Chapter 26
Reliability-Centered Maintenance (RCM) Approach for a Process Industry: Case Study

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Abstract Process industries, which produce paper, steel, composite sheets, etc., are considered as continuous type of industries. These industries are running round the clock to cater heavy requirements of such products. Problems, failures, or breakdowns occurring in such industries lead to heavy loss in productivity, loss of production, and expected yield from the plant. Maintenance strategy planning is a crucial part for such plant. There are several techniques adopted for maintenance such as breakdown maintenance (BM), preventive maintenance (PM), condition-based maintenance (CBM), reliability-centered maintenance (RCM). In the current case study, a process plant catering to composite sheets manufacturing required for automotive applications is considered. RCM methodology adopted includes a systematic collection of failure and repair data of systems and subsystems for several years related to a sheets manufacturing line. Based on the data collection failure modes of system, its effect, mean time to fail (MTTF), and mean time to repair (MTTR) were analyzed. A systematic model of current state of plant is simulated in ReliaSoft which has provided availability, reliability, criticality, and related data. Criticality analysis is used to calculate equipment criticality number for the critical components which are considered to be maintenance significant items (MSI). Post-criticality analysis decision for maintenance strategy planning is decided by pair-wise comparison method of analytical hierarchical process (AHP).

Keywords Reliability Centered Maintenance (RCM) · Process plant · Analytical Hierarchy Process (AHP) · Criticality analysis

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M. Tyagi et al. (eds.), *Optimization Methods in Engineering*,
Lecture Notes on Multidisciplinary Industrial Engineering,
https://doi.org/10.1007/978-981-15-4550-4_26

26.1 Introduction—Plant/Process Overview

In current era, all industries are trying their best against challenges about quality, productivity, and cost associated with product. Sustainability in tough competitions is really a challenge for industries. Plant under study currently has monopoly for the composite sheet manufacturing, which follow a limited patented process. Plant under study is essentially a continuous type of process industry, which manufactures composite sheets. Plant/system/setup is illustrated in Fig. 26.1. Plant has several subsystems essentially consisting of:

1. Power supply for motor
2. Extruder motor
3. Gearbox
4. Granules mixer
5. Extruder screw
6. Ceramic heaters (barrel zone)
7. Ceramic heater (adaptor zone)
8. Asbestos heaters (die zone)
9. Thermocouple
10. Power supply for control panel
11. Chiller rolls
12. Cooling bath
13. Haul-off station
14. Cutting saw.

Process consists of a screw extruder in which raw material is melted and formed into a continuous product such as sheets. In the extrusion, granular material is fed from a hopper into the barrel of the extruder. Extruded material goes through die and chill rollers for controlling thickness and width (as per sheet configurations), and also material cooling is achieved at this stage. Cooled sheet then goes through guide rollers to haul-off station and then to cutting station where appropriate sheet length is achieved.

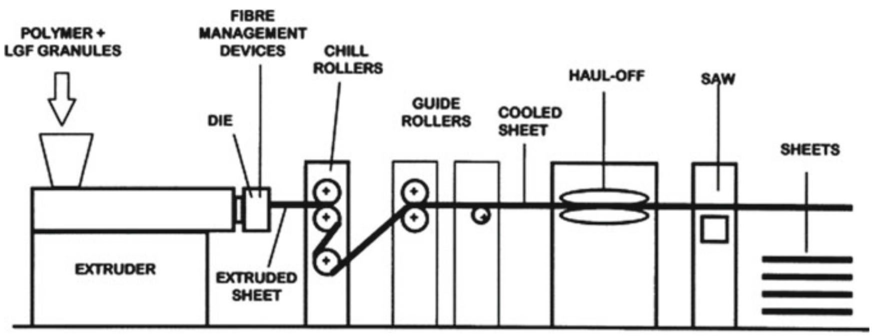

Fig. 26.1 Extrusion-rolling process industry setup

In current work, steps followed for reliability-centered maintenance (RCM) implementation for the plant is as follows:

1. Functional block diagram of plant
2. Functional failure analysis for system/subsystems
3. Criticality analysis of system
4. Decision-making/analytical hierarchical process (AHP) for maintenance strategy finalization
5. Maintenance plan implementation.

