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Research Article

Reduction of Faults due to Preventive Maintenance Non-compliance in Pakistan's Glove Sector using DMAIC Approach

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Abstract: In this era, the Pakistani glove manufacturing companies are striving for higher operational efficiencies to meet the forecasted demands of US$1.25 billion in Asia by 2025. Endeavouring for excellence these companies are hampered by limited operational efficiencies due to poor compliance of scheduled preventive maintenance (PM). Affected equipment encounters numerous faults and as a result a higher unplanned downtime. This paper aims to reduce such faults using DMAIC (Define, Measure, Analyse, Improve and Control) approach on a glove manufacturing equipment. Applying DMAIC, the analysis indicated that a fault "Former linkage assembly issue" contributed 33.3% of total recurring faults, 34% of total unplanned downtime. The Root cause for this fault namely "loosening and plays in former linkage assembly" was diagnosed by the project team for possible remedies. An experimental analysis carried out during the noncompliance period identified that increasing the frequency of a remedial task for this root cause "tightening and adjustment in linkage assembly" from 5 days to 2 days resulted in an increase in equipment OEE increase from 75.85% to 77.15%. This along with other improvement tasks was incorporated practically as well as in the company`s CLIT (cleaning, lubrication, inspection, and tightening) sheet, and SOP was created. These improvements will lead to a reduction of faults during future cases of PM noncompliance events. This paper certainly adds value for glove sector engineers to imply similar process improvement approaches in their companies to reduce chronic faults recurrences and maximize the operational efficiency under PM noncompliance situations.

Keywords: DMAIC, industrial glove, fault reduction, manufacturing process, preventive maintenance, maintenance noncompliance, overall equipment effectiveness.

1. INTRODUCTION

To ensure survival in today`s fiercely competitive global economy, higher operational efficiencies are targeted by the manufacturing firms [1] particularly by Pakistani glove companies, since market reports forecast Asia Pacific industrial gloves sector to reach US $1.25 billion by 2025 compared to US $0.66 billion in 2016 [2]. These industries have adopted effective maintenance to improve desired operational efficiencies [1], ensuring on-time distribution of quality products to the clients [3].

In accomplishing effective maintenance, poor compliance of maintenance activities has turned out to be a significantly faced challenge. Many industries consider it as a mere liability and demonstrate an unwillingness to spend in order to keep equipment in optimum condition [4], [5]. These activities often get neglected in tightly scheduled production plans, triggering higher downtimes and frequent occurrence of equipment faults.

This paper approaches this problem in a similar way as [6] by applying DMAIC (Define, Measure, Analyze, Improve, Control) approach to reduce the frequently occurring faults and higher unplanned downtimes due to preventive maintenance (PM) noncompliance in an industrial glove manufacturing company. This paper investigates the faults during the noncompliance region using DMIAC approach and analyzes the root causes of a major fault to reduce its impact.

The paper also carries out an experimental analysis to determine the optimum frequency for executing the necessary remedial tasks to overcome the root causes and maximizing OEE (Overall

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Equipment Effectiveness) under PM noncompliance situations. Section 2 below provides the literature review about the paper, DMAIC methodology/ analysis will be presented in section 3, while results and conclusion will be presented in section 4.

2. LITERATURE REVIEW

Section 2.1 below provides the literature about maintenance policies, section 2.2 discusses literature about MPIs, section 2.3 discusses literature about DMAIC, while section 2.4 discusses literature about the rubber glove manufacturing process.

2.1 Maintenance Policies

In general, maintenance is defined as taking all necessary actions required to maintain the functionality of equipment to a required working condition [7]. Among various classifications, maintenance is broadly categorized as corrective maintenance (CM) and precautionary maintenance. CM permits to take corrective actions when equipment is under failure mode whereas precautionary maintenance (can be preventive, predictive or proactive) prevents equipment from failing through inspections and detections [8]–[10]. Preventive maintenance, in particular, intends to prevent downtime and consists of scheduled tasks executed at fixed intervals of time, measured in different units (e.g. cycles, time) [11]. PM is essential for Pakistan glove companies to deliver on time distribution to customers since healthcare awareness, health threats and industrial usages in Pakistan have caused an uprise in glove usage. The market researches indicate that gloves usage is expected to increase in Asian markets, particularly in China, Pakistan, and India [12].

