Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

Determining Equipment Criticality Criteria and Resistive Maintenance Assessment Questions

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ABSTRACT

Based on their mission and vision, companies choose different indicators to measure their performance. Indicators that are important in the oil, gas, refining and petrochemical industries include safety, health, environment, energy, production, quality, cost, income, exports, stress, risk, maintainability, reliability, availability, replacement cost, commitment, motivation, and profitability. The actual situation assessment and comparison with the target indicators allows identification and analysis and plan the required necessary refining actions. Assessment and control are one of the stages of roadmap for continuous improvement. In this paper 1- Based on key indicators of determining the sensitivity of equipment and their coefficients by Delphi method and the questionnaire and classification of critical equipment in Tabriz petrochemical industry based on it.2- Performing RCM stages on four critical equipment. 3- Looking at maintenance from the perspective of Balance Score Card(BSC). 4- Developing assessment and interview questions based on the resistive maintenance model (Number of questions is 130), the number of questions varies based on the experiences of assessors, the type of activity, and the size of the organization.

Keywords: Criteria, Criticality, BSC,RCM, Assessment

Received 17/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

1. INTRODUCTION

The main strategy of maintenance of companies is based on the policy of continuous production [1], reduction and the complete elimination of emergency stops [2]. The policies related to maintenance in most oil companies, including petrochemicals and refineries in Iran are:

1.1 Preventive maintenance/Condition monitoring (PM / CM):

All equipment has been identified and coded according to the executive method, and related repair checklist was developed for each of them, which includes the inspection activities, preventive maintenance [3]and[4] routines, replacement parts if necessary, and lubrication. This approach, as one of the main strategies of the planning unit of maintenance, is developed and provided to maintenance groups (Instrumentation, Electrical, Machinery, Mechanics, and Maintenance services) in order to increase the availability of equipment and reduce the time of emergency stops. The executive records of all these activities are recorded and maintained in the form of the equipment maintenance maintain record to analyze the results.

The effectiveness of these approaches is assessed by the reliability indicators (MTBF) [5], availability (MTTR)[6], the percentage of implementation of PM programs and the rate of emergency maintenance [7], defined in the strategic management process [8] as well as the quality of the maintenance activities. In the vibration measurement and analysis of the vibrations, with the goal of reducing emergency stops and increasing the reliability of very sensitive equipment, rotary machines, the CM approach is used [9]. Calibration of all measuring equipment and instrumentation are performed according to the instructions and timetable of their calibration by the instrumentation maintenance unit. In order to improve the instrumentation repair unit, the instrumentation of the calibration reference equipment is calibrated by valid external calibration laboratories and the relevant certificate is obtained.

1.2 Predictive maintenance based on (Pd.M. / CBM) status [10]:

By performing regular monitoring of parameters related to performance and the status of rotary machinery and equipment (vibration, pressure, temperature and oil, etc.), it is tried predict the impending failures and make necessary maintenance.

Received 17/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

1.3 Computerized Maintenance Management System (CMMS):

Computerized Maintenance Management System (CMMS) is used in most companies [11]. Companies are aware of the importance of CMMS, but there is debate how much this tool is used efficiently.

1.4 Overhaul:

One of the other approaches of companies to manage the equipment is overhaul [12]. Accordingly, based on information of production control unit and process conditions, as well as the frequency of overhaul problems, the proposed plan for the overhaul of the production units of the complex are delivered to examine the management by the process department (petrochemicals). After obtaining the necessary approvals for the next year executive plan, it is announced that several meetings will be held to examine and coordinate all aspects of overhauls such as material, equipment, necessary human resources, space for maintenance [13], etc. in this regard.

Based on pre-announced timetable at the scheduled time, the stages of service tripping are performed and the unit is provided to the technical and repair personnel. During the performance of the repair operation, the meetings to examine status of the works are hold and daily reports are delivered to management in the form of MSP software files. Finally, the overhaul final meeting is hold Post Over Haul Meeting (P.O/H.M) is prepared and stored in the Integrated Maintenance Planning Archive System. The effectiveness of this approach is monitored using the process indicator approved in the system. If there is a deviation from the program, the reasons and learnt lessons of overhaul are analyzed after approval in the final meeting and its software documentation will be kept in the maintenance planning unit.

