Evaluating the impact of TPM in a railway and mining component manufacturing company.

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Abstract

This paper evaluates the impact of Total Productive Maintenance (TPM) in a railway and mining component manufacturing company. Literature suggest that TPM is an approach innovative to maintenance and its major goals are no defects, no accidents and no breakdowns. Many authors have argued that TPM improves quality, equipment productivity, prevents unexpected breakdowns and reduces defects. Reliable manufacturing equipment is considered as a major contributor to the profitability and performance of manufacturing systems in today's extremely evolving environment. Most organizations function effectively today because the equipment is reliable and available thereby maximising production throughput and profit.
A case study was conducted and it involved a mixed method approach where both quantitative and qualitative data was gathered and analysed. The company implemented TPM through the following initiatives; autonomous maintenance, employee improvement, planned maintenance, quality maintenance, education and training and safety and health. TPM was implemented for eighteen months. This study made use of the following maintenance improvement tools, TPM, Failure Mode Effects and Critically Analysis (FMECA) and cause and effect diagram. Maintenance performance factor such as Overall Equipment Effectiveness (OEE) was analysed before and after TPM implementation.
The results of this study showed that TPM implementation contributes to equipment reliability. There was an improvement in overall organizational performance. Through FMECA, maintenance tasks were prioritized and risk priority numbers (RPN) were calculated for particular equipment. Key performance indicators such as productivity and OEE were on an upward trend while there was a reduction in defect rates. Communication among workers, workers and management, and among different departments was improved. Worker motivation was improved through autonomous maintenance. However maintenance performance in some departments was found to be too low due to unavailability of data and worker inconsistency. This paper contributes to the theory and practice of TPM implementation. Hypotheses tests could not be done due to very low levels of respondents.

Key words: TPM, equipment reliability, manufacturing, productivity and worker involvement.

1. Introduction

In today's dynamic and evolving environment, there has been a dramatic increase in competition among diverse manufacturing industries, (Jain, et al., 2014). The intense competition and motivation for profits has forced manufacturing organisations to implement several productivity improvements methods and techniques, in order to meet obstacles presented by the constantly increasing market demands, (Samuel, et al., 2002). Top management has been forced to check the operation and performance of every business task, including production or maintenance to achieve a competitive advantage, (Pintelon, et al., 2006). The effective combination of maintenance function has been regarded by manufacturing organisations as a potential concept of competitive advantage and saving of costs, (Ahuja and Khamba, 2007). Kulkarni and Dabade (2012), suggested that maintenance related costs in manufacturing account for 25 percent of the overall operating costs.

It has been observed that inadequacy of maintenance practices in the past, has drastically influenced organisational competitiveness by minimising throughput and reliability of manufacturing facilities, (Ahuja and Khamba, 2007). This has led to a decline in manufacturing facilities, lowering of availability of equipment due to extreme system down time, declining of production quality and unreliable delivery performance. Kaur, et al., (2013), concluded that quality and maintenance functions are essentials factors for attaining sustainability in manufacturing organisations. As such, manufacturing organisations should implement effective and efficient maintenance approaches. "Implementation of TPM in any organisation improves overall equipment effectiveness, by increasing equipment availability, reducing rework and rejections and improving the overall productivity of an organisation" (Wakira and Singh, 2012). However, it has been argued that TPM can improve recent techniques such as six sigma procedures, (Hanged and Kumar, 2013b). According to Eti, et al., (2006), TPM has showed to be the maintenance philosophy that hinders failure of an organisation.

2. Research objectives

The research objectives of this paper are:

- To evaluate the impact of Total Productive Maintenance (TPM) in a railway and mining component manufacturing company.
- To highlight contributions of the maintenance function.

3. Literature review

3.1 TPM

Ben-Daya, et al., (2009), suggests that "TPM consists of three words, which are:
Total: signifies to consider each aspect and involves everyone from top to bottom;
Productive*:* emphasis on attempting to do it while production is running and minimize problems for production; and
Maintenance*:* means keeping equipment in good condition autonomously by production operators".

