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Productivity improvement in tyre manufacturing plant

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ABSTRACT

This paper focuses on studying the production processes at Tyre manufacturing plant in order to understand the current productivity and suggesting the ways to improve the same. In any production processes, the major factors affecting the productivity are the non-value added activities and defects/non- conformities generated plus the rework done to eliminate the defects. DMAIC methodology is used to carry out the study. Initially, the current performance of the system is studied and measured using techniques like Time study and Process Capability. Next techniques like FMEA and Root Cause analysis are implemented to analyze and identify the sources of non-conformities. Improvement in the Loading and Unloading Efficiency is achieved from 58.835% to 100 %. Since 4 seconds were saved for every batch which resulted in saving 940 seconds or 15.677 minutes per shift. This resulted in increasing the batch number from 235 to 245 batches per shift per mixer. Also, the 3M/4M condition is suggested to reduce the major defect from potentially occurring in both Tyre building and Tyre Curing department.

Keywords*— Tyre industry, DMAIC, Productivity improvement, Fishbone diagram, Tyre defects*

1. INTRODUCTION

The tyre industry is a process based type of industry. It has 5 major processes which are Banbury Mixing, Component Preparation (Extrusion, Calendering and Bead Winding), Tyre Building, Tyre Curing and Tyre Inspection. Natural Rubber, Carbon black, Sulphur and Textile Fabric are major materials used in Tyre Manufacturing Industry. Here it produces mainly Truck and Tractor tyres. Productivity in any industry is affected by many factors such as production time, type of machinery and operations used in industries, surrounding environment, product quality, etc. So it becomes very important for the industry to monitor all the above factors and see that they are maintained in such a way that it always helps in enhancing/maintaining the productivity of the industry. Here the major focus is given on eliminating non-value added activities along the production process and ways to reduce the occurrence of defects generated during the production of tyres. As operations done by machines are already set it is not possible to alter so focus will mainly be on operations done by workers manually or any work which involves human assistance.

2. LITERATURE REVIEW

Fernando Calderon [1] stated that DMAIC (Define Measure Analyze Improve Control) applied in the chocolate industry has resulted in improving the existing process. Further identification of waste was done with the combination of Time studies which also have helped to identify operating time improvements. All improvements have resulted in $1700 worth of saving. However, the Fishbone Diagram could have been used to find the root causes. Himanshu Vasnani, Amit Tiwari, Dr Neeraj Kumar, Mahendra Labana [2] stated that Value Stream Mapping used in steel reinforcing bar industry has the ability to identify waste in any processes by identifying and removing non-value-adding activities. Steel bar cutting process with more value-added activities plus higher inventory speed was achieved by having the early morning deliveries and presenting a second late morning delivery. Millan Arellano [3] stated that flow process charts and time study used in the printing industry for making t-shirts can be used effectively to get a proper view of the process. They claimed that 5-minute savings in machine idle time or 25% reduction in changeover time was observed. Wa-Muzemba Anselm Tshibangu [4] describes a two-step strategic-tactical Lean Six Sigma methodology used in Printing Press to improve productivity. First, to understand the problem a DMAIC procedure is used. Secondly, to identify various wastes and propose a set of techniques a more tactical Lean approach is used to reduce the identified wastes. A possible reduction of $300,000 in yearly operational capital was achieved through improvements made. Sunny Shokeen [5] has completely reviewed the formation of master and final rubber in the Tyre industry. Natha Kuptasthien and Teerapong Boonsompong [6] demonstrated the implementation of Six Sigma technique and DMAIC improvement methodology in Electronic Manufacturing industry to reduce DPPM (Defects Parts per Million) and improve first yield output. Here there is a reduction from 1,154 DPPM to 314 DPPM and increase in 1st yield output from 98.4% to 99.66%. Nilda Tri Putri, Bayu Hidayat, Sha'ri Mohd. Yusof, Dicky Fatrias, Ahmad Syafruddin Indrapriyatna [7] show the implementation of six sigma technique used in the Cement industry to reduce Defects. Here Fishbone Diagrams and FMEA (Failure Mode and Effect Analysis) are used to identify the source or root cause of non- conformance. Wichai Chattinnawat [8] stated the efficient and systematic use in the Electronic industry of DMAIC methodology used with why-why analysis to improve the quality. It includes identifying the VFC (Vital Few Causes) of the product and the process and removing them from the production process by applying the why-why analysis for identifying their root causes. Reduction in the percentage of defect is achieved from 7.65% to 3.51 %.