1.5 Minor and refine maintenance based on technical service instructions:

Based on reports received from operators or technical inspectors regarding the operational status of the equipment, some measures are taken in line with refine maintenance to avoid secondary failures and their consequences. A part of these activities are performed based on the implementation of preventive maintenance strategy, and according to existing standards, this strategy is placed in class of planned maintenance and repair. Due to the close relationship between operations, maintenance, human resources, training, engineering support, logistics, and commerce would not be

Received 17/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

possible without promoting other related processes, and the desired results would not be achieved. Therefore, the company's approach in line with Ministry of Oil announcement is deploy of the physical asset management system, based on the strategic plan of management of physical assets of the oil industry.

1.6 RCM, RBI, TPM, BPR :

Petrochemical companies are operating to use the reliability centered maintenance(RCM)[14]and[15], risk based inspection(RBI)[16], total productive maintenance(TPM)[17]and[18] and business process reengineering(BPR)[19] methods, but there is deep gap between them and optimal using and deploy of the mentioned methods.

2. EQUIPMENT CRITICALITY CRITERIA AND DETERMINATION OF THEIR COEFFICIENTS:

In order to determine the sensitivity of the equipment, based on the experience and field surveys, experts determined ten criteria, and considering these criteria and their coefficients, 80 oil and academic experts were surveyed and the coefficients with arithmetic mean and final ten criteria are presented in Table1[20]. According to these criteria, Tabriz petrochemical equipment was classified by maintenance, operation, safety, technical and management specialists, which its results are listed in Tables 2. and the RCM method for Grade A was implemented on selected one based on the table 3 the stages of RCM for one sample of gas turbine[21], compressor, pump and UPS have been presented in tables 4 to 8. Based on the sensitivities obtained, we can determine the type of maintenance (table.3) and technical inspection according to criticality type (table.2) .

Table 1. 10 criteria for calculating criticality of equipment

Quality	Performance	Safety	Environment	Operational Risk
11	10	12	10	9
Reliability	Availability	Maintainability	Energy	Cost
10	9	10	8	11