RCM is the optimum mix of reactive, time or interval-based, condition-based, and proactive maintenance. It is actually a procedure to identify preventive maintenance (PM) requirements of complex systems [1]. RCM is a way of capturing the potential causes of downtime and poor performance by preventing failures and having a proactive approach to operations and maintenance (O&M) [2].

26.2 Functional Block Diagram

Reliability block diagrams (RBDs) allow modeling the failure relationships of complex systems and their subcomponents and are extensively used for system reliability, availability, and maintainability analyses [3]. The reliability block diagram of the process plant under study is shown in Fig. 26.2. The raw material is fed into the hopper and passes through the different temperature zones where it is heated and melted in extruder. The melted material is pushed forward by screw and then passes through the molding mechanism (die) to form the product composite sheet.

Melting zones (Fig. 26.3) of plant consists of three zones:

Barrel zone: Ceramic heater (eight heaters)
Adaptor zone: Single heater
Die zone: Asbestos heater (six heaters).

Haul-off unit: After cooling, the product goes through finishing, sometimes additional coatings for its protection. It is carried out in the haul-off station.

Cutting/sawing unit: Final stage of process is cutting. After haul-off, it can be sent for cut into desired length for further use.

26.3 Functional Failure Data Analysis

In this section, collection of historical data related to subsystems of the process plant is carried out. Collected data is systematically analyzed to evaluate MTTF and MTTR based on the failure and repair data. Table 26.1 shows the illustrative data collected for "power supply for motor."

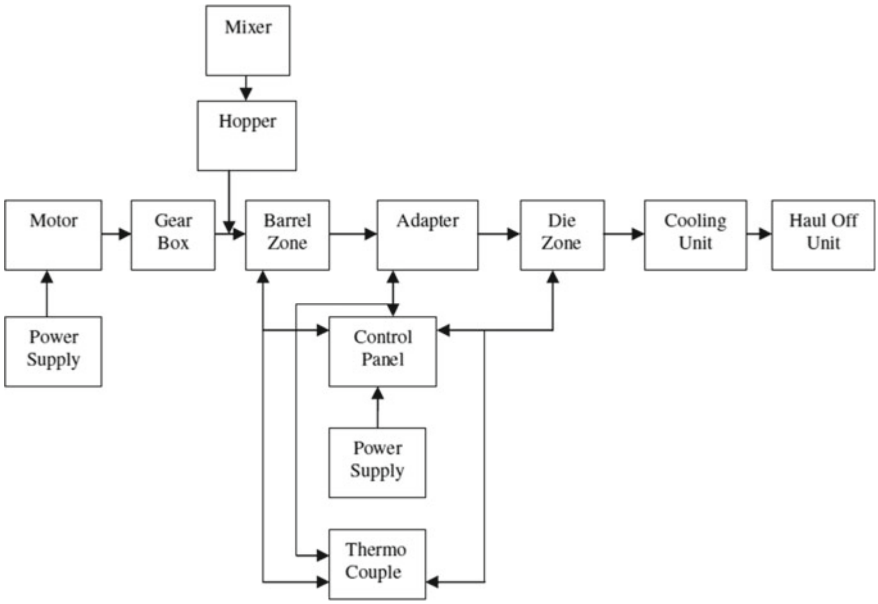

Fig. 26.2 Process plant block diagram

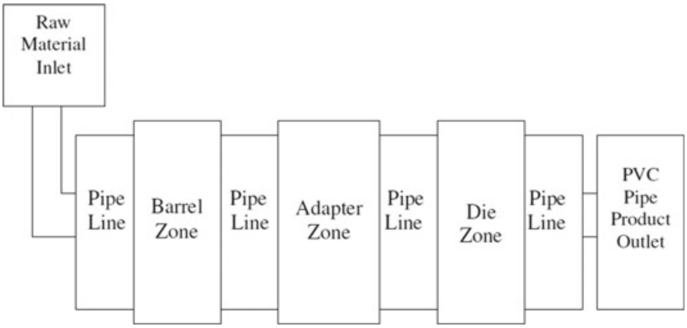

Fig. 26.3 Melting zones

Likewise for all the subsystems, data is gathered, and MTTF and MTTR are calculated.