2.2 Maintenance Performance Indicators

To maximize benefits of above discussed maintenance policies, a balance of maintenance performance, risks, and costs must be accounted for [13], [14]. In order to assess these parameters, the performance indicators (PIs) are employed, assessing goals progress against set objectives [15]. In particular, MPIs measures the maintenance impact on process performances by comparing their real-time operational condition against benchmarked targets [16]. MPIs are classified into two groupings as shown in Fig. 1. Leading indicators; which indicates the maintenance efforts and lagging indicators; which indicates maintenance results and achieved output [17]. In this paper, the already implemented MPIs in the studied company will be used for measurement purposes.

2.3 DMAIC Approach

DMAIC refers to a quality strategy for improving processes that help companies to solve problems and improve processes [6]. It consists of five interconnected phases namely; Define, Measure, Analyze, Improve, and Control [18]. These are discussed briefly below:

- ✔ Define: The first stage of DMAIC process involves identification of a problem, understanding it and defining the required resources necessary to make the goal achievable [19] including goal of the project, team member selections, roles definition, customer necessities and expectations [6].
- ✔ Measure: This stage consists of collecting information about the process with the identified problem [19] and provides a structure to evaluate the current performance of that process as well [6].
- ✔ Analyze: This stage of DMAIC consists of using various tools for analyzing the root causes of the identified problem from the measured data [19] and understanding why these faults occurred [6].
- ✔ Improve: This stage comprises of taking essential remedial actions in order to minimize/ eliminate the identified problem [19] such as fault recurrence and high unplanned downtime in our case.
- ✔ Controlling: The last stage of DMAIC consists of sustaining the improvements and documenting them in necessary places [6].

2.4 Rubber Glove Manufacturing Process

Industrial rubber gloves are utilized in automotive, healthcare and food industries as a PPE ensuring safe operations by providing mechanical and

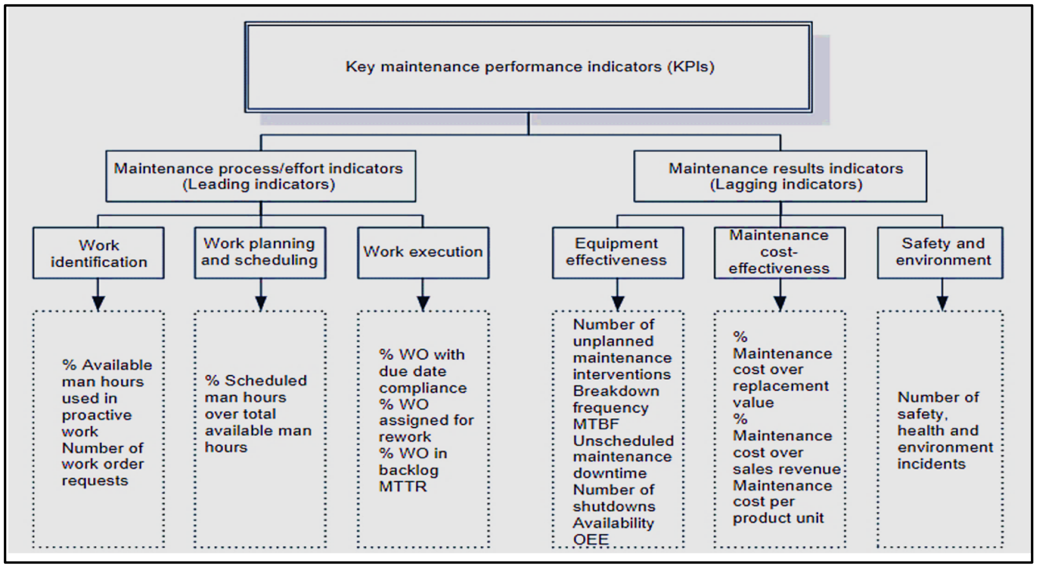

Fig. 1. Key performance indicator taken from [16]

chemical protection [20].