Table 2. Critical equipment criteria judged by 80 Experts on 151 equipment

Received 17/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

No.	Equipment	Type Of Equipment	Quality	Production	Safety	Environment	Operational Risk	Reliability	Availability	Maintainability	Energy	Cost	Sum	Criticality Type
			Primary Criteria											
			11	10	12	10	9	10	9	10	8	11	100	
1	11-C1	Compressor	10	10	10	8.8	9	9.5	8	9.8	8	11	94	A
2	11-MX	Mixer	8.5	9.5	11	9.3	8.5	9.5	8.5	9.5	7.8	10	92	A
3	11-MMX	Electrical	9.8	9.5	11	8.8	8.5	9.3	7.5	9.3	8	11	92	A
4	11-E1	Exchenger	9.5	10	10	9	9	9.8	8.5	9.5	6.8	9.3	92	A
5	11-E2	Exchenger	9.5	10	10	9	9	9.8	8.5	9.5	6.8	9.3	92	A
6	11-MC	Electrical	9.5	10	10	8.5	9	9.8	7.8	8.3	8	11	92	A
7	11-R1	Reactor	11	9.3	9.8	8.8	9	9.5	8.8	8.8	6	10	91	A
8	11-C2	Compressor	8	9	11	9.5	7.8	8.8	7.8	9.3	6.3	8	85	A
9	11-C3	Compressor	8.5	6.8	11	8.8	6.8	8.5	8.3	9.8	7.3	9.5	85	A
10	11-C4	Compressor	8.5	9.8	9	7.8	7.3	8.8	8.3	8.8	7	9.3	84	A
11	11-C5	Compressor	8.3	8.8	10	8.3	8	8.8	7.5	8.5	6.5	9.3	84	B
12	11-C6	Compressor	8	9.3	9.3	8.3	7.8	9	8.3	9	6.5	8.3	84	B
13	DCS	Instrument	9.3	8.5	11	6.8	8.8	7.5	6.8	8.5	6.3	8.8	82	B
14	11-Q1	Rotary	9	8.8	10	8.3	7.5	8	7.3	8.8	6	7.8	82	B
15	11-Q2	Rotary	8.5	8.8	10	8.3	7.5	8	7.3	8.8	6	7.8	81	B
16	11-Q3	Rotary	8.8	8.8	10	8	7.8	7.8	7	8.3	6	7.5	80	B
17	11-Q4	Rotary	8.8	8.8	10	8	7.8	7.8	7	8.3	6	7.5	80	B
18	11-Q5	Rotary	8.5	8.8	9.5	7.8	7.8	7.8	7	8.3	6	7.5	79	B
19	11-Q6	Rotary	8.5	8.8	9.5	7.8	7.5	7.8	7	8.3	6	7.5	79	B
20	11-Q7	Rotary	8.5	8.8	9.5	7.8	7.3	7.8	7	8.3	6	7.5	78	B
21	11-E-3	Exchenger	8.3	8	8.8	7.5	6.8	7.8	7.5	6.5	4.3	6.8	72	B
22	11-E-4	Exchenger	8.3	8	8.8	7.5	6.8	7.8	7.5	6.5	4.3	6.8	72	B
23	22-C1	Rotary	11	10	10	7.8	8.5	9.3	8.5	9.8	8.3	10	93	A
24	22-W1	Rotary	11	10	11	6.5	8.8	9.5	8.5	9.8	8.5	10	93	A
25	22-R1	Reactor	11	9.8	11	9	9	8.5	8.5	9	7	10	92	A
26	22-R2	Reactor	11	9.8	11	9	9	8.5	8.5	9	7	10	92	A
27	22-R3	Reactor	11	9.8	11	9	9	8.5	8.5	9	7	10	92	A
28	22-W2	Rotary	11	10	10	5.8	8.5	9.3	8.3	9.8	8.5	9.8	91	A
29	22-T1	Tower	11	9.8	11	9	8.3	8.5	7.5	9	7.5	10	91	A
30	22-W3	Rotary	11	10	9.8	5.8	8.5	9.3	8.3	9.8	8.5	9.8	90	A
31	22-UV1	Instrument	11	8.5	12	8.3	8.3	8.8	8.8	9.3	6.8	7.8	89	A
32	22-UV2	Instrument	11	8.5	12	8.3	8.3	8.8	8.8	9.3	6.8	7.8	89	A
33	22-UV3	Instrument	11	8.5	12	8.3	8.3	8.8	8.8	9.3	6.8	7.8	89	A
34	22-UV4	Instrument	11	8.5	12	8.3	8.3	8.8	8.8	9.3	6.8	7.8	89	A
35	25-MX1	Rotary	10	9.5	8.3	8.5	8.8	9	7.8	8.8	8	9.8	88	A
36	22-F1	Furnce	9.3	9	11	8.3	8.5	8.8	8	8.8	7	9.8	88	A
37	24-H1	Heater	9.3	9	11	8	7.5	8.3	7.3	8.8	8	9.8	86	A
38	24-W 4	Rotary	10	9.8	9.3	9.3	8.3	7.3	7	7.3	7.8	9.8	86	A
39	25-S1	Rotary	8.3	9	10	8.5	7.8	8.5	8.3	9	7.3	8.8	85	A
40	25-S2	Rotary	8.3	9	10	8.5	7.8	8.5	8.3	9	7.3	8.8	85	A
41	25-S3	Rotary	8	8.8	10	9.3	8.8	8	7.8	7.8	7.5	9	85	A
42	22-AE1	Fix	10	9.5	10	8.5	7.5	8.3	7	8	6.5	9.5	85	A
43	24-MX2	Rotary	9.8	9.5	7.8	8.3	8	8.8	7.5	8.3	7.3	8.8	84	B
44	24-MX3	Rotary	9.8	9.5	7.8	8.3	8	8.8	7.5	8.3	7.3	8.8	84	B
45	22-E1	Fix	10	8.8	10	8.8	8	7.8	7.5	7.3	6.5	8.5	84	B
46	21-P1	Pump	8.5	7.8	9	9	7.3	9	7.5	8.5	7.5	9	83	B