Reliability block diagram (RBD) based on the relations between subcomponents is formulated. Illustrative RBD of "power supply for motor" is shown in Fig. 26.4.

RBD indicates a graphical representation of the components of the system and how they are reliability-wise related. The diagram represents the functioning state (i.e., success or failure) of the system in terms of the functioning states of its components. Components are connected either by series or parallel configurations. Likewise, RBD for all the components are prepared.

Table 26.1 Failure and repair data of subsystems

Component/part: power supply for motor									
S. No	Failure dates	Repair dates	Failure cause	Process stoppage	Remarks	MTTF/MTBF (h)	MTTR# (h)	Case	Run days
1	10/10/2015	12/10/2015	Voltage fluctuations/line burn	1 day	Run back-up for 1 day	11,880	48	–	495
2	12/5/2016	13/05/2016	Transformer breakdown	0 day	Run back-up for 1 day/Transformer replacement	5040	0	–	210
3	17/06/2017	17/06/2017	Transformer overheat	0 day	Run back-up for 1 day	9456	0	–	394
					Total	26,376	48		

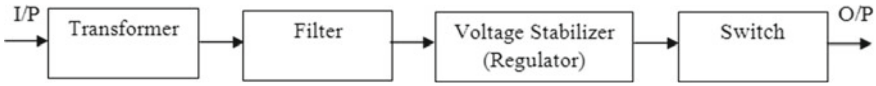

Fig. 26.4 RBD of power supply for motor

Using ReliaSoft's simulation software, whole process plant RBD is built up with reference to process plant block diagram (Fig. 26.1). All the failure and repair data/instances are simulated for 10,000 h, and results are observed. Failure modes and its effect are analyzed. Table 26.2 indicates MTTF, MTTR and % availability at component/subcomponents level.

Motor 1 winding failure criticality index (RS FCI) is 60.887%. This implies that 60.887% of the times that the system failed, a component Motor 1 winding failure were responsible. Note that the combined RS FCI of Motor 1 winding and voltage stabilizer is 67%. In other words, Motor 1 winding and voltage stabilizer contributed to about 67% of the system's total downing failures.

Motor 1 winding downing event criticality index (RS DECI) is 58.56%. This implies that 58.56% of the times that the system was down were due to component Motor 1 winding being down. Note that the combined RS DECI of Motor 1 winding and Voltage Stabilizer is 64.73%.

Simulation result summary is represented in Table 26.3 which represents information about downtime, uptime, mean availability, point availability and few important parameters as well.

Based on the outcome of study, following components were shortlisted for further criticality analysis considering the impact on production, impact on safety, impact on availability of standby and impact on capital cost are given in Table 26.4. For this analysis, all important stakeholders such as industry management, production team members, maintenance team and person from academia considered while designing evaluation scale and consequent deciding of scores for all the subsystems components.

26.4 Criticality Analysis

There are some challenges to balance the high level of reliability at an economic cost. For instance, performing the maintenance actions on all components of a distribution system may not be economical. Therefore, the critical components of the distribution system should be identified, and the maintenance actions should only be performed on them [4]. Identification of maintenance significant items (MSI) is one of the key phases of the reliability-centered maintenance (RCM), which is a screening phase where the number of items for analysis is reduced [5].