3. METHODOLOGY IMPLEMENTED

The Design of this project is carried out using a Six Sigma method, DMAIC (Define, Measure, Analyze, Improve, Control), which is the ideal methodology for improving upon existing processes. DMAIC is a data-driven quality methodology used to improve the processes. It is a fundamental part of a Six Sigma initiative and can be implemented as a quality or process improvement procedure.

3.1 Define phase

D stands for Define where the specific problem is identified and the project goals and objectives are defined. The define phase and project scope were identified after a discussion with the guide at the plant. The problem statement or objective of the project is to study the current productivity and provide suggestions to improve the same. It basically includes studying all the processes and departments associated with tyre manufacturing and measure current process performance in order to find any inefficiencies and wastage present which can be eliminated to improve the current performance.

3.2 Measure phase

M stands for Measure where the current performance of the system determined and quantification of the problem is done. Identifying the current process performance was the goal of the measure phase. Here flow process charts were drawn for each of the five major departments to get proper knowledge about the sequence of activities taking place across each department. Time studies were conducted to know about time is taken for a given operation or activity. Efficiency, Yield Rate and Process Capability were the measures used to rate the performance of each department and depending upon the results obtained further studies were conducted.

3.2.1 Banbury Mixing: In Banbury mixing pre-masticated rubber in the form of a sheet is feed into Banbury mixer along with Sulphur powder. Here time study was conducted on all 3 Banbury Mixers present in Banbury department to know the current performance of the same. 6 readings were taken on each mixer to get more accurate values. A stopwatch was used to get the timings for each activity in time study. As mentioned earlier, the focus is mainly on activities performed by human therefore only loading and unloading part of Banbury Mixing is considered for the Time Study. Once the time was recorded for each activity, the efficiency of loading and unloading for each mixer is calculated using the formula for efficiency involving time for value added and non-value added activities.
Total number of activities in loading and unloading = 5
Number of non-value added activities = 2 [2-3]

Table 1: Final average efficiency in Banbury mixer

Machine	Average Loading and Unloading Efficiency (%)
Banbury Mixer 1	58.502
Banbury Mixer 2	58.850
Banbury Mixer 3	59.155

3.2.2 Tuber/Extruder: Here various components like Tread, Sidewall, etc. are produced by feeding the output rubber from Banbury mixer into tubers better known as Pin Barrel extruder. Here in this Tuber/Extruder department Process Capability study was conducted on all 3 Dual Tuber Machines to know how much capable is the process and the machine. On each machine, various process parameters were taken like Length, Weight, Width and Raised Width. In order to maintain the uniformity, a study is conducted on only thread components on all 3 Dual Tubers. Around 50 samples were taken for each study. Once the study is concluded, the major inputs like Process specifications, Tolerance limit, and Process average values were fed into Pre-Developed Program on Microsoft Excel to obtained Process capability (C_p) and Process Capability Index (C_{pk}).

Table 2: Process capability study in tuber

Machine	Process Parameter	Unit	Process Specs	±Tol	Process Average	C_p	C_{pk}
DT1	Length	mm	2225	10	2224.9	2.26	2.25
DT1	Weight	Kgs	19.45	0.55	19.443	1.87	1.85
DT1	Width	mm	300	6	299.20	2.16	1.87
DT1	Raised Width	mm	194	3	194.40	1.81	1.57
DT2	Length	mm	2225	10	2231.0	1.15	0.46
DT2	Length	mm	2225	10	2224.46	2.11	2.00
DT2	Length	mm	2230	10	2229.10	2.15	1.96
DT2	Weight	Kgs	23.4	0.7	23.88	1.97	0.62
DT2	Width	mm	330	6	329.25	2.06	1.80
DT2	Raised Width	mm	210	3	208.20	1.49	0.60
DT3	Length	mm	2720	10	2722.44	1.67	1.27
DT3	Weight	Kgs	37.8	1.1	37.9763	1.92	1.61
DT3	Width	mm	410	6	408.28	2.55	1.82
DT3	Raised Width	mm	230	3	228.28	1.65	1.6

From the above table we can observe that at DT1, DT 2 and DT 3 for all the studies conducted by using process parameters like Length, Weight, Width and Raised Width, the Process capability (Cp) and Process Capability Index (Cpk) is found to be greater than or equal to 1.33. So we can conclude that the process is consistent (the machine is capable of producing products within limits) and is centred (the process is within the specification limits). Therefore the process is excellent at Dual Tuber.