Received 17/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

47	21-E2	Fix	8.5	8.5	9.8	8.8	8	8	8.3	7.5	6.5	9.3	83	B
48	22-E3	Fix	10	8.8	11	8.5	7.8	7.8	7.5	7.3	6.3	8.5	83	B
49	22-E4	Fix	10	8.8	11	8.5	7.8	7.5	7.5	7.3	6.3	8.5	83	B
50	24-P2	Pump	8.5	9.3	8	6.8	7.8	9	8.3	8.8	7.5	8.5	82	B
51	24-P3	Pump	8.3	9.3	8	6.8	7.8	9	8.3	8.8	7.5	8.5	82	B
52	21-C2	Comprossor	8.3	7.3	8	8.3	7.3	9.8	8.8	8	7.8	8.3	82	B
53	24-P4	Pump	8.3	9.3	8	6.8	8.3	8.8	8	8.3	7.5	8.5	82	B
54	24-P5	Pump	8.3	9.3	8	6.8	8.3	8.8	8	8.3	7.5	8.5	82	B
55	21-P6	Pump	8	7.8	9.3	9	6.5	9	7	8	7.3	8.8	81	B
56	21-F2	Furnece	8.5	8	10	7.5	7.8	8.3	7.3	8	6.3	8.8	80	B
57	25-MX4	Rotary	7.8	8.3	7.8	8.3	7.3	7.5	7.3	8	7.3	8.3	78	B
58	31-C1	Compressor	11	9.8	12	10	9	10	8.8	9.5	8	11	99	A
59	32-MX1	Agitator	11.3	9.8	12	10	9	9.5	8	9.8	8	11	98	A
60	32-MX2	Agitator	11.3	9.8	12	10	9	9.5	8	9.8	8	11	98	A
61	32-MX3	Agitator	11.3	9.8	12	9.5	8.8	9.3	8.5	10	8	11	98	A
62	32-MX4	S. Agitator	11.3	9.8	12	9.8	9	9.8	7.8	10	8	11	98	A
63	32-MX5	S. Agitator	11.3	9.8	11	9.5	9	9.8	8	10	8	11	98	A
64	32-MX6	Agitator	10.8	9.5	12	9.8	8.8	9.8	8.5	10	8	11	97	A
65	32-MX7	Agitator	10.8	9.5	12	9.8	8.8	9.8	8.5	10	8	11	97	A
66	32-C2	Blower	11	9.5	12	10	8.8	9.5	8.5	10	8	10	97	A
67	32-C3	Blower	11	9.5	12	10	8.8	9.5	8.5	10	8	10	97	A
68	32-D3	San Drier	11.3	9.8	11	8.5	9	10	8.8	9.8	8	11	97	A
69	32-MX8	Agitator	10.8	9.5	12	9.8	8.5	9.5	8.3	9.8	7.8	10	96	A
70	32-MX9	Agitator	11	9.3	11	10	9	9.5	7.8	10	7.8	10	96	A
71	32-XT1	C. Breaker	11.3	9.8	9.5	9	9	10	8.8	9.5	8	11	96	A
72	32-XT2	C. Breaker	11.3	9.8	9.5	9	9	10	8.8	9	8	11	95	A
73	31-MX10	S. Agitator	11	8.8	11	9.8	8.3	9	8.3	10	8	10	95	A
74	32-XT3	C. Breaker	11.3	9.8	9.5	9	9	10	8.3	9	8	11	95	A