The manufacturing process of rubber gloves from [6], and predominantly the process in the studied company is summarized in the following 7 steps:

- Raw material testing; raw material testing cuts down superfluous expenditures as it prevents out-of-specification products manufacture [6], [21]. In the case of the studied company, various procedures are performed for testing under the organization`s test facility.
- Compounding; in this stage, several chemicals including latex are blended together. The compound is weighed and tested for health to ensure specific requirements are met.
- Dipping; In the case of the studied company, prior to dipping the liners are mounted onto the preheated moulds and then dipped through a series of pre-coagulant, compound latex and post-coagulant tanks. For a particular style of gloves, the final step is to dip the gloves in a foaming tank to enhance the gripping performance of the gloves.
- Leaching and vulcanizing; gloves are then moved through the leaching process by passing gloves into treated water at around 80-90C to get rid of the extractable materials, chemical remainder and non-rubber constituents. Whereas the vulcanisation process consists of combining rubber and sulfur, heated and cured resulting in the formation of tough and firm rubber along with improved properties [22]. In the case of the studied company, leached gloves are passed through a series of burners in a natural gas oven where they are cured, and vulcanization takes place.
- Stripping and tumbling; the cured gloves are dried in the same oven, and finally stripped off manually from the formers. No tumbling process is required.
- Quality control; the product is inspected by quality control for various measures.
- Packing; specifically sized gloves are weighed, packed and loaded in the boxes to be ready to be delivered to the customers.

3. METHODOLOGY

3.1 Defining the Problem

The first phase of the DMAIC approach is to identify the existing problem in the studied system. According to the studied company`s preventive maintenance plan, PM on the studied equipment was scheduled to be executed on the 13th of August 2018. Due to higher production demands in August 2018, planners ignored the PM schedule, rescheduled it twice, and finally planned it on 29th October 2018. This noncompliance resulted in numerous faults on the equipment and hampered its operational efficiency in terms of time, material, expenditure and customer dissatisfaction due to the inability of delivering products on time to the customer.

The objective through this approach was to reduce the frequent fault recurrence and related downtime due to noncompliance of PM activities. The study started with frequent meetings with the management committee, who gave their full support. A project team was created, consisting of a production manager, senior maintenance manager, improvement project leader, machine operator, and 3 senior maintenance technicians.

A project charter in a similar approach to [6] was deployed to present the project`s objective and possible outcomes as shown in Table 1.

3.2 Measuring the Problem

The fault recurrences and related downtime data were collected from the company database from July to October 2018. According to company records, six major faults were examined for the mentioned plant while other less frequently occurring faults were categorized as others.

Since the rescheduled PM took place on 29th October instead of 13th August, the faults during September and October counted for the PM noncompliance period while faults during July and August counted for the PM compliance period. The total faults and related unplanned downtime of July and August are presented in Table 2, whereas the same for September and October are presented in Table 3. In order to detect the critical faults during the noncompliance phase, the total fault recurrences and downtime presented in Table 2 and Table 3 were compared in bar charts, as shown in Fig. 2 and Fig. 3. Fig. 2 compares the fault recurrences under noncompliance region with fault recurrences under the compliance region, whereas Fig. 3 compares the fault wise unplanned downtime in a similar manner. The comparisons shown in Fig. 2 and Fig. 3 identified the most frequent recurring fault was “Former Linkage Assembly Issue”. This fault contributed to 33.3% of total faults (30 faults out of 90 total faults) and 34% of the total unplanned downtime (40.07 hours out of total 118 hours) during the noncompliance period.

3.2.1 Measurement of Operational Losses during Noncompliance Phase

To measure the operational losses of equipment under noncompliance region, the maintenance related data was taken from the company database from August to October 2018 as shown in Table 4. Operational losses were gauged by measuring already implemented MPIs at the studied equipment. The MPIs equations used for calculations are briefly discussed in section 3.2.1.1.

