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Increasing the Capacity of Plant Bottlenecks by Using of Improving the Ratio of Mean Time between Failures to Mean Time to Repair

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***Abstract*—**A significant percentage of production costs is the maintenance costs, and analysis of maintenance costs could to achieve greater productivity and competitiveness. With this is mind, the maintenance of machines and installations is considered as an essential part of organizational functions and applying effective strategies causes significant added value in manufacturing activities. Organizations are trying to achieve performance levels on a global scale with emphasis on creating competitive advantage by different methods consist of RCM (Reliability-Center-Maintenance), TPM (Total Productivity Maintenance) etc. In this study, increasing the capacity of Concentration Plant of Golgohar Iron Ore Mining & Industrial Company (GEG) was examined by using of reliability and maintainability analyses. The results of this research showed that instead of increasing the number of machines (in order to solve the bottleneck problems), the improving of reliability and maintainability would solve bottleneck problems in the best way. It should be mention that in the abovementioned study, the data set of Concentration Plant of GEG as a case study, was applied and analyzed.

***Keywords*—**Bottleneck, Golgohar Iron Ore Mining and Industrial Company, maintainability, maintenance costs, reliability.

I. Introduction

In traditional management, maintenance has been considered as support tools and non-productive with little advantages for organizations. In the new approach, maintenance is considered as an essential part of organizational functions and applying effective maintenance strategies, causes significant added value in productive activities. Because of this, maintenance (as a main principle) is used as a distinctive competence in manufacturing companies. Increasing the reliability and maintainability factors in many production systems by using of optimization methods and management of operations resulted in costs reduction and productivity improvement [6], [9].

There is vast literature on reliability and maintainability factors with a high number of books and articles. References [3], [11], [24] described concurrent engineering in detail and presented applicable examples in different kind of industries. Reference [7] studied the models and evaluated reliability as a function of time and usage. Reference [4] reported on 26 cases on reliability and maintainability and statistical techniques illustrated included modeling. In the mentioned study, the comprehensive examination consists of experiment and its simulation, failure investigation and FMEA analysis, application of preventive maintenance and other effective tools were applied. Reference [21] reported that the impact of delays, due to machine breakdowns, is not limited exclusively to the production rate but affects the scheduling and productivity of the entire manufacturing operations as well. Reference [17] identified a link between quality improvement and productivity. The relationship between machine reliability and system productivity was also investigated by Reference [15] who determined the productivity throughput based on different states of the same system. Reference [2] highlighted the relationship between maintenance and quality, stressed its importance, and proposed a broad framework for modeling the maintenance–quality relationship.

Investigating of literature showed that there is a scarcity of field failure data of production circuits. Reference [10] showed four weeks' actual production data from two automotive body-welding lines. His aim was to reveal the nature of randomness in realistic problems and to assess the validity of exponential and independent assumptions for service times, inter-arrival times, cycles between failures, and times to repair. Reference [25] described the failure analysis of computerized numerical control (CNC) lathes; the field failure data was collected over a period of two years on approximately 80 CNC lathes. Reference [16] published a statistical analysis of failure data for an automated pizza production line. The analysis included identification of failures, computation of statistics of the failure data, and parameters of the theoretical distributions that best fit the data, and investigation of the existence of autocorrelations and cross correlations in the failure data. References [22], [23] developed the reliability and maintainability analysis of strudel and feta cheese production line at machine, workstation and entire line level; statistical approach was used to study the failure and repair data and finally the best fitness index parameters were concluded, and the reliability and hazard rate modes for all workstations and both production lines (strudel and feta cheese) were calculated.

Reference [20] conducted reliability and maintainability

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analysis for juice bottling industry by applying statistical techniques on field failure data. In this paper, the subject that instead of increasing the number of machines (in order to solve the bottleneck problem), solve bottleneck problems by improving reliability and maintainability factors was investigated by using the industrial data set. On the other hand, in this study, we have tried to fix the bottleneck problem of production lines with calculating ratio of mean time between failures (MTBF) to mean time to repair (MTTR) in the beginning and if that was acceptable, the bottleneck problem will be solved with another methodology. Otherwise, the first action for overcoming of the bottleneck problem is improving the reliability and maintainability factors. It was shown that the mentioned approach could assist organizations in decreasing the costs.

II. Process of Iron Concentration Plant and Problem Description

GEG is one of the biggest companies in Iran. GEG has 6 factories now and one of these factories is Concentration Plant. In this factory iron ore with 50 percent grades (as Fe percent) is converted to iron concentrate with more than 67 percent grades. The iron concentrate production line consists of five workstations (Fig. 1). In this circuit, at first iron ore with maximum size of 150 centimeters is converted to iron ore with dimensions of 20 centimeters in gyratory crushing area. Then iron ore entered the sag-mills and is converted to iron ore with dimensions of 600 microns. The next step is dry magnetic separators area. This area has eight set separators and every set consists of three separators as rougher, cleaner and scavenger that their layout is shown in Fig. 2.