3.2.3 Calendering: In Calendering process capability study is conducted to know the current performance of the system. Here they produce components like Body Ply, Inner Liner etc. Here in this Calendering department Process Capability study is conducted on 6 Banner Cutter Machines to know how much capable is the process and the machine. On each machine Raised Width is taken as a process parameter.

Table 3: Process capability study in calendering

Machine	Process Parameter	Unit	Process Specs	±Tol	Process average	C_p	C_{pk}
Banner1	Raised Width	mm	930	6	930.45	1.72	1.59
Banner2	Raised Width	mm	830	6	830.38	1.30	1.21
Banner3	Raised Width	mm	970	6	969.57	1.54	1.43
Banner3	Raised Width	mm	220	6	221.55	1.82	1.35
Banner4	Raised Width	mm	395	6	395..38	1.70	1.59
Banner4	Raised Width	mm	395	6	395.38	1.70	1.59
Banner5	Raised Width	mm	920	6	919.55	1.43	1.33
Banner5	Raised Width	mm	920	6	920.23	1.81	1.74
Banner6	Raised Width	mm	905	6	905.32	1.43	1.35
Banner7	Raised Width	mm	970	6	970.14	1.09	1.07
Banner7	Raised Width	mm	920	6	917.71	1.41	0.87
Banner7	Raised Width	mm	830	6	829.55	1.72	1.59

From the above table we can observe that at Banner1, Banner3, Banner4, Banner5, Banner6, Banner7 for all the studies conducted by using Raised Width as process parameter the Process capability (Cp) and Process Capability Index (Cpk) is found to be greater than or equal to 1.33 at most of the studies. But for Process Capability study done on Banner2 with Raised Width as a process parameter, the Process Capability Index (Cpk) is found to be less than or equal to 1.33. Here since Process capability (Cp) is showing value more than 1.33 which means that the process is consistent (the machine is capable of producing products within limits) the process can be centred as per the requirement to improve the Process Capability Index (Cpk). So we can conclude that the process is consistent (the machine is capable of producing products within limits) and can be centred as per the requirement.

3.2.4 Tyre Building: It is a process of assembling components produced in the previous department to form a Green Tyre. Here tyre building process is broken into steps to determine the time taken by each step which is added up at the end to obtain total time taken for the tyre building process. Once the Time was recorded for all the activities across all three selected Tyre Building Machines, the performance of the existing Tyre Building system was calculated by using the efficiency formula involving time for value added and non-value added activities. Here 5 readings are taken at each machine, total time is calculated which is a summation of both value-added time and non-value added time. Once efficiencies are calculated average efficiency is calculated for each of the machines.

Total number of activities = 17

Number of non-value added activities = 1 [17]

Table 4: Final average efficiency in tyre building

Machine	Average tyre building operation efficiency (%)
Tyre Building Machine 1	95.268
Tyre Building Machine 2	95.671
Tyre Building Machine 3	95.276

The yield rate is another way to measure the current performance of the system. It is defined as the percentage of non-defective items of all produced/manufactured items and is usually indicated by the ratio of the number of non-defective items against the number of produced/manufactured items. In order to know the current Yield Rate in Tyre Building section, the data of total Green tyres produced along with the Green tyres which were held back was obtained from the quality assurance department. Here data of 5 months from September 2018 to January 2019 was collected. Green tyres are held in Tyre Building inspection section due to various reasons. It could be due to the presence of a certain defect in the Green tyre or due to production of Green tyre out of its specifications or inconformity's occurring in Green tyres due to mistakes done by the worker performing the Tyre Building operation or inconformity's occurring in Green tyres due to error in Tyre Building machines during its operation or due to production of faulty parts (sidewall, thread, ply, bead, band) or due to some other hidden phenomenon. Currently, in Tyre Building department, there are 41 possible non-conformities/defects which can be detected during the Green tyre inspection.

Off Bead Center contributes to largest number with 2220 rework done for last 5 months closely followed by Band, not Cover Bead, GT Overweight, Stock Peeling and Covering Band Wrinkle with 1909, 1229, 1018 and 653 rework done. It shows that only 5 defect constitutes around 70% of the Tyre Building defects. Other defects like Cover Ply Open, Air traps, Ply Wrinkle, High Tread Ending, Inner Liner Damage, Contamination etc. constitutes for remaining 30% of Tyre Building defects. The analysis is done on the major defect to know the root cause of the defect for which FMEA is conducted along with Fishbone diagram in the next section.

