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Reliability evaluation and Risk based maintenance in a process plant

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Abstract

An effective operation of process plant depends on the maintenance practices followed and its operating reliability. In process plants having increasing demand for its product, the effective operation is very important. This must be met by increasing its production. Prior to an increase in production, reliability evaluation and maintenance planning are unavoidable. Ultimate aim is to increase the performance of the machineries without compromising safety or environmental issues. Maintenance strategies of the plant affect the performance of the machineries and hence affects production. Allocating more maintenance resources for the components having high risk of failure will improve the total availability of the system. Thus it is considered as the first step to improve reliability of components. Calculating availability of the plant will give a good measure of reliability of the components in the system. Assessment of the risk of failure is equally important as reliability evaluation and plays an important role in improving plant availability. This work discusses the importance of evaluating reliability and risk of failure in planning a maintenance schedule and thereby improving availability of the plant. A model for improving plant availability has been proposed. By applying this model, an optimum maintenance schedule for the process plant can be formed. Improvement in availability of plant after employing the optimum schedule was calculated. A case study of a cement plant has been used to demonstrate the methodology. Results indicate that the methodology is successful in identifying the critical equipments and improving the availability of the system.

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Keywords: Reliability, Availability, Risk based maintenance, Fault tree analysis, Risk priority number, Downtime, Ropeways.

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1. Introduction

In today's competitive environment, companies are under intense pressure to sell their products in the market. Process plants having high demand for its product may have to run for more time. Without planning a preventive maintenance schedule, failures can happen in the process systems at any level. Downtime happens only when there is a replacement or repair for worn-out parts. The time for which the components work successfully between its replacements is defined as its life. Reliability, describes the ability of a system or component to function under specified conditions for a specified period of time. It is theoretically defined as the probability of failure, the frequency of failures, or in terms of availability. The use of less reliable components and the lack of perfect maintenance schedule are main concerns and will lead to plant failure eventually. Unexpected failures usually have adverse effects on the environment and may result in major accidents. Various studies have been done in this field by Khan [1] and Haijun Hu [2], shown the close relationship between maintenance practices and the occurrence of failures of the system. The main challenge is to implement a maintenance strategy which maximizes availability and efficiency of the equipment/system, decrease the rate of deterioration of the components, ensures safety and environmental friendly operation, and reduces the total cost of the operation. This can be achieved only by adopting a structured approach to the study of component failure and the execution of an optimum strategy for inspection and maintenance [1].

This paper discuss the importance of evaluating reliability and risk of failure in maintenance planning and thereby improving availability of the plant. A model for maintenance planning is proposed. A case study of a cement plant is used to demonstrate the methodology. Improvement in availability of the plant after employing the proposed risk based maintenance schedule is demonstrated.

2. Proposed model

2.1. Description of the model

One of the main objectives of Risk based maintenance (RBM) is to minimize failures of the components without affecting the environment. This approach uses information obtained from the study of failures and their consequences. Risk analysis is a technique for identifying, characterizing, quantifying, and evaluating the loss due to an event. Risk analysis approach integrates probability of failure and consequence analysis. It aims to improve maintenance planning and decision making by reducing the probability and consequences of failure of equipment. This is done so that the maintenance effort is optimized to minimize the total risk of failure [1]. The proposed model to improve the availability of the system is shown in Figure 1.

For implementing RBM, the system will be divided in to subsystems. Availability of subsystems will be calculated using fault tree analysis (FTA). The modes of failure of each component in the sub system is studied and its effect on the whole system is identified. Next step is to find the critical components. For that, a method called risk priority number (RPN) is used. In risk evaluation step, the estimated risk is compared with an acceptable risk criteria. We identify a specific risk acceptance criteria to be used in a situation depending on the nature and type of the system. Different acceptance risk criteria are available in the literature [2] [3] [4] [5]. In the present study an RPN value is taken as acceptable risk if this value of risk for a component is negligibly affecting the downtime of the whole system. Finally, the estimated values of risk are compared to the acceptable criteria. Thus the subcomponents which exceeds the acceptable criteria are classified as critical components. The study is then focused on the methods to minimize the consequences of these critical components. Thus an optimum maintenance schedule is to be estimated so as to decrease the downtime. The Availability of the system is recalculated after employing the risk based maintenance. This method will decrease the probability of failure of sub components as well.