In the first separator magnetic materials are separated by magnet and the remaining materials are tale. Both of magnetic materials and tale materials go to the next separator. If magnetic materials on this stage are separated by magnet angle of drum separator again, these materials are known as dry concentrate. If tale materials at this step aren't separated by magnet again, these materials are known as tale material. The materials that in the first step were separated as magnetic materials and in the next step were separated as tale materials or vice versa are known as middle materials. Therefore, the outputs of this stage (dry separation) are divided into three parts: dry concentrate, middle materials and dry tale. Dry concentrate is known as one type of final product. Tale materials go to another factory and middle materials go to the next area of the plant (wet separation).

In wet separation area, the middle materials are milled again in ball mills. These materials after grinding go to wet magnetic separators (LIMS) step. In this step, there is one separator with arrangement of rougher, cleaner and recleaner drums. Therefore, the output of this step is divided into two parts: wet concentrate and wet tale. After dewatering of wet concentrate (in disk filters), the wet concentrate will mix with dry concentrate (derived from pervious section) and product will be ready for sale. According to the stations capacities, section of bottleneck is related to the dry magnetic separator area. For the mentioned problem, the first solution is purchasing new separator sets. In this paper, it has been shown that instead of increasing the number of separators sets in order to solve the bottleneck problem, the bottleneck problem can be solved by improving reliability and maintainability factors.

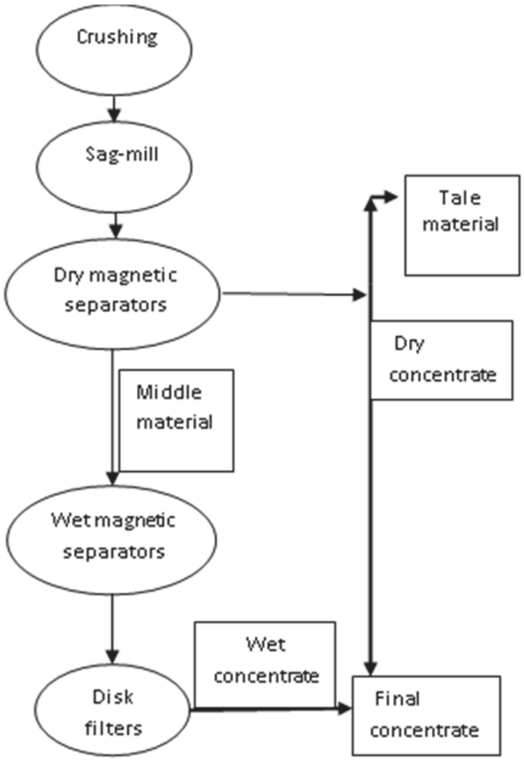

Fig. 1 Schematic presentation of iron Concentration Plant

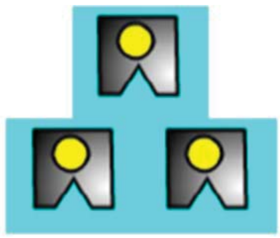

Fig. 2 Arrangement of each set separator

III. Calculate MTBF and MTTR for Bottleneck

There are eight separator sets in plant and each set of separators consists of three separators and if a separator stops working, then set will stop. Therefore, life cycle every set equals with minimum life cycle 3 separators. Based on the pervious data, life cycle of each separator follows exponential function with μ=24 hours = $\frac{1}{\lambda}$ and the life cycle of each set separators obtained as follows [8], [12], [14]:

Definition: Exponential distribution with parameter λ:

$$f(t) = \lambda e^{-\lambda t} \quad t \geq 0$$

Exponential cumulative distribution function:

$$F(t) = 1 - e^{-\lambda t} \quad t \geq 0$$

Reliability distribution function:

$$R(t) = \exp(-\lambda t) \quad t \geq 0$$

$F(t)=p(T\leq t)=p(\min(x_1,x_2,x_3)\leq t)=1-p(\min(x_1,x_2,x_3)> t)=1-P(x_1>t).$ $P(x_2>t).$ $P(x_3>t)=1-R(t_1).R(t_2).R(t_3) =1-\text{Exp}(-\lambda_1 t).\text{Exp}(-\lambda_2 t).\text{Exp}(-\lambda_3 t) =1-\exp(-t(\lambda_1+\lambda_2+\lambda_3))$

$$f(t)=\frac{dF(t)}{dt} \rightarrow f(t)=(\lambda_1+\lambda_2+\lambda_3)\exp(-t(\lambda_1+\lambda_2+\lambda_3))$$

Therefore, density function of set is an exponential function with $\mu = \mu_1 + \mu_2 + \mu_3$:

$$\lambda 1 = \frac{1}{24} \quad \lambda 2 = \frac{1}{24} \quad \lambda 3 = \frac{1}{24}$$

$$\lambda_1 + \lambda_2 + \lambda_3 = \frac{3}{24}$$

$$\text{MTBF} = T_a = \frac{1}{\lambda} = 8 T_a = \text{MTBF} = \frac{1}{\lambda} = \frac{24}{3} = 8$$

Based on the pervious data, MTTR obtained as follows:

$$t_e = \text{MTTR} = \frac{\text{total maintenance time}}{\text{number of repairs}} = 117\text{min or about 2 hours}$$

IV. Calculating the Number of Available Machines

According to the Fig. 3, the number of available machines can be calculated based on the ratio of T_a to t_e and the total number of machines (k). These values calculated and equal to $T_a=8$ and $t_e=2$ hours in section 3 for each set separators and k equal to 8. Therefore, $\frac{Ta}{te}$ = 4 and number of available machines equal to 5. At first the managers wanted to have bought 3 sets separator (k=11) and solve the bottleneck problem but this isn't an acceptable solution and would increase cost, because if you buy even 8 sets (k=16) instead of three sets the number of available machines equal to 5 and other machines will go to repair or queue of repair (Fig. 3).