Table 1. Project charter format studied from [6]

Title of project	**Faults reduction in industrial gloves manufacturing equipment**
Reasons for selecting the project	A high number of faults recurred due to noncompliance of PM activities which caused lower OEE and the company was unable to deliver products on time to the customer.
Objective of the project	To reduce the recurring faults applying DMAIC approach in the industrial gloves manufacturing equipment.
Project members	Senior maintenance manager, production manager, improvement project leader, 3 senior maintenance technicians and machine operator.
Expected financial outcomes	A significant cost saving due to fault reduction
Boundary of the project	Focusing the gloves on “large” (L) and “extra-large” (XL) size
Expected customer out-comes	Receiving on-time product to the customer with expected quality

Table 2. Total faults recurrences and unplanned downtime for Jul. and Aug. 2018 (PM compliance period)

Type of fault	Total fault recurrences	Unplanned downtime of fault (hours)
Burner lockout issues	3	4.85
Burner temperature issues	8	4.20
chain related issues	10	5.67
Compound tank related issues	11	6.99
Foam tank related issues	9	5.2
Former assembly linkage issues	31	13.68
Others	10	4.90

Table 3. Total faults recurrences and unplanned downtime for Jul. and Aug. 2018 (PM compliance period)

Type of fault	Total fault recurrences	Unplanned downtime of fault (hours)
Burner lockout issues	6	12.62
Burner temperature issues	11	11.85
chain related issues	12	14.12
Compound tank related issues	12	15.56
Foam tank related issues	6	13.10
Former assembly linkage issues	46	50.07
Others	13	10.75

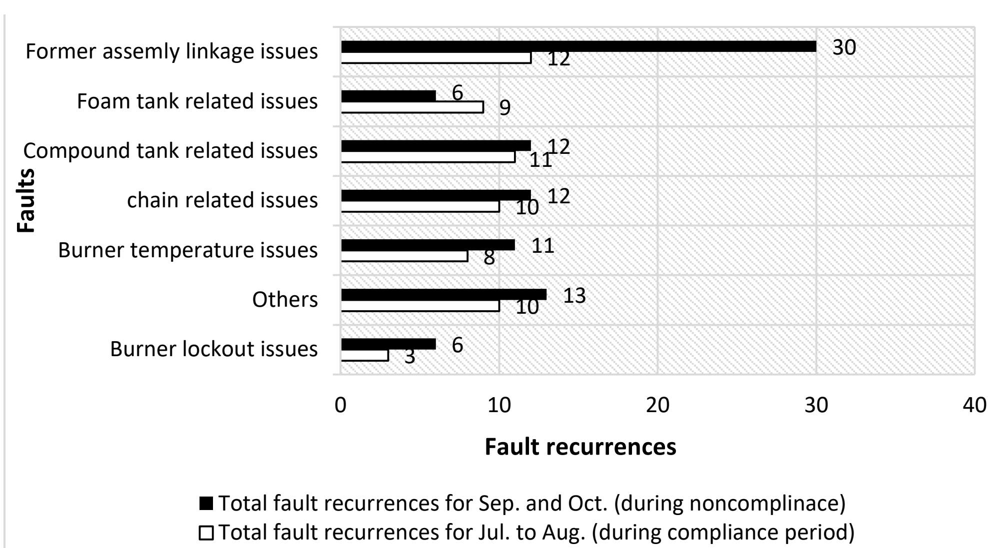

Fig. 2. Total fault recurrences comparison in Sep. and Oct. (during noncompliance period) vs Jul. and Aug. (during PM compliance)