Fredriksson and Larson (2012), defined TPM "as an approach to maximise equipment effectiveness by means of principles of teamwork, empowerment, zero defects, zero breakdowns and zero accidents". Prabhuswamy, et al., (2013), describes "TPM as a system of retaining and improving the integrity of production and quality systems through machineries, equipment, procedures and workforces that add business value to the organisation". Rhyne (1990), a TPM contributor, defined TPM as "a partnership between maintenance and production functions in the organisation to enhance product quality, reduce manufacturing cost, reduce waste, increase equipment availability and improve the organisations state of maintenance".

Japan Institute of Plant Maintenance (JIPM) suggested that "TPM initiative involve an eight-pillar implementation strategy that results in significant increase in labour productivity through controlled maintenance, reduction in maintenance costs and reduced production stoppages and downtimes". Figure 1 shows eight-pillar approach for TPM.

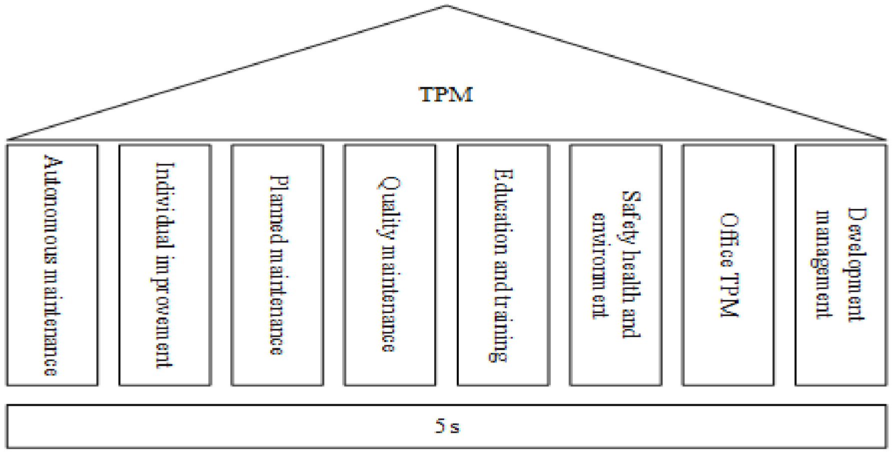

Figure 1. Eight-pillar approach for TPM implementation, (Ben-Daya, et al., 2009)

"TPM utilizes problem solving techniques such as brainstorming, cause and effect diagrams, 5M approach, Pareto analysis, bottleneck analysis, 5S, set up time reduction, waste minimisation, Poka-yoke systems, statistical process control, team based problem solving, recognition and reward program and simulation as tools to analyse and solve problems", (Jain, et al., 2014). Table 1 shows detailed maintenance and organisational improvement strategies associated with the respective TPM pillars.

Table 1. Issues addressed by various TPM pillars (Ahuja and Khamba, 2007)

TPM Pillar	Description
"Autonomous maintenance	• Fostering operator ownership. • Performing cleaning, lubricating, tightening, adjustment, inspection, readjustment on production equipment.
Focused improvement	• Systematic identification and elimination of losses. • Working out loss structure and loss mitigation through structure why-why, FMEA analysis. • Achieve improved system efficiency. • Improved OEE on production systems.
Planned maintenance	• Planning efficient and effective PM, PdM and TBM systems over equipment life cycle. • Establishing PM check sheets. • Improving MTBF, MTTR.
Quality maintenance	• Achieve zero defects. • Tracking and addressing equipment problems and root causes. • Setting 3M (machine/man material) condition.
Education and training	• Imparting technological, quality control, interpersonal skills. • Multi -skilling of employees. • Aligning employees to organizational goals. • Periodic skill evaluation and updating.
Safety, health and environment	• Ensure safe working environment. • Appropriate work environment • Eliminate incidents of injuries and accidents. • Provide standard operating procedures.
Office TPM	• Improve synergy between various business functions. • Remove procedural hassles. • Focus on addressing cost-related issues. • Apply 5S in office and working areas.
Development management	• Minimal problems and running in time on new equipment. • Utilise learning from existing systems to new systems. • Maintenance improvement initiatives".