75	32-XT4	C. Breaker	11.3	9.8	9.5	9	9	10	8.3	9	8	11	95	A
76	32-MX11	Mixer	11.3	9.8	9	7.5	8.5	10	8.8	10	8	11	94	B
77	32-MX12	Mixer	11.3	9.8	9	7.5	8.5	10	8.8	10	8	10	93	B
78	32-MX13	Mixer	11.3	9.8	9	7.5	8.5	10	8.8	10	8	10	93	B
79	32-MX14	Mixer	11.3	9.8	9	7.5	8.5	10	8.8	10	8	10	93	B
80	32-C4	C. Blower	10.8	9.5	9	7.3	9	10	8.8	10	8	9.8	92	B
81	32-C5	C. Blower	10.8	9.3	8.5	7.3	9	10	8.8	10	8	9.8	91	B
82	32-C6	V. Pump	10.8	9.3	8.3	9	8.8	9.5	8.3	9.8	7	8.3	89	B
83	31 P 1	Deg. Pump	10.8	6.8	11	8.8	8.5	9.5	8.8	9.3	6	8.8	88	B
84	31 P 2	Deg. Pump	10.8	6.8	11	8.8	8.5	9.5	8.8	9.3	6	8.8	88	B
85	32-C7	Ex. Fan	10.3	9.3	12	9	8	8.8	7.5	9.8	6.5	7.3	88	B
86	32-C8	V. Pump	10.8	9.3	8.5	8.8	8.5	9.3	8	9.8	6.8	8.3	88	B
87	31 P 3	B. Pump	10.5	6.8	12	9	6.5	9.3	8.3	10	6	9.8	88	B
88	32-MX1	Agitator	10.5	9.5	11	8.8	7.8	7.5	7.3	9.8	6.3	9	88	B
89	32-C-9	V. Pump	10.8	9.3	8.5	8.8	8.5	9	8	9.8	6.8	8.3	88	B
90	32-C10	D. Fan	10.3	9	11	9	8	8.8	7.5	9.8	7	6.5	87	B
91	31 P 3	B. Pump	10.3	6.5	12	8.8	6.8	8.5	8.5	10	6	10	87	B
92	31 P 4	R. B. Pump	10.5	6.8	12	8.5	6.3	8.5	8.5	10	5.8	10	87	B
93	31 P 5	R. B. Pump	10.3	7	12	8.3	6	8.3	8.8	10	6	10	87	B
94	31 P 6	B. Pump	10.8	6.3	12	8.8	6.5	8.8	8	9.8	5.8	10	86	B
95	31 P 7	P. Pump	10.8	6.5	12	8.5	6.3	8.8	8	10	5.8	9.5	86	B
96	31 P 8	N.M. Pump	10.5	7	12	8.8	7.3	9.8	8.8	7.8	6	8.5	86	B
97	31 P 9	N.M. Pump	10.5	7	11	8.8	7.3	9.8	8.8	7.8	6	8.5	86	B
98	31 P 10	B. Pump	10.3	6	12	8.5	6.5	8.3	8	10	5.8	10	85	B
99	32-MX2	S. Agitator	9.3	8	9	8.3	7.3	8.3	8.5	9.3	7	9.8	85	B
100	31 P 11	D. F. Pump	10.5	6.5	11	8.5	7.5	9.5	8.5	7.8	6	8.5	84	B
101	31 P 12	A.W Pump	10.3	6.3	12	8.8	6.8	8.8	8.5	8.3	6	8.5	84	B
102	31 P 13	A.W Pump	10.8	6.8	11	8.5	7	9	8.8	7.8	5.8	8.3	84	B