2.2. Fault tree analysis

Fault tree analysis is a deductive analysis in which the causes of an events are deduced [6]. It gives an illustration of how equipment failure, human error and external factors have contributed towards a failure or event. It uses logical gates and small events to present the path of failures through different steps and hence a fault tree is constructed for the particular event. Root causes for the top event can be found out from various intermediate events [7].

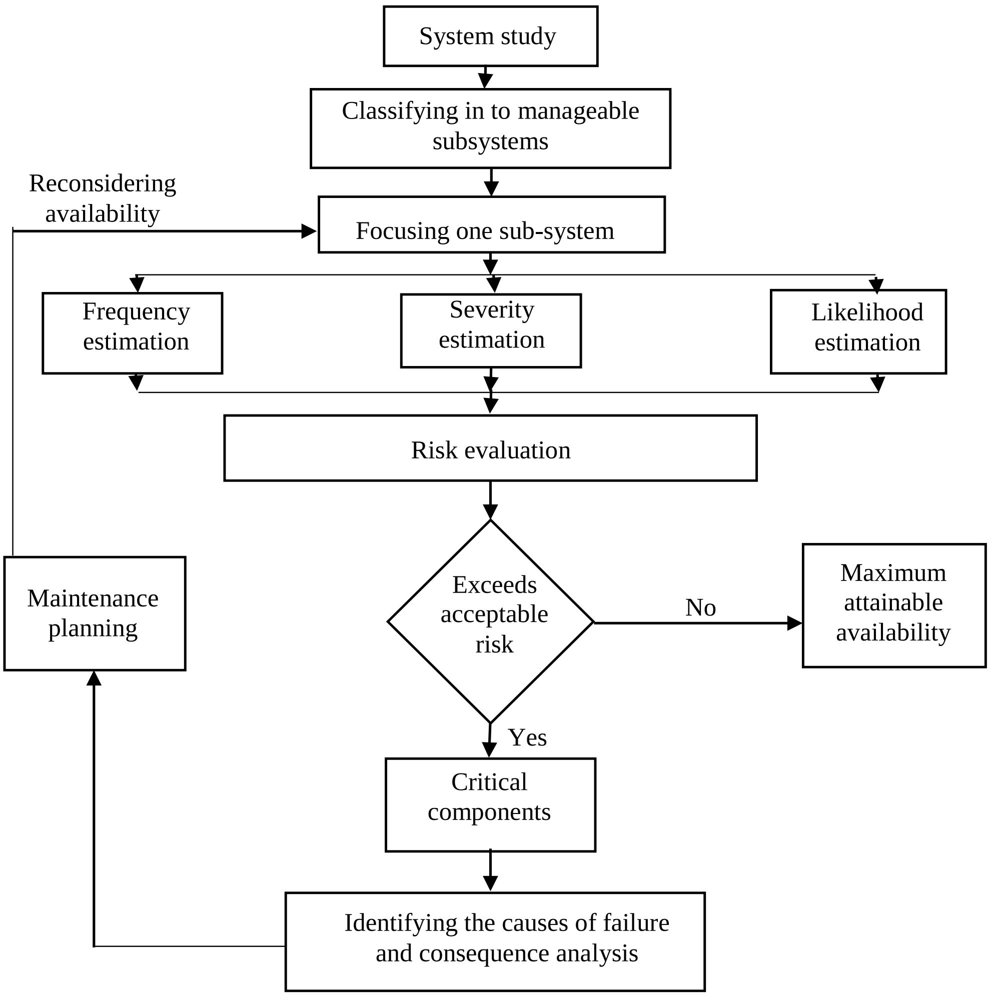

Figure. 1. Proposed model for RBM

2.3. Risk priority number

The risk priority number (RPN) is not a measure of risk, but of risk priority. By calculating the value of RPN, it will be easy to allocate the limited maintenance resources to the most important failures. Stamatis (2003) derived a formula for the calculation of RPN.