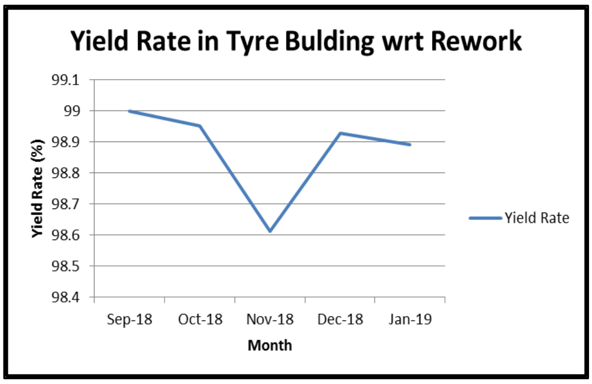

Fig. 1: Yield rate in tyre building

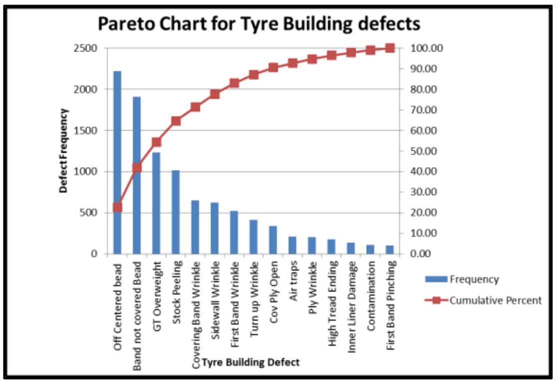

Fig. 2: Pareto chart for tyre building defects

3.2.5 Tyre Curing: Tyre curing is a process where the green tyre is converted to the final form of the tyre. Here time is calculated between the two curing cycles which are added to curing time to determine total cycle time required for one tyre.

Total Time = Total Curing Time + Time between Two Curing Cycles (Loading and Unloading)

Once Time is recorded for all the activities across all three selected Tyre Curing Machines (3 each for Truck and Tractor tyres), the value-added time and non-value added time were calculated and performance of the existing Tyre Curing loading and unloading system was calculated by using the efficiency formula involving time for value added and non-value added activities.

Total number of activities = 15
Number of non-value added activities = 3 [9-10-11]

Table 5: Final average Efficiency in Tyre Curing

Machine (Tractor)	Average tyre curing loading and Unloading Efficiency (%)	Machine (Truck)	Average tyre curing loading and Unloading Efficiency (%)
Tyre Curing Machine 1	95.562	Tyre Curing Machine 1	95.394
Tyre Curing Machine 2	95.490	Tyre Curing Machine 2	95.393
Tyre Curing Machine 3	95.391	Tyre Curing Machine 3	95.400

In order to know the current Yield Rate in Tyre Curing section, the data of total Cured tyres produced along with the Cured tyres which were held back was obtained from the quality assurance department. Here data of 5 months from September 2018 to January 2019 was collected. In Tyre Curing department once the tyres are cured in Curing press, they are cured further in PCI units at the required pressure to prevent the contraction of tyres due to a sudden change in temperature when removed from the press. Cured tyres are inspected carefully before transporting them to the Tyre shipping department. Cured tyres which do not meet the required specifications are held back and are sent to repairing section to remove the non-conformity if possible. Cured tyres whose non-conformity is not possible to remove are considered as scrap.