Table 26.2 MTTF, MTTR and % availability at component/subcomponents level

S. No	Component	Subcomponent	MTTF (h)	MTTR (h)	Availability (%)	RS FCI failure criticality index (%)
	Power supply for motor	Transformer	26,376	48	0.995474	0.01
		Filter			1	0.00
		Voltage stabilizer			0.988206	6.42
		Switch			1	0.00
	Motor 1 (M1) and Motor 2 (M2)	Winding_M1	23,376	149	0.895181	60.89
		Shaft_M1			1	0.00
		Bearing_M1			0.996153	1.07
		Winding_M2			1	0.00
		Shaft_M2			0.956748	0.01
		Bearing_M2			1	0.00
	Gearbox	Input shaft	25,152	69	1	0.00
		Coupling			0.999905	0.82
		Gear pairs			0.999331	1.43
		Output shaft			0.999284	3.73
	Mixer	Motor_Mixer	25,032	36	0.999076	1.79
		Blade			0.999922	0.82
		Hopper			0.999904	1.25
	Screw extruder	Barrel	23,376	552	1	0.00
		Screw			0.994533	1.26
		Bearing			0.99854	1.59
	Die	Guide	25,488	118	0.999864	0.89
		Die			0.999938	0.28
	Chiller roller and bath station	Rolls	23,424	60	0.999097	1.27
		Bearing			0.999757	1.41
		Cooling path			0.999798	0.65
	Haul-off station	Haul-off station	33,456	10	0.9998	0.00
	Cutting saw station	Guide	25,536	19	0.999946	1.41
		Motor to cutting saw			0.999957	0.45
		Cutting saw			0.999866	1.75
	Barrel zone heaters (eight heaters)	BZ_Heater_1	22,800	35	0.999901	0.00
		BZ_Heater_2	22,320	29	0.999888	0.00
		BZ_Heater_3	25,392	28	0.999818	0.00

(continued)

Table 26.2 (continued)

S. No	Component	Subcomponent	MTTF (h)	MTTR (h)	Availability (%)	RS FCI failure criticality index (%)
		BZ_Heater_4	24,840	12	0.999954	0.00
		BZ_Heater_5	24,720	31	0.999628	0.00
		BZ_Heater_6	25,560	7	0.973183	0.00
		BZ_Heater_7	22,800	35	0.999508	0.00
		BZ_Heater_8	24,864	8	0.999872	0.00
		Connector			0.999876	2.16
	Thermocouple	Ni	22,704	10.5	0.999938	1.61
		Cr			0.999977	0.59
		Control panel to thermostat			1	0.00
	Power supply for control panel	Transformer CP	25,608	14	0.999891	1.71
		Filter CP			0.999928	0.94
		Regulator CP			0.999932	1.77
		Switch CP			0.999961	1.01
	Adaptor zone heater	AZ_Heater	25,824	64.5	0.999719	1.02
	Die zone heater (six heaters)	DZ_Heater_1	23,328	15	0.999909	0.00
		DZ_Heater_2	23,304	14	0.999887	0.00
		DZ_Heater_3	24,696	18	0.999898	0.00
		DZ_Heater_4	23,496	16	0.99982	0.00
		DZ_Heater_5	24,048	15	0.999882	0.00
		DZ_Heater_6	25,680	18	0.999884	0.00

In this, need is to calculate the criticality related to systems, and subsystems related to the process plant. The equipment criticality (EC) is assessed based on the effect of errors/faults, right from the time of installation, and is quantified with scores 2, 4, 6, 8, 10 in Table 26.5. The formula for calculating EC is EC = (30P + 30S + 25A + 15C)/10.

where EC is the equipment criticality (%), P is the production, S is the safety, A is the equipment stand by availability, and C is the capital cost. Evaluation scale for consequence of failure potential for impact on production, safety, availability of standby and cost incurred. Evaluation scale is indicated in Table 26.5.

Accordingly, criticality analysis is performed, and results are indicated in Table 26.6, considering the impact on production, safety, availability of standby and capital cost factor.