3.2 Failure Mode Effects and Critically Analysis (FMECA)

FMECA can be utilised to categorise potential product or process failures, the expected modes of failures, failures and causes using the risk priority numbers (RPN), (Blanchard, 2014). "It is defined as an engineering technique that is used to define, identify and eliminate known or potential failures, problems and errors from the system design, process or service before they reach the customer", (Stamatis, 2003). RPN is expressed as the following:
RPN = (severity rating)(frequency rating)(probability of detection rating)
RPN assists in identifying critical areas for further improvement. The study conducted by Kumar and Chaturvedi (2011), utilised FMECA in an integrated steel plant and concluded that FMECA helps in identifying all possible failure causes with specific reference to the component of systems and subsystems. Dyadem (2014), lists benefits of FMECA as follows:

- Identifies crucial attributes of the product or process.
- Improves customer satisfaction.
- Improves business competitive advantage and concept.
- Improves overall productivity, safety, cost efficiency and product quality.
- Assistance in identifying errors and coming up with suitable solutions.

3.3 Overall Equipment Effectiveness (OEE)

Blanchard (2014), stated that "the measure of TPM can be expressed in terms of OEE, which is a function of availability (A), performance rate (P), quality rate (Q)".

OEE = (availability) (performance rate) (quality rate)

Where:

$$\text{Availability} = \frac{loading\ time - downtime}{loading\ time}$$

$$\text{Performance rate} = \frac{(output)(actual\ cycle\ time)}{loading\ time - downtime} \times \frac{ideal\ cycle\ time}{actual\ cycle\ time}$$

$$\text{Quality rate} = \frac{input - (quality\ defects + start\ up\ defects + rework)}{input},,$$

According to Ahuja and Khamba (2007), OEE measures the performance of a productive system. "The role of OEE goes beyond the task of just monitoring and controlling the manufacturing system performance" (Ahuja and Khamba 2007). OEE has become widely accepted as a quantitative tool essential for measurement of productivity operations (Samuel, et al., 2002).

4. Methodology

The research methodology of this study includes relevant literature review and a case study in a railway and mining component manufacturing company. "A case study is an empirical enquiry that explores a contemporary phenomenon within its real life environment" (Yin, 2009). The case study fulfills the goal of evaluating the impact of TPM in a railway and mining component manufacturing company. The case study included gathering and analysis of quantitative and qualitative data. The company's manufacturing operations were assessed using FMECA analysis, (Blanchard, 2014). The procedure includes:

- "Identifying the different failure modes.
- Determining the causes of failure: that is the causes responsible for the occurrence of each failure.
- Determining the effects of failure.
- Determining the severity of a failure mode.
- Determining the frequency of occurrence.
- Determining the probability that a failure will be detected.
- Analysing failure mode criticality. RPN is calculated.
- Identifying critical areas and recommending modifications for improvement".

A cause and effect diagram was utilised to assistance in establishing the relationships between failures and their possible causes. "A cause and effect diagram is a tool that facilitates in identifying, sorting and displaying possible causes of a specific problem or quality characteristic" (Dyadem, 2014).

A Pareto analysis is a quality control tool that was utilised to select a few number of tasks that produce most of the problems that contributes to machine breakdowns.

5. Results

5.1 Cause and effect

Brainstorming technique was utilized to identify possible causes that resulted in failure of equipment reliability. Four categories of causes were identified namely material, equipment, methods and manpower. These major causes were then used to develop the cause and effect diagram. The research identified that, firstly, batches of poor quality of input material produced defective products. Secondly, lack of training and operators' errors can have an effect on equipment reliability. Thirdly, machine problems, which included improper setting, poor lubrication and maintenance has an effect on the operation. Lastly, incorrect methods leads to the production of defective products. Figure 2 shows the cause and effect diagram. The results of the cause-and-effect diagram presented to the company areas that needed attention. For example it was deemed necessary to train employees on the need to change worn out tools, improve setting up the job and loading the correct machine program.