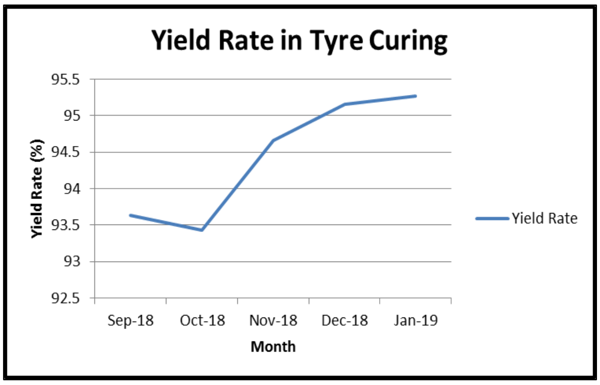

Fig. 3: Yield rate in tyre building

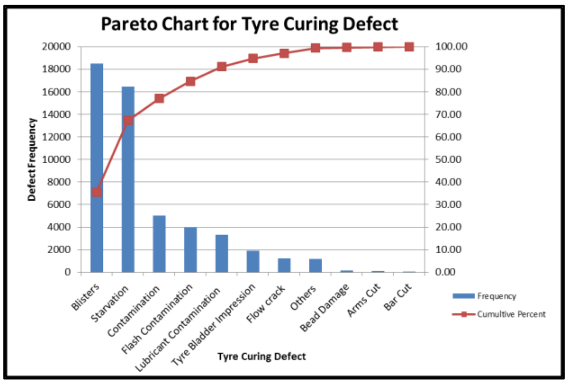

Fig. 4: Pareto chart for Tyre Curing defects

Blisters contribute to the largest number with 18480 rework done for last 5 months closely followed by Starvation, Contamination and Flash Contamination with 16458, 5045 and 4014 rework done. It shows that Blisters constitute for around 35.57% of Tyre Curing defects followed by Starvation, Contamination and Flash Contamination which constitutes 31.68%, 9.71% and 7.73 % respectively. It shows that only 4 defect constitutes around 80% of the Tyre Curing defects. Other defects like Tyre Bladder Impression, Lubricant Contamination, Flow crack, Bead Damage Arms Cut, Bar Cut etc. constitutes for remaining 20% of Tyre Building defects. The analysis is done on 3 major defects to know the root cause of the defects for which FMEA is conducted along with Fishbone diagram in the next section.

3.3 Analyze phase

Aim of this phase is to analyze the problems that are identified in the measure phase. After using the Pareto chart, major defects for both the departments were shortlisted. Here in this section both Cause and Effect diagram plus FMEA (Failure Mode and Effect Analysis) are conducted to know the root causes for the major defects.