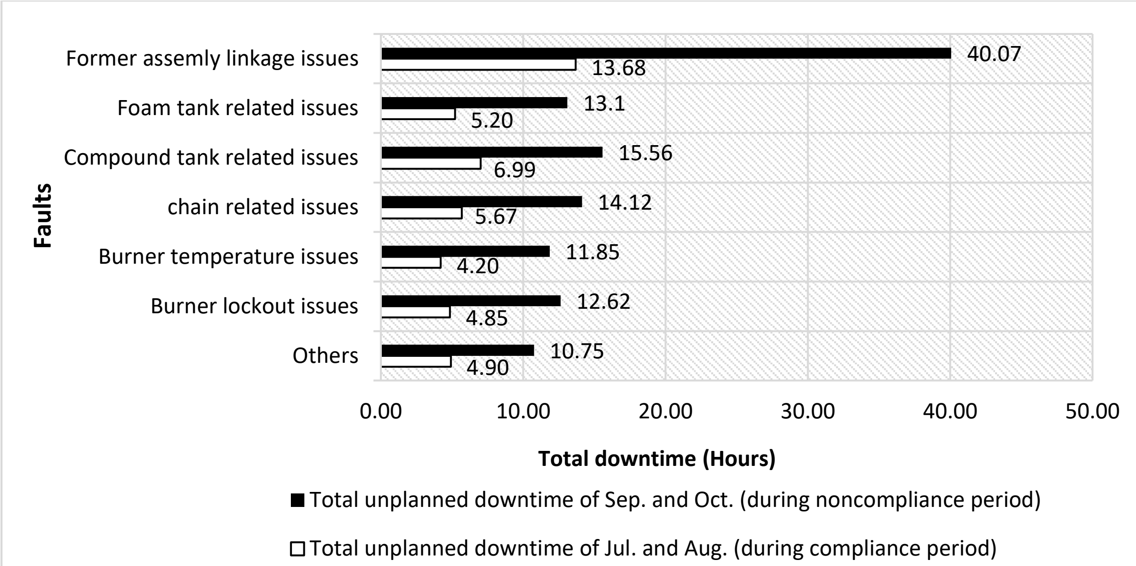

Fig. 3. Faults wise comparison of unplanned downtime for Sep. and Oct. (during noncompliance) vs Jul. and Aug. (during PM compliance)

Table 4. Maintenance-related data from August to October 2018 from the company database

	August 2018	**September 2018**	**October 2018**
Loading time (Hours)	1112	1033.27	1101.80
Total production (dp)	38072	36737	32391
Availability losses (Hours)	140.17	185.50	220.52
Preventive Maintenance (Hours)	0	0	96
Unplanned Downtime (Hours)	16.24	47.60	80.47
No. of unplanned work orders	20	41	54
Performance rate (%)	96.30	97.00	96.10
Rejection (dp)	710	471	429

3.2.1.1 Related MPIs equation used for measurements:

a. Mean Time Between Failures; average time between failures[23], calculated as shown in Eq.1.

$$\mathrm{MTBF} = \frac{\Sigma\,(\text{Machine uptime})}{\text{Number of Failures}} \tag{1}$$

Where,
Uptime; Time for which equipment is running at a required standard of performance.
Number of failures; Number of times machine fails to run at a required standard.

b. Mean Time To Repair; average time to repair after failure[23], calculated as shown in Eq.2.

$$\mathrm{MTTR} = \frac{\Sigma\,(\text{Machine downtime})}{\text{Number of Failures}} \tag{2}$$

Where,

Downtime= Time for which machine is not running at a required standard of performance.

c. Unplanned downtime; time for which machine is not capable of running due to unscheduled repairs (not on the approved maintenance schedule), calculated as shown in Eq.3.

$$\text{Unplanned downtime} = \Sigma(\text{Machine downtime not on schedule}) \quad (3)$$

d. Overall equipment effectiveness; determines the proportion of truly productive manufacturing time, and includes machine effectiveness and efficiency [24], calculated as shown in Eq.4.

$$\text{OEE} = \text{Availabilty x Performance x Quality} \quad (4)$$

Whereas according to [22] and [25],
Availability rate; machine time available to run as per schedule, calculated as shown in Eq.5.

$$\text{Availability rate} = \frac{\text{Operating time}}{\text{Planned production time}} \quad (5)$$

$$\text{Operating time} = \text{Planned Production Time} - \text{Downtime} \quad (6)$$

Performance; the measure of how good a machine runs while it is running.
Quality rate; the measure of parts within specification against produced, calculated as shown in Eq.7.

$$\text{Quality rate} = \frac{\text{Acceptable pieces}}{\text{Total pieces}} \quad (7)$$

$$\text{Total Pieces} = \text{Acceptable pieces} + \text{Rejection} \quad (8)$$

e. Number of unplanned work orders (W0); measures the number of unplanned work orders on a machine, calculated as shown in Eq.9.

$$\text{Number of unplanned WO} = \Sigma(\text{ Number of unplanned generated WOs}) \quad (9)$$

f. Failure rate; gives anticipated number of times an item will fail in a specified time period [26], calculated as shown in Eq.10.

$$\text{Failure rate } (\lambda) = \frac{\text{Number of failures}}{\text{Total time}} = \frac{1}{\text{MTBF}} \quad (10)$$

g. Availability: part of the time during which plant is capable of delivering at an acceptable level. [27].