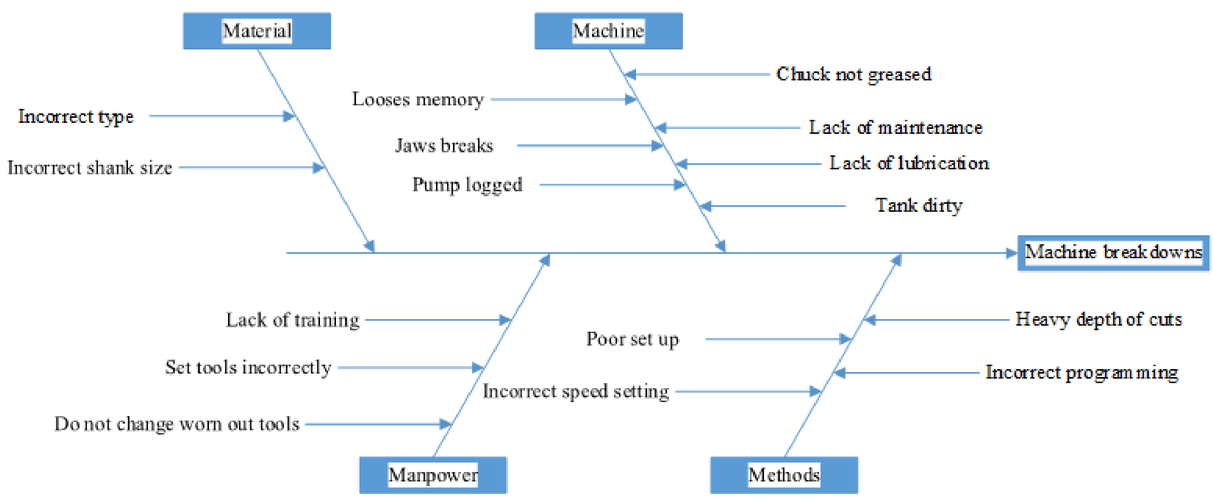

Figure 2. Cause and effect diagram on typical machine breakdowns

5.2 FMECA analysis

The cause and effect diagram was utilised to help identify potential causes of failure modes used in the FMECA table. Ten failure modes were identified out of which seven major problems were prioritised based on the risk priority number. A scale of 1-10 was applied to the failure modes to determine the (1) severity; the seriousness of the effect (S), (2) frequency of occurrence (F) and (3) probability that a failure will be detected (P). Table 2 shows the scale used for the failure modes.

Table 2. Scale for failure modes

Rating	Description
Severity	
1	"Minor effects
2-3	Low effects
4-6	Moderate effects
7-8	High effects
7-10	Very high effects"
Frequency	
1	Remote
2-3	Low
4-6	Moderate
7-8	High
9-10	Very high

Probability	
1	"Minor effects
2-3	Low effects
4-6	Moderate effects
7-8	High effects
9-10	Very high effects"

Table 3: Calculated values of RPN

Machine	Failure	Cause	Effect	S	F	P	RPN Initial	S	F	P	RPN after corrective action
Turret lathe	Turret not turning	Lack of lubrication	Electric motor trips	6	5	5	150	3	4	3	36
	Machine crush	Wrong program	Defects	10	3	7	210	8	4	3	96
		Incorrect tool setting	Defects	8	6	7	336	8	3	3	72
	Machine loosing memory	Leaks into panel	Defects	9	7	6	378	5	5	4	100
	Chuck not clamping	Not greased	Jaws break	8	2	10	160	6	2	5	60
	Machine coolant alarm	Dirty tank	Pump pulls shaving	8	8	7	448	6	5	5	150
	Broken U-Drill	Wrong set up	Defects	7	4	6	168	3	5	3	45

Table 3 shows a summary of the RPN of the seven failure modes. Both RPN values before and after TPM implementation were calculated. Incorrect tool setting and wrong program identified the failure mode that has the highest RPN value as machine crush, which had a total RPN value of 546. Furthermore, wrong programming which has an RPN of 210 also contributed to the failure mode of machine crush. However, corrective actions taken such as training of workers resulted in the reduction of prioritised failure modes.