Table 26.3 Simulation result summary

Parameter	Mean value
Mean availability (all events):	0.914493
Std deviation (mean availability):	0.073282
Mean availability (w/o PM & inspection):	0.914645
Point availability (all events) at 10,000:	0.553
Expected number of failures:	38.371
Std deviation (number of failures):	19.419899
MTBF (total time) (h):	260.613484
MTBF (uptime) (h):	238.329285
MTBE (total time) (h):	250.657977
MTBE (uptime) (h):	229.22504
System uptime/downtime	
Uptime (h):	9144.932989
CM downtime (h):	808.23215
PM downtime (h):	1.51969
Total downtime (h):	855.067011

Table 26.4 Components shortlisted for criticality analysis of process plant

S. No.	Subcomponent
1	Voltage stabilizer
2	Winding_M1
3	Bearing_M1
4	Gear pairs
5	Output shaft
6	Motor_Mixer
7	Hopper
8	Screw
9	Bearing
10	Rolls
11	Bearing
12	Guide
13	Cutting saw
14	Connector
15	Ni
16	Transformer CP
17	Regulator CP

Table 26.5 Evaluation scale for consequence of failure potential for impact on production, safety, availability of standby and cost incurred

	10	8	6	4	2	0
Impact on production (P)	Unable to regain loss to attain production quota-must reduce further order/booking	Cannot make up lost production at facilities—have to purchase outside service	Lost production can be recovered within facilities but at additional cost (e.g., overtime)	Can recover lost production through readily available excess capacity but has significant impact on buffer inventory putting other operations at risk of delays in supply	Lost productions has no significant impact on buffer inventory levels	No lost production
Impact on safety (S)	Multiple fatality	Fatality	Disabling injury	Lost time injury	Minor injury	No injury
Availability of standby (A)	Non availability of standby in near places wherein time to make system available is ≥1 month	Non availability of standby in near places wherein time to make system available is ≥0.5 month	Non availability of standby in near places wherein time to make system available is ≥1 week	Non availability of standby in near places wherein time to make system available is ≥3 days	Non availability of standby in near places wherein time to make system available is ≥1 day	Non availability of standby in near places wherein time to make system available is <[1] 1 day
Cost (C)	Incurred increased cost of ≥Rs.50,000/-	Incurred increased cost of ≥Rs. 25,000/- but <Rs. 50,000/-	Incurred increased cost of ≥Rs. 10,000/- but <Rs. 25,000/-	Incurred increased cost of ≥Rs. 5,000/- but <Rs. 10,000/-	Incurred increased cost of ≥Rs. 1000/- but <Rs. 5000/-	No increased costs are incurred

Criticality analysis shows the maintenance significant items (MSI) which belongs to class 'A' as depicted in Table 26.6. To make sure breakdown does not affect neither production nor safety aspects and thus to increase productivity of system, appropriate strategy is decided based on further decision-making technique of analytical hierarchical process (AHP).

Table 26.6 Equipment/subsystem criticality

Subcomponent	Frequency of failure	Impact on production (criticality number)	Impact on safety (criticality number)	Availability of standby (criticality number)	Cost (criticality number)	Impact on production	Impact on safety	Availability of standby	Cost	Equipment criticality (%)	Class
Voltage stabilizer	2.463	8	0	2	4	240	0	50	60	35	B
Winding_M1	43.713	8	2	4	8	240	60	100	120	**52**	A
Bearing_M1	1.604	8	0	2	4	240	0	50	60	35	B
Gear pairs	0.549	8	2	2	4	240	60	50	60	**41**	A
Output shaft	1.433	2	0	0	2	60	0	0	30	9	D
Motor_Mixer	0.685	8	0	2	4	240	0	50	60	35	B
Hopper	0.481	2	0	0	2	60	0	0	30	9	D
Screw	0.482	8	0	8	6	240	0	200	90	**53**	A
Bearing	0.61	6	0	2	4	180	0	50	60	29	C
Rolls	0.488	8	0	2	10	240	0	50	150	**44**	A
Bearing	0.541	8	0	2	4	240	0	50	60	35	B
Guide	0.54	2	0	0	2	60	0	0	30	9	D
Cutting saw	0.671	2	2	0	2	60	60	0	30	15	D
Connector	0.828	2	0	2	2	60	0	50	30	14	D
Ni	0.617	2	0	2	2	60	0	50	30	14	D
Transformer CP	0.655	2	0	0	2	60	0	0	30	9	D
Regulator CP	0.68	2	0	0	2	60	0	0	30	9	D