3.2.2 Measurement of the Operational Losses due to PM Noncompliance

The calculated MPIs for the noncompliance region (September and October) and PM compliance region (August) are presented in Table 5. The MPIs equation 1-10 (discussed in section 3.2.1.1) were used for this calculation. As seen in Table 5, MPIs fall considerably during the "noncompliance region", such as OEE fell from 82.59% to 75.85%during noncompliance phase reflecting the criticality of PM noncompliance.

3.3 Analyzing the Problem

Previously the faults recurrence was compared in Fig. 2 which identified an utmost fault "Former Linkage Assembly Issue" causing the major impact due to PM noncompliance. In this phase, the root causes of this critical fault "Former Linkage Assembly Issue" were investigated. The analysis started with several brainstorming sessions with technical and improvement team members to find out why the former linkage assembly issue occurred more frequently during the noncompliance period. The root cause gathered from brainstorming sessions were put into a cause and effect diagram as shown in Fig. 4. After initial consideration 5 faults came into consideration namely; jamming of assembly due to inadequate lubrication; male/ female linkages deterioration/ worn; roller cam deterioration / worn; and changing of formers due to production changeovers and loosening and plays in former linkage assembly. After considering all the possible causes it was concluded by the committee members that the cause namely "loosening and plays in former linkage assembly" was mainly responsible for recurrence of this fault.

3.4 Improving Phase

In this phase, the main cause namely and "loosening and plays in former linkage assembly" was evaluated for possible remedies. Several brainstorming sessions were conducted in along with the machine operator and senior maintenance technician. The team members were given the task to freely discuss their ideas about how to minimize these root causes in the case of PM noncompliance. One observation from the production manager was to increase the inspection of tightening and adjusting frequencies of former linkages during the noncompliance period. Replying to this another observation was to also provide a quick former changeover procedure to reduce the change time for one or more poor assemblies. Observation further

Table 5. Calculations of MPIs for the month of August to October 2018 on the studied equipment

Performance indicators	Aug-18		Sep-18	Oct-18	
		Scheduled PM not executed on 13- Aug	Noncompliance region		Rescheduled PM executed on (29- Oct)
Mean Time Between Failure	67.47		20.71	12.69	
Mean Time to repair	0.81		1.16	1.49	
Failure rate (%)	1.46		4.61	7.30	
Operating time (Hours)	971.83		847.77	881.28	
Availability rate (%)	87.40		82.05	79.99	
Acceptable production (dp)	37362		36266	31962	
Quality rate (%)	98.14		98.72	98.68	
OEE (%)	82.59		78.57	75.85	