5.3 Pareto analysis

Pareto analysis was used for the selection of limited number of failures that produce significant overall effect.

Table 4. Pareto analysis data

Failure	Frequency	Cumulative frequency	% Cumulative frequency
Machine crush	546	546	30
Coolant alarm	448	994	54
Machine loosing memory	378	1372	74
U-Drill broken	168	1540	83
Chuck not clamping	160	1700	92
Turret not turning	150	1850	100
Total	1850		

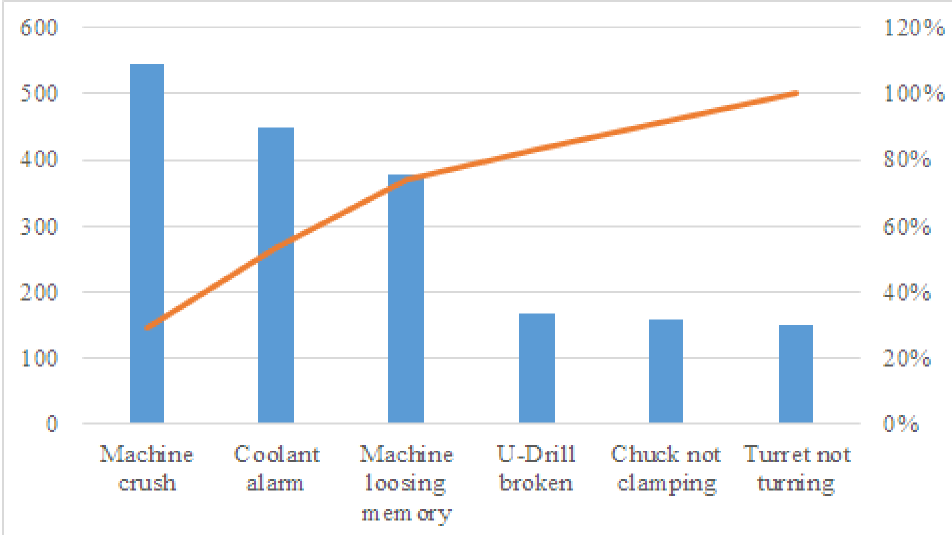

Figure 3. Pareto analysis curve for failures

The initial RPN values were considered in constructing the Pareto graph. The Pareto chart shows that the most significant problems the company need to focus on is the machine crush, coolant alarm, machine losing memory and U-Drill breaking. These four problems constitute 83% of the problems.

5.4 Delivery Reliability

Delivery performance measurement was utilised to analyse reliability of the company. Delivery performance measurement is another metric for business performance (Muyengwa and Marowa, 2015). Typical measures for delivery reliability used are percentages of customers orders met in full, percentages of order lines met in full, percentages of order value met and pecentages of line item quantities met (Ghobadian and Gallear, 1997). Figure 4 presents quaterly delivery reliabilty for 2016 and 2017. Delivery reliability data was validated by sales and production personnel.