RPN (Risk Priority Number) = (Severity of failure) x (Likelihood of detection of failure) x(Frequency of failure). (1)

The three parameters mentioned are rated in the scale from 1 to 10 accordingly as follows [8]:

- Severity of failure (s):
  1 = Still works, no performance impact, no danger; 2-4 = Still works, poor performance; 5 = Limited function and/or some danger; 6-9 = severely limited function, almost useless; 10 = Inoperable and/or serious danger.
- Frequency of Occurrence (o):

1= No chance, lots of operating experience, low uncertainty; 2-4 = little chance, some operating experience and some testing to validate design, good information and low uncertainty; 5-7 = some chance, no operating experience and minimal testing - design based on analysis, good information; 8-9 = Good chance of occurrence sometime during life of product, poor information about loads and operating conditions, wild guess at models, no testing; 10 = 100% Chance of occurrence during life of product.

- Likelihood of Detection and Avoidance of failure (l):
  1 = 100% chance to detect and avoid; 2-9 = some chance to detect and avoid; 10 = no chance to detect and avoid.

2.4. Risk based maintenance

The main objective of this method is to allocate the maintenance resources wisely. By doing so, the components which are critical are more focused. It consists of two stages; Risk assessment and Maintenance planning. Risk assessment is the main phase of risk-based maintenance [9]. Risk can be defined as the probability of occurrence of the failure. Risk assessment involves nothing more than identifying potential threats that may occur in the existing system. This step mainly consists of risk estimation and risk evaluation. This is carried out using RPN method. The second phase, maintenance planning includes scheduling a maintenance plan allocating more resources to critical components.

3. A case study in a process plant

A case study has been done at Malabar Cements ltd, Palakkad, Kerala. The study is focused on the ropeway conveyors in the cement plant. The special type monocable ropeways with spring-loaded grips are used for carrying the crushed limestone. The rope conveyors connects the span of 6500 meters between the limestone mines and the processing factory. The conveyor contains almost 200 buckets over its entire span to transport limestone from mines to processing industry. The buckets are linked to the steel ropes by a carriage system. The carriage system is attached to the rope by means of detachable jaws with the force provided by the belleville springs.

3.1. Data collection

The reasons for stoppage of the system and the details of the downtime are collected for over a period of two years. The data is analyzed with the help of fault tree. Unit of the values shown in the fault tree illustration is in hour, and it shows the downtime of the whole system due to a particular failure. The fault tree is shown in the Figure 2. Downtime charts are prepared based on the fault tree. A summary of downtime charts is shown in Table 1. Downtime chart for stoppages due to bucket failures is shown in Table 2 as an example. Similar charts were prepared for line failures, station failures and miscellaneous failures.

Table 1. Summary of downtime charts

Reasons for stoppage	2013-14 (minutes)	2014-15 (minutes)	In total
Line failure (A)	70675	65230	135905
Station failures (B)	16810	15030	31840
Bucket failures (C)	13280	19020	32300
Miscellaneous failures (D)	58895	47255	106150
Total stoppage time (E)=(A+B+C+D)	160950	146535	307485

Table 2: Stoppage due to bucket failures

Events	2013-14(minutes)	2014-15(minutes)	In total
Rope out from towers due to grip slippage	4375	8425	12800
Rope out from towers due to jaw failure	4550	4245	8795
Rope out from towers due to Hanger Bearing failure	0	0	0
Draw bar failure / Tongue Bolt failure	1110	215	1325
Both Jaws failure	205	360	565
Bucket parking / charging	300	680	980
Chain bolt fixing	370	305	675
Roller out	1405	2250	3655
Bucket jamming	965	2540	3505
TOTAL (C)	13280	19020	32300

3.2. Availability of the system

Total running time (F) during the period was observed as 5,07,670 minutes. Effective stoppage time (H) after deducting the downtime due to scheduled maintenance jobs was computed as 2,71,100 minutes. Availability of the material handling system computed using eqn (2) is 0.652. That is, the system is running for 65 percentage of the total given time. This is comparatively less for a material handling system in a process plant.

$$Availability = \frac{Total\ running\ time(F)}{Total\ running\ time(F) + Effective\ stoppage\ time(H)} \tag{2}$$

3.3. Risk assessment of the components

The ropeway system has numerous sub components. As per previous studies, bucket-carriage assembly is a main component in the system which has more effect on downtime. Thus the risk assessment is focused on it. Calculated values of RPN of some of the components in the carriage assembly are shown in Table 3.

