in Industrial Engineering. she has also obtained Cum Laude and Deans Merits award of her year of completion. She has also written a paper on the use of Kaizen principle and line balancing technique that was presented at the 33rd South African Institute of Industrial Engineering conference that took place in October 2022. This Journal paper was then also published in the South African Journal of Industrial Engineering. Her research interests are Toyota Production Systems, Lean manufacturing, optimization and Kaizen.

Mendon Dewa is a senior lecturer in the Department of Industrial Engineering at the Durban University of Technology in South Africa. Dr Mendon Dewa holds a Bachelor of Engineering degree in Industrial Engineering from National University of Science and Technology, a Masters in Manufacturing Systems and Operations Management from the University of Zimbabwe and a Doctorate of Engineering from Durban University of Technology. He has presented at local and international conferences and has written several journal articles. He has also supervised postgraduate students and has a strong passion for optimisation of manufacturing systems and operations management.