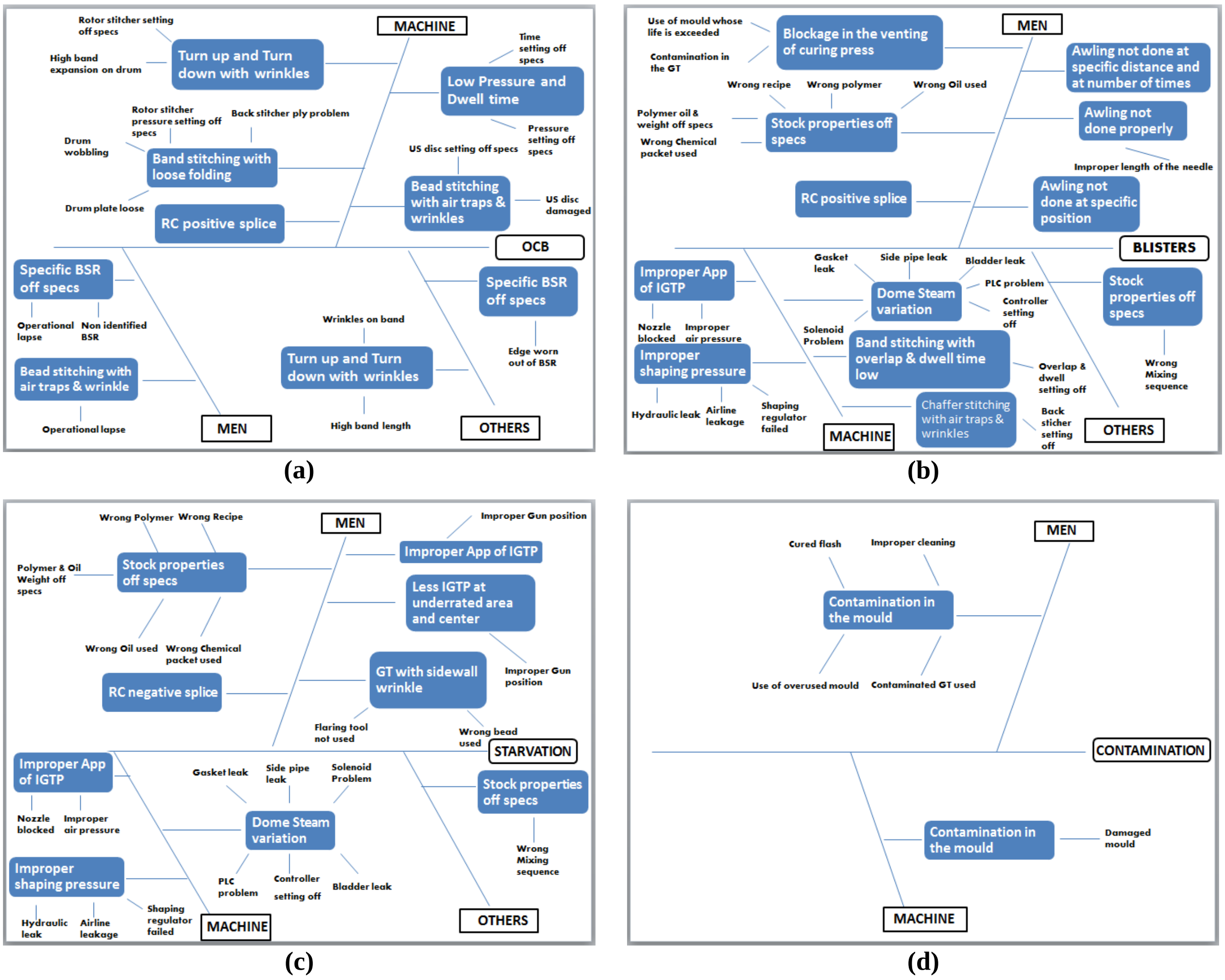

Fig. 5: Fishbone diagram for (a) Off centered bead (b) Blisters (c) Starvation (d) Contamination

In both the department that is Tyre Building and Tyre Curing it is not possible to arrow onto a particular activity to be the cause of the given defect and in most of the cases it is seen that a defect is a combination of various causes together. Here the effort is made to highlight the possible critical cause and why it is taking place. Here important or critical causes are identified after analysis and discussion with the quality department, floor supervisors and operators.

Table 6: Major causes for the defects

Defect	Area	Sr. No	Cause	Sub causes
Off Centered Bead	Bead fitting and stitching	1	Finger distance low	Finger distance setting off specifications
		2	Bead off centred	Wrong bead
		3	Low pressure and dwell time	Pressure setting off specifications
				Dwell time setting off specifications
		4	Bead setting without air trap and wrinkles	Operators fault
				US disc setting off specifications
				US disc damaged
		5	Drum spotting not ok	Setting off specifications
		6	Specific BSR off specification	Operational lapse
				Non identified BSR
				Edge worn out of BSR
Starvation	Banbury Mixing	1	Stock properties off specification	Wrong recipe
				Wrong polymer
				Polymer weight off specification
				Wrong oil used
				Oil weight off specification
				Wrong filler used
				Filler weight off specification
				Wrong chemical packet
				Wrong mixing sequence
	Curing of GT	2	Improper tyre shaping pressure	Hydraulic leak
				Airline leakage
				Bladder pin hole
				Shaping regulator failed

Blisters	Awling of the GT	1	Awling not done properly	Improper length of the needle
				Improper rpm and pressure of the gun
		2	Awling not done at a specific position	Operational error
		3	Awling not done for a specific number of times	Operational error
Contamination	Curing of the GT	1	Contamination in mould	Improper cleaning
				Contaminated Green Tyres used
				Use of overused mould
				Cured flash
				Damaged mould

3.4 Improve Phase

Aim of this phase is to provide the improvement to the problems identified in the measure phase depending upon the analysis carried out in the previous phase.

3.4.1 Loading and unloading efficiency in Banbury mixing: Here suggestion was given to combine step 2 and step 3 wherein closing of the bottom drop door and opening of the top door would happen simultaneously by using on one single push button. This would result in reducing the time by half from 8 sec to around 3 to 4 seconds. Per batch around 4 seconds is saved. This would result in improving the Loading and Unloading efficiency. Comparison is shown in the table given below as how it would affect the entire process.

Table 7: Comparison between current and proposed suggested system

Important parameters	Current	Proposed
Total number of activities	5	4
Number of non-value added activities	2	0
Average total time is taken for activities 2 and 3 together (in a sec)	8	4
Average Time is taken per batch for Loading and Unloading (in a sec)	20	16
Batches produced currently on an average per shift	235	245
Average Loading and Unloading Efficiency (%)	58.835	100

3.4.2 Defects in tyre building and tyre curing: In order to reduce the defect from potentially occurring a 3M/4M condition was suggested which comprises of condition to be followed, the requirement for that given condition, ways to check and maintain it. 3M/4M conditions were generated only after proper discussion with Industry guide, supervisors from the respective department and other staff in the industry having experience and knowledge. Below tables comprises of 3M/4M condition applied to each of the major defect identified and analyzed in the previous sections.