Criticality analysis shows the maintenance significant items (MSI) (High equipment % criticality) which belongs to class ‘A’ (indicated in bold).

26.5 Analytical Hierarchical Process (AHP) for Maintenance Strategy

AHP [6] is carried out for each MSI considering the maintenance, production and management team, consulted to make their preferences after communicating them above results. Breakdown maintenance (BM), condition-based maintenance (CBM), reliability-centered maintenance (RCM) and preventive maintenance (PM) are considered for systematic analytical approach of pair-wise comparison in AHP. Key parameter of consistency index (CI) and consistency ratio (CR) < 0.1 is observed which signifies correctness of results. The outcome of AHP for each MSI is depicted in Table 26.7.

26.6 Conclusion About Maintenance Strategy

Study has revealed importance of reliability evaluation and maintenance decision making. Study also reveals focusing on MSI instead of examining all the components related to plant. Risk assessment related to critical components can be analyzed for MSI in criticality analysis. Winding of Motor 1 which drives gearbox, gear pairs of gearbox, extruder screw and roll found to be MSI. For the 4 MSI, maintenance strategy adopted with the systematic approach of RCM.

Simulation result justified that after every seven days, some or the other component of the plant is going through breakdown and needs attention for maintenance.

Reliability of the plant is falling below 0.75 after 130 h of plant run.

AHP has considered active participation of all important stake holders from production, maintenance and management to decide maintenance strategy in conjunction with RCM and criticality analysis results.

By adopting RCM, critical systems can be targeted, and rest noncritical system maintenance can be planned with other techniques such as preventive maintenance, breakdown maintenance. This reduces overall cost of maintenance of plant. Accordingly maintenance activities can be planned to have better productivity and profitability of process plant.

Table 26.7 Maintenance strategy for MSI

Motor 1 winding			
Attributes	A2 matrix	Rank	Description
A	0.122	4	Breakdown maintenance
B	0.251	2	Condition-based maintenance
C	0.389	1	**Reliability-centered maintenance**
D	0.13	3	Preventive maintenance
E	0.106	5	Scheduled maintenance
CI = 0.05357			
CR = 0.04058			
Gear pairs			
Attributes	A2 matrix	Rank	Description
A	0.0929	5	Breakdown maintenance
B	0.3592	1	**Condition-based maintenance**
C	0.2722	2	Reliability-centered maintenance
D	0.1524	3	Preventive maintenance
E	0.1192	4	Scheduled maintenance
CI = 0.04259			
CR = 0.03227			
Screw of screw conveyor			
Attributes	A2 matrix	Rank	Description
A	0.0943	5	Breakdown maintenance
B	0.249	2	Condition-based maintenance
C	0.3743	1	**Reliability-centered maintenance**
D	0.1643	3	Preventive maintenance
E	0.124	4	Scheduled maintenance
CI = 0.0662			
CR = 0.05015			
Rolls in chiller unit			
Attributes	A2 matrix	Rank	Description
A	0.0962	5	Breakdown maintenance
B	0.351	1	**Condition-based maintenance**
C	0.254	2	Reliability-centered maintenance
D	0.154	3	Preventive maintenance
E	0.149	4	Scheduled maintenance
CI = 0.03964			
CR = 0.03003			

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