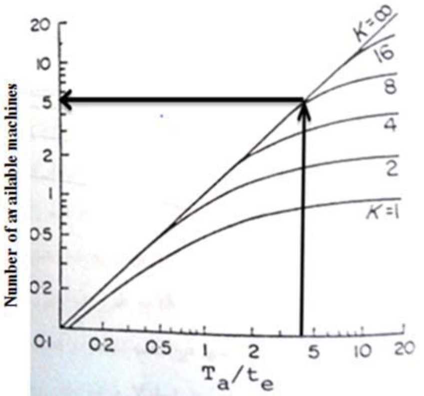

Fig. 3 Number of available machines base on rate T_a to t_e [18]

V. Failures Analysis and Improve Reliability and Maintainability

To increase the rate of Ta to t_e should be increased T_a and should be reduced t_e. T_a is the mean time between failures of a system during operation. A good example of the significance of T_a can be found in the mining industry, where proper lubrication of field service equipment in rugged industrial environments can increase the T_a of heavy haul trucks, crushers, separators, and sag mills. This is critical in remote areas, where maintenance and repair contractors may not be able to access the equipment easily or regularly. Continuously operating field equipment, such as sawmills, fuel trucks, and lubrication trucks, all require a high degree of serviceability. By measuring the T_a of each piece of equipment, operators have a very good idea of the expected lifetime of that machine. Being able to understand when a tool may fail helps when creating a maintenance schedule and thereby helping avoid unplanned downtime [19], [5], [1].

t_e is the average time it takes for a tool or process to recover from any failure. Downtime reduction often requires looking at a system holistically, not one or two parts of the whole. Consider the semiconductor industry. The t_e of a microelectronics assembly process should include all the integral parts of that process, such as wafer handling equipment, gas, and chemical distribution systems. Calculating the t_e of a single component in a process tool in isolation would not provide a useful metric. Once t_e is measured accurately, it can be improved. Technology plays a critical role in reducing downtime. In semiconductor plants, for example, cutting-edge, self-diagnostic flow meters can constantly monitor potentially harmful gases and chemicals, without requiring a person to be present in a dangerous working environment, and trend the data to identify when systems are heading into a repair or failure mode so time can be scheduled in advance of a system failure and the repair can be made in optimal conditions vs. an unscheduled down time event [13], [5], [1].

According to Pareto chart, the most important problem of separators (more than 70 percent) was gearbox and chain breakage.

A technical team was formed to solve the problems. The roots of failure were poor quality parts and dust. Team proposed two solutions: Changing of suppliers at first and removing the sources of pollution. By using of these solutions T_a increased from 8 to 12 hours. In addition to, the following actions were taken to reduce MTTR and improve maintainability:

- Changes in connections from screw to pins, usb wires and other connections
- Increasing the space around the separator for repairing
- Increasing the safety stock for commonly used parts
- Training of technicians and operators

With these solutions t_e decreased from 2 to 1.5 hours. Now, with these parameters: K=8, T_a=12, t_e=1.5.

The number of available set separators equal to 7 (Fig. 4).

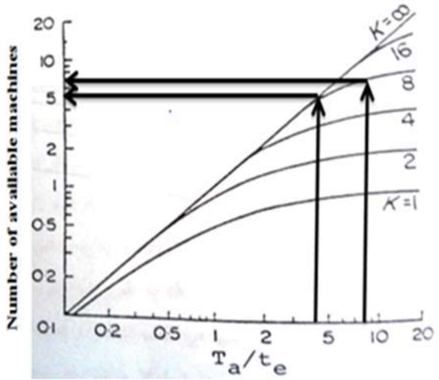

Fig. 4 Number of available machines base on rate T_a to t_e [18]

VI. Conclusions

- It was pointed out that the number of available set separators increased from 5 to 7 due to the improve rate of T_a to t_e from 4 to 8 (Figs. 3 and 4).
- This paper shows that the importance of reliability and maintainability factors as one of the best ways to reduce costs, increase production and improve productivity.
- Improvement of maintenance conditions of dry magnetic separators reduced energy consumption.
- Given the current competitive market there isn't the possibility of increasing profit by increasing prices and the only way to increase profit is reduce costs and analysis of maintenance costs resulted in lower costs.

There is a future research scope for using lognormal distribution, Weibull distribution or other distribution functions in machine reliability analysis or investigating of improve rate of T_a to t_e with other layouts equipment.

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