As per collected data, downtime due to hanger bearing failure is zero in the given period of 31 months. Risk priority number (or risk) of hanger bearing failure is 54. That is RPN =54 is taken as acceptable risk. Only the components exceeding this risk value has to be considered for maintenance planning. Components with high risk are: 1.Belleville spring, 2. Bridge for bucket carriage, 3. Fixed jaw, 4. Hold down roller with spindle, 5. Lock nut for carriage roller, 6.Main roller nut, 7. Moving jaw, 8. Tongue and 9. Tongue pin.

3.4. Maintenance schedule for the system

Consequences due to failures of critical components were studied and it contributes 1167.75 hours (70065 minutes) of downtime. By employing a risk based maintenance schedule, a maximum of 1167.75 hours of downtime can be reduced, theoretically. Bureau of Indian standards has been followed for proposing this maintenance schedule and shown in Table 4 [10] [11] [12].

3.5. Recalculation of availability

By adopting RBM, some of the failures of the critical components can be avoided. Hence effective stoppage time can be reduced. The new effective stoppage time calculated for the system under consideration is 1,46,950 minutes. The recalculated availability using eqn (2) is 0.7758. That is the material handling system works for 77.58% of total time in two years. Previously, the availability was 65.2 %. Hence a 12.3 % percentage increase in availability is achieved.