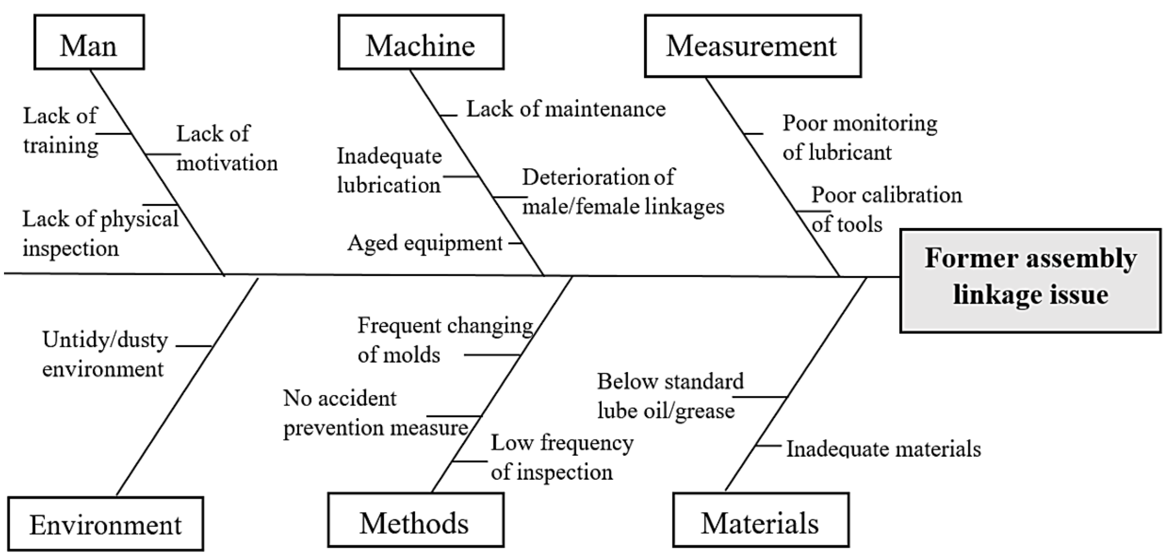

Fig. 4. Cause and effect diagram of the critical fault “Former assembly linkage issue”

stated to provide training to employees to carry out proper inspections and quick changeovers. Senior maintenance manager suggested adding accident proof profile to prevent a jammed assembly to come in contact with the equipment or provide a sensor to immediately stop chain in case of such contact. After considering all the likely causes it was decided by project members that a remedial task “tightening and adjustments of former linkage” is affecting the faults downtime considerably. It was decided that its frequency must be adjusted while otherprovisions like accident proof profile and sensors will also be incorporated at the equipment.

3.4.1 Experimental Analysis for Determining Frequency of the Remedial Task

The frequency of executing the remedial task "tightening and adjustments of former linkages" for the root cause "loosening and plays in former linkage assembly" was determined experimentally to study its effect upon the equipment OEE. As previously discussed in section 3.2.1.1, OEE consists of three major factors: performance rate, availability rate, and quality rate. Since the authors are specifically studying the variations in unplanned downtime due to this root cause, the remaining faults are assumed constant for all experimental measures. The quality rate and performance rate are also assumed constant since the variations in unplanned downtime will only affect the availability rate. The frequency for this task currently incorporated by the studied company is after every 5 days. To start the experiment, fault data of "Former linkage assembly issue" was taken from the current noncompliance situation for three consecutive sets of 5 days (each), yielding an OEE of 75.81% using equations 4-8 discussed in section 3.2.1.1.

In the next phase, the frequency of the task was reduced 5 days to 4 days and OEE was calculated in a similar manner. The frequency was reduced further up until an OEE of 77.16 % resulted at a frequency of 1 day as presented in Table 6 and Fig. 5. To maintain a balance of resources and performance, the project team after several brainstorming sessions settled for OEE of 77.15% at an inspection frequency of 2 days.

3.4.2 Implemented Improvements for Loosening and Plays in "Former Linkage Assembly"

In addition to identifying the optimum task frequency from the previous section, other provisions including accident proof profiles and sensors were also incorporated in the equipment. All related improvements are summarized below:

- Tightening and adjustments activity on former linkages increased from once per 5 days to once per 2 days resulting in OEE increase 75.81% to 77.15 %
- Instruction to planning engineers to limit the production changeovers during noncompliance period on that particular equipment and plan the changeovers elsewhere.
- Accident-proof profiles incorporated along with the main cam profile at several areas.
- Special workers trained for quick removal of jammed/broken assemblies to limit downtime

Table 6. Experimental analysis for frequency determination of remedial task

Root cause	Remedial Task	Frequency of the task	Set Number	Total fault downtime in 5 days	Mean fault downtime (Hours)	Availability rate (%)	Effect upon equipment OEE (%)
Loosening and plays in former linkage assembly	Tightening and needed adjustments informer linkage assemblies	5 days	1	3.71	3.89	79.35	75.81
			2	4.04			
			3	3.94			
		4 days	1	3.85	3.71	79.61	76.06
			2	3.91			
			3	3.37			
		3 days	1	2.92	3.05	80.19	76.62
			2	3.14			
			3	3.09			
		2 days	1	1.69	1.66	80.75	77.15
			2	1.40			
			3	1.89			
		1 day	1	1.30	1.33	80.76	77.16
			2	1.90			
			3	0.79			