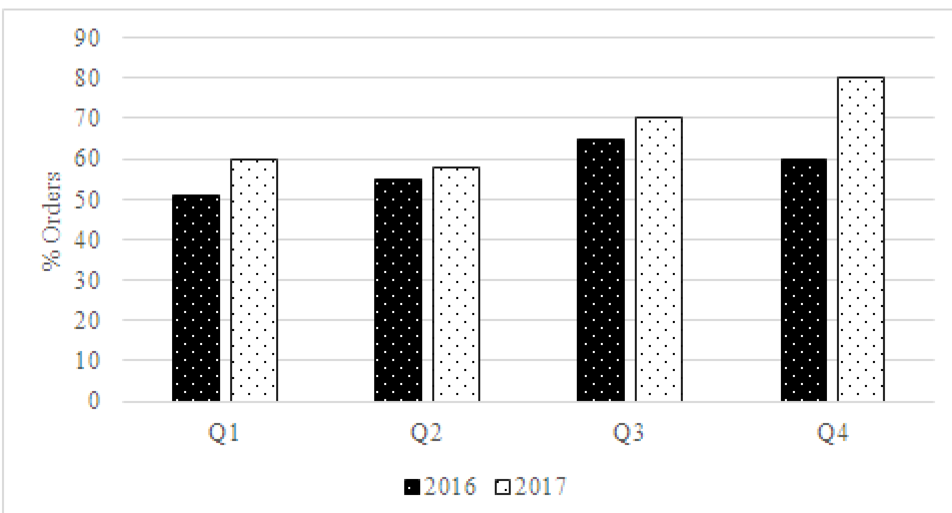

Figure 4. Delivery Reliability

It can be seen from Figure 4 that, the company's reliability was high for all quaters in 2017 after the implementation of TPM as compared to 2016. Noticeable increase in reliability in quarter 4 can be attributed to the maturing TPM.

5.5 OEE results

OEE of the machine was calculated using the company's last nine-month data. It can be seen that, OEE vary throughout and ranges from 49.86% to 79.24%. Table 5 shows the calculated values of OEE for the equipment after implementation of TPM. Data used to calculate OEE was confirmed by the continuous improvement team and the production personnel.
OEE = (availability) (performance rate) (quality rate)

Table 5. OEE results after implementation of TPM.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Availability	0.76	0.68	0.84	0.79	0.85	0.80	0.86	0.79	0.81
Performance rate	0.77	0.78	0.80	0.94	0.98	0.98	0.97	0.98	0.96
Quality rate	0.90	0.94	0.94	0.96	0.92	0.93	0.95	0.93	0.94
OEE (%)	52.67	49.86	63.17	71.28	76.64	72.91	79.24	72	73.09

Table 5 shows that there is a general increase in machine availability and performance rate. However the causal effect of TPM on these two key performance indicators could not be tested through some hypotheses due to few respondents.

6. Discussion

A team of Industrial Engineers that was in charge of continuous improvement developed and improved standard operating procedures (SOPs). 5S was used to sort components and poka-yoka principles were used in assembling. Workers were taught basic maintenance of their machines and how to correctly fill in preventive maintenance check sheets. The use of basic tools for quality improvement such as check sheets, pareto and control charts were introduced. The company took their employees for training in TPM. This was found to have enhanced their competitiveness. Multi skilling was introduced in the company. Basic electrical maintenance was being done. Production meetings were held on a weekly basis were workers could suggest possible solutions. At one station management agreed to the redesign of jigs that were used. Tangible and intangible factors that were noticed in the company were reduced errors, improved quality and improved employee morale. The researchers noticed that top management was strong and supportive in the implementation of TPM, and this kept all the employees motivated to achieve better results.
However, the research could not express, in terms of monetary value, the return on investment made by these training efforts. The research did not focus on quality of training offered and quality of methods and techniques applied. Barriers to job-related training that were identified in this research were; employees were very busy at work, courses offered were costly and offered at an inconvenient time and place, and lack of employer support on courses offered outside the company. Employees wanted to attend such courses because it had benefits of certification. Hypotheses test could not be calculated due to very low levels of respondents received by the researchers.

7. Conclusion

TPM has begun to be a management criterion in all kinds of organisations. TPM concepts can be effectively practiced to enhance manufacturing performance in the organisation. An effective TPM program can address the organisations maintenance related obstacles with the perspective to optimise equipment performance. The study reveals that TPM concepts can assist manufacturing organisations in the search for achieving enhanced manufacturing performance. Therefore, it is important for organisations to integrate maintenance related performance aspects into the overall organisation performance systematic approach. Quality tools such as the cause and effect diagram are appropriate for designing and producing reliable systems. This paper could not test hypotheses due to very low levels of respondents and the researchers have agreed to make this testing part of their future work. This paper did not calculate the demand rate of the major products manufactured by this company. Maintenance efficiency and costs were also not calculated and will be treated as part of future work.

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