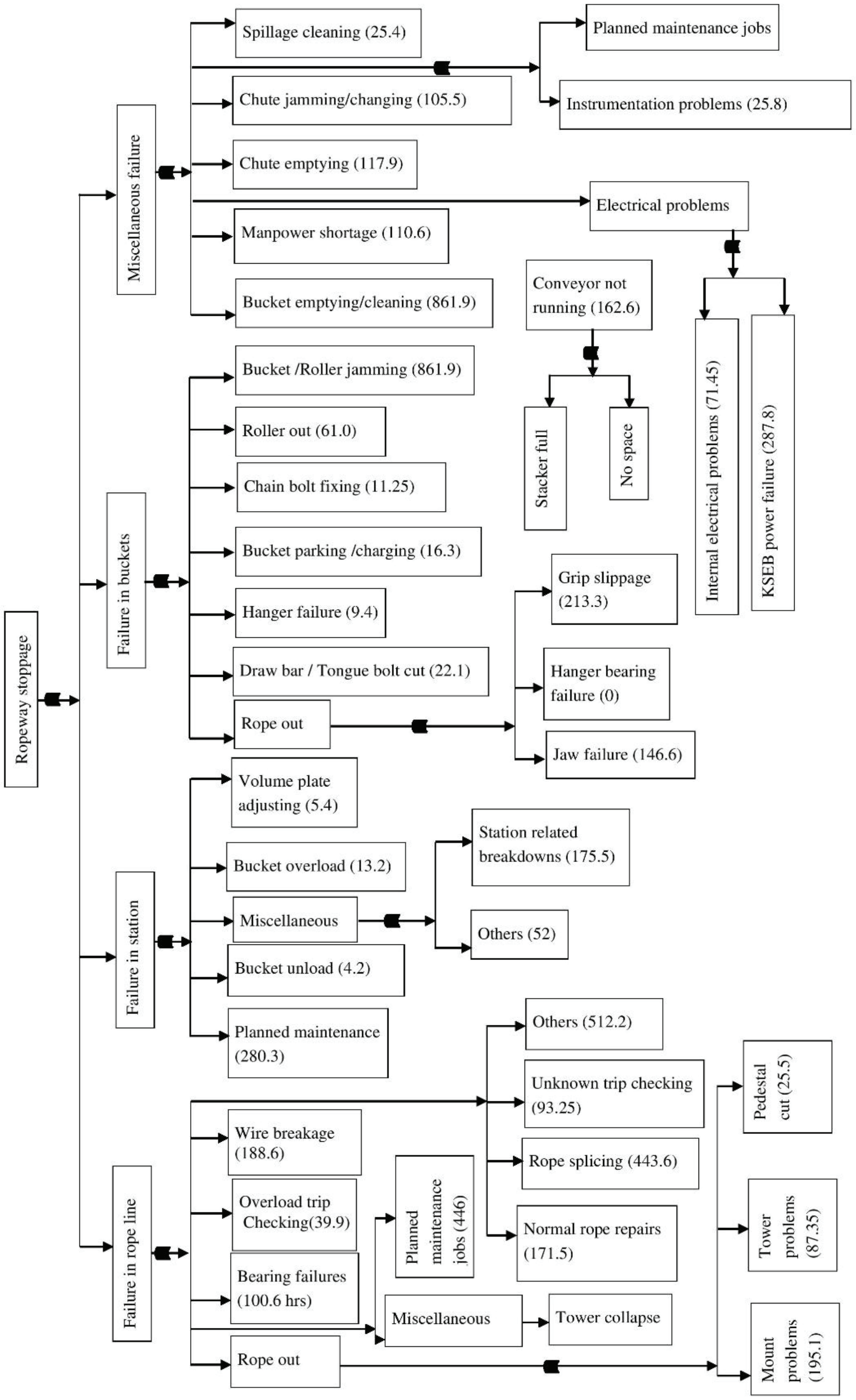

Figure 2: Fault tree representation for the ropeway stoppage

Table 3: Risk Priority Number of components in the carriage assembly

ITEM	SEVERITY	FREQUENCY	LIKELYHOOD	RPN
Belleville Spring	8	10	9	720
Bridge For Bucket Carriage	9	4	2	72
Bush For Bucket Hanger	2	4	6	48
Bush 1 For Moving Jaw(Big)	4	6	2	48
Bush 2 For Moving Jaw (Med)	4	6	2	48
Bush 3 For Moving Jaw (Small)	4	6	2	48
Fixed Jaw	8	3	3	72
Hanger Bearing	3	3	6	54
Hinge Block Pin	6	3	3	54
Hold Down Roller With Spindle	4	4	6	96
Jaw Pin	7	5	1	35
Hinge Pin Bush	3	2	7	42
Locknut For Carriage Roller	4	3	6	72
Main Roller Nut	6	3	5	90
Moving Jaw	8	3	3	72
Ms Plate Washer For Carriage	5	4	2	40
Side Roller Bearing Housing	2	3	6	36
Tongue	5	6	2	60
Tongue Pin	4	7	2	56
Cir-clip Internal	2	4	6	48

Table 4: Proposed maintenance schedule

Sl no	Maintenance operation	Inspection/Repair/Replacement frequency	Relation with the consequence
1	Ensure that the bucket has gripped the rope	Every time bucket leaves the locking module	Rope out due to grip slippage
2	No two loaded buckets come close together	Every time a bucket leaves the station	Bucket jamming, Material spillage
3	Working of all the valves at the loading system	Every time a bucket is loaded	Bucket jamming, Overloaded material in buckets
4	No defective carriage is allowed to pass through	For every bucket	Draw bar failure, Both jaws failure, rope out due to jaw failure.
5	Tightening all the bolts and screws in towers	30 days	Rope out from towers, Tower collapse
6	Spindles of all sheaves are in position and tightened	3 days	Rope out from towers
7	Conditions of the all the mounts in towers	15 days	Rope out from towers due to mount problem.
8	Alignment of the drive for the chain haulage, braking device and launching devices	3 months	Bearing failure
9	Check the condition of rope(free from corrosion)	6 months	Continued trip with failed rope
10	Fixed jaw should not be loose	Every time bucket leaves station	Jaws failure, grip slippage
11	Tongue should not be bent	Every time bucket leaves	Rope out from towers
12	Grease lubrication level of rope	Once daily	Grip slippage (excess lubrication), Rope wear (inadequate lubrication)
13	Wear at the portion where the locking ramp presses the moving jaw	Once in a month	Locking of the carriage will not happen