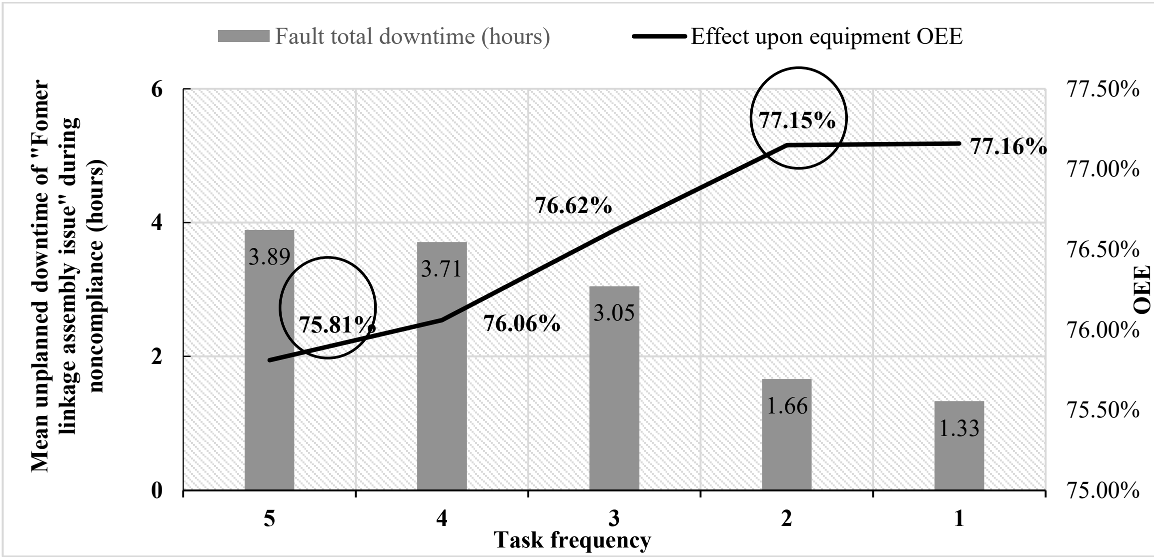

Fig. 5. Experimental analysis for frequency determination of remedial task

to a minimum.

- Sensors incorporated in the equipment to stop chain in case of contact immediately.

3.5 Controlling Phase

After the improvements have been implemented, the last objective under the DMAIC approach is the control phase to standardize the altered work methods/processes ensuring that the improved processes have remained in control. In the case of this project, the improvement activities are incorporated in the CLIT (clearance lubrication Inspection and tightening) sheet along. The altered inspection frequencies are documented as a standard operating procedure to be following under such situations of noncompliance.

4. RESULTS AND CONCLUSION

This paper presented a productive case of faults reduction on an industrial rubber glove manufacturing equipment by applying the DMAIC problem-solving approach. The conducted analysis diagnosed a frequently recurring fault "Former linkage assembly issue" which was contributing to 33.3% of total faults and 34% of total unplanned downtime during the noncompliance phase. The studied manufacturing company was hampered by the operational losses in the noncompliance phase as equipment performance metrics fall considerably, OEE fell from 82.59% to 75.85%. These losses were crucial and affecting the on-time distribution of products to the customer. Using the DMAIC approach, the main root cause of this fault namely "loosening and plays in former linkage assembly" was identified by the project team. The experimental analysis indicated that increasing frequency of a remedial task for this root cause "tightening and adjustments in linkage assembly" from 5 days to 2 days lead to in an increase in OEE increase from 75.81% to 77.15% during noncompliance period. This along with other brainstormed improvements was incorporated practically as well as in the CLIT sheets, and a SOP was formed to be followed under noncomplinace situations. These improvements will lead to a reduction of faults in this company which will of great benefit for both the customer's satisfaction and financial savings. This paper can be used as a guiding reference for glove sector engineers and managers to analyze their plant with respect to such situations and carry out specific improvement projects in their companies, similar to the one presented in this paper.

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