Table 8: 4M condition for Off Centered Bead

4M	Condition	Requirement	How to check	How to maintain
Machine	No excess play between BSR bush and shaft	Clearance to be 0.5 mm max	Feeler Gauge	PM schedule (as per the frequency)
	No loose BSR segments	Segment bolts to be tightened	Open end spanner	Check and tighten on the 1st day of every week
	Drum condition	No loose plates, No offset/step off plates	Shake plates by hand, check for missing pin/bolt, broken welds	PM schedule
	Correct PLC program	As per specification	Follow up each step, visually	Verify during drum/size change
	Finger to drum edge distance	55 mm	Using Vernier caliper	PM schedule
	Bead setting time	4 seconds	Stop watch	Verify during drum/size change
	Bead spotting	Both beads should act at the same spot	PLC count & with marking	For every tyre
Method	Proper centering of outer bead	Both outer beads to be set concentric even if BSR if off centered	Visually	See that mark on the stub shaft coincide with marking on BSR while inserting an outer bead
	Tyre completion with all steps	No step skipping	Visually	Ensure for every tyre
	No loose folding	Ensure 1st band stitching and remaining band turn ups without wrinkles	Visually	Ensure for every tyre
	No loose flipping/flipper wrinkles	Bead flipping machine clamping rollers working ok	Visually	PM schedule
	Correct bead ID	Meeting specification	On bead ID machine	Set up verification for every bead wheel change and shift change
	Correct bead	Supply of identified beads	Visually, line ID	Check while supplying on every machine
Man	GT without Off Centered Bead	Trained builder	Visually	During scheduling

Table 9: 3M condition for Starvtion

3M	Condition	Requirement	How to check	How to maintain
Method	Preparation of the Green Tyre for loading	Uniform application of the paint	Visual	For every tyre
Material	Defect free Green Tyre	Proper setting of components of Green Tyre	Visual	For every tyre
Machine	Shaping PRV (Lesire valve)	No cut packing (SS diaphragm), Stage 1 shaping regulator ok, Stage 2 shaping regulator ok	Open and check	During PM schedule and overhaul
	Defect free Green Tyre	The specified setting of the pressure and tread centering	Visual	For every tyre

Table 10: 3M condition for Blisters

3M	Condition	Requirement	How to check	How to maintain
Men	No air traps present in Green Tyre	Proper awling process done at specific distance and number of times	Follow the specification	For every Green Tyre
	No impurities in the vents of press mould	Proper cleaning of vents	Visually	To be inspected during every round before loading
	No impurities in the vents of press mould	Use of mould only till its specified life	Visually	PM schedule
Machine	No air traps present in Green Tyre	Proper rpm and pressure of pneumatic gun used for awling	Visually and Pressure gauge	For every Green Tyre
Material	No impurities in the vents of press mould	No contamination on the Green Tyre	Visually	For every Green Tyre
	Proper awling application for removing air traps	Use of proper needle for awling	Visually	For every Green Tyre

Table 11: 3M condition for contamination

3M	Condition	Requirement	How to check	How to maintain
Men	Cleaning of the bladder	Bladder free from the foreign material and cured rubber flash	Visually	To be inspected during every round before loading
	Cleaning of mould	Mould free from the foreign material and cured rubber flash	Visually	To be inspected during every round before loading
Material	Contaminated free Green Tyre	Green Tyre to be free from the foreign material	Visually	For every tyre

4. CONCLUSION

This paper has presented the productivity improvement study conducted in Tyre manufacturing plant. Various techniques like Time study, Fishbone Diagram, FMEA etc. were implemented and improvements were suggested in 3 areas. Improvement in the Loading and Unloading Efficiency was achieved from 58.835% to 100 % by combining step 2 and step 3 which resulted in reducing the time by half from 8 sec to around 3 to 4 seconds. This led to eliminating non value added activities 2 and 3 thus improving the Efficiency to 100 %. Also since 4 seconds were saved for every batch which resulted in saving 940 seconds or 15.677 minutes per shift. This would result in increasing the batch number from 235 to 245 batches per shift per mixer. Also, the 3M/4M condition is suggested to reduce the major defect from potentially occurring in both Tyre building and Tyre Curing department.

5. ACKNOWLEDGMENT

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