14	Broken belleville spring washers or flattened washers	Daily	Inadequate gripping force occurs, grip slippage
15	All the bolts in the carriage should be tightened	Before start or while parked	Bucket parking
16	Roller caps should be intact	Every time bucket leaves	Roller out
17	Hold down rollers should not be worn out	Every time bucket leaves	Draw bar failure
18	Catch arm fixing bolts should be tightened	At the start	Material spillage
19	Working of the locking module/unlocking module	Two weeks	Grip slippage

4. Conclusions

The work has proved the importance of reliability evaluation and maintenance planning in a process plant. The proposed model can be generalized for any process plant. The model suggested for carrying out the maintenance plan is effective in proposing a maintenance schedule.

Risk assessment of the various components in the system paves way for the identification of critical components. Thus focusing on the critical components rather than examining all the components in the system has an advantage of optimum usage of maintenance resources.

The case of a material handling system in a cement plant was considered to demonstrate the proposed model. The calculated availability of the plant was 0.652.The recalculated availability after employing the risk based maintenance is 0.77. By applying the Risk based maintenance, an increase in availability of 12.3% can be achieved.

Increasing the availability of the system altering the maintenance schedule alone is considered in this project. However, there is certain chance of increasing the availability by considering the design factors of the material handling system.

References

[1] Faisal I. Khan, Mahmoud M. Haddara. Risk-based maintenance (RBM): a quantitative approach for maintenance/inspection scheduling and planning. Journal of Loss Prevention in the Process Industries 16 (2003) 561–573.

[2] Haijun Hu, Guangxu Cheng, Yun Li, Yiping Tang. Risk-based maintenance strategy and its applications in a petrochemical reforming reaction system. Journal of Loss Prevention in the Process Industries 22, (2009) 392–397.

[3] Andrija Volkanovski, MarkoCepin and BorutMavko. Application of the fault tree analysis for assessment of power System reliability. Journal of Reliability Engineering and System Safety 94 (2009) 1116–1127.

[4] R. A. Cox. Use of Quantitative Risk-Assessment in Plant Design. Journal of Applied Energy 42, (1992) 33-62.

[5] N. Sellappan and K. Palanikumar. Modified Prioritization Methodology for Risk Priority Number in Failure Mode and Effects Analysis. International Journal of Applied Science and Technology, Vol. 3 No. 4 (2013).

[6] Ali Nourish Gharahasanlou, Ashkan Mokhtarei, Aliasqar Khodayarei and Mohammad Ataei. Fault tree analysis of failure cause of crushing plant and mixing bed hall at Khoy cement factory in Iran. Case Studies in Engineering Failure Analysis, (2014) 33–38.

[7] Ahmed Ali Baig, Risza Ruzli, and Azizul B. Buang. Reliability Analysis Using Fault Tree Analysis: A Review. International Journal of Chemical Engineering and Applications, Vol. 4, No. 3, June 2013.

[8] Stamatis, D. H. Failure Mode and Effect Analysis: FMEA from Theory to Execution. (2nd edition), Milwaukee: American Quality Press (2003).

[9] N.S. Arunraj and J. Maiti. Risk-based maintenance—Techniques and applications. Journal of Hazardous Materials 142 (2007) 653–661.

[10] IS 5229:1998. Code of practice for design and construction: Aerial ropeways for transportation of passengers- continuous movement mono-cable with automatic grips. Bureau of Indian Standards (1998).

[11] IS 9706:1997. Code of practice for design and construction: Aerial ropeways for transport of material. Bureau of Indian Standards (1997).

[12] IS 5228:2003. Code of practice for construction: Continuous movement mono- cable ropeways with fixed grips intended for transportation of passengers. Bureau of Indian Standards (2003).