Received 17/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

103	31 P 14	R. Pump	10.5	7	11	8.8	7	8.8	8.8	6.5	6	9.3	84	B
104	31 P 15	MW. Pump	10.8	6.5	11	8.3	7.3	8.3	8.5	7.8	6	9.3	83	B
105	31 P 16	Pump	10.5	6.3	12	8.3	6	8	8.3	9.8	5.5	9.3	83	B
106	31 P 17	R. Pump	10	6.3	11	8.5	7.3	9.8	8.5	6.3	5.5	9.5	83	B
107	31 P 18	W. Pump	10.5	6.3	11	8	7.3	8.5	8.8	7.5	6	8.8	82	B
108	32-C11	C. Blower	8.8	9.8	9	7.3	8.8	8.8	7.5	7.8	6.8	7.5	82	B
109	31 P 19	D. F. Pump	10.3	6.3	11	8	7.5	9.3	8.3	7.5	5.8	8.3	82	B
110	31 C 20	A. O. Pump	11.3	7.3	12	6	6.8	9.8	8.5	7	6.5	6.8	82	B
111	32-C21	C. Blower	9.3	9.8	8.8	6.8	8.8	8.5	7.5	7.5	7	7.5	81	B
112	32-C22	C. Blower	9	9	9	7	9	8.8	7.5	7.3	6.8	7.3	81	B
113	32-C23	C. Blower	8.5	9.3	8.5	7.3	8.5	8.5	7.8	7.5	7	7.3	80	B
114	31 C 24	C.O. Pump	11	7.3	12	5.8	6.5	9.5	8.3	6.8	6.5	6.5	80	B
115	32-MX3	Agitator	9.3	7.3	9.5	8.5	6.5	7.5	7	10	6.5	7.3	80	B
116	32-P20	W. Pump	10.3	8.8	9.5	6.8	7.8	8.3	7	8.3	6	7	80	B
117	31-MX4	M. Pump	10.8	9.3	12	5	6	8.8	8.5	7.5	4.8	7	79	B
118	32-P21	W. Pump	9.8	8.5	9	7	8	7.3	6.8	8.5	6.5	7.3	79	B
119	32-RV1	R. Valve	7.3	9	8	6.8	7	7.8	6.3	7.8	7	6.8	74	B
120	32-RV2	R. Valve	7.3	8.8	8	6.5	6.8	7.8	6.3	7.8	7	6.8	73	B
121	32-RV3	R. Valve	7.3	9	7.5	6.5	6.8	7.8	6.5	7.8	7	6.8	73	B
122	32-RV4	R. Valve	6.3	8.8	8	6.8	7	7.5	6.5	7.8	6.8	7	72	B
123	71-T1	Rotary	11	9.7	11	9.1	9	9.7	8.6	9	7.7	11	95	A
124	76-K1	Rotary	10	9.7	11	9.3	9	9.1	8.7	9	8	10	95	A
125	76-K2	Rotary	10	9.7	11	9.3	9.1	9.7	8.9	9.3	7.7	10	95	A
126	75-K3	Rotary	10	9.6	11	9.1	9	9.1	8.6	9	8	10	94	A
127	71-FDF1	Rotary	10	10	10	9	8.7	9.4	8.6	9.1	7.9	10	93	A
128	71-DCP1	Electrical	9.7	10	11	9.7	8.3	9	8.3	8.3	7.7	11	93	A
129	71-UPS1	Electrical	10	10	11	9.3	8	9.3	8	9	7.7	10	93	A
130	88-TK1	Rotary	9.6	9.6	9.7	8.9	8.3	9	8.1	9.3	7.9	9.1	89	A
131	76-V1	Rotary	9.2	9	10	8.8	8.4	9	7.8	9.2	7.8	9	89	A
132	C. BOX 1	Fix	9.3	9	11	9.2	8.5	8.3	8	8.7	7.7	9.3	89	A
133	74-P1	Rotary	8.6	9.1	10	8.7	8.1	8.3	8.4	9.4	7.7	9.1	88	A
134	71-P-2	Rotary	9.3	9.2	9.5	8.8	8	8.5	8.5	9.2	7.5	8.8	87	A
135	74-T2	Rotary	8.4	8.9	9.3	8.9	8	8.7	8.4	9.1	7.7	9	86	A
136	71-P-3	Rotary	8.8	8.7	9.8	8.3	7.3	8.2	7.7	8.5	7	8.8	83	B
137	75-D1	Rotary	8.6	8.4	9.2	8.2	7.4	8.4	7.6	8.4	7	8.2	81	B
138	01 C 1	Rotary	10.6	9	10	8.9	7.9	9.1	7.4	9.1	7.9	9.6	90	A
139	01 C 2	Rotary	10.6	9	10	8.9	7.9	9.1	7.4	8.9	7.7	9.6	89	A
140	51 C 3	Rotary	9.7	8.7	10	8	7.9	8.9	7.6	8.9	7.6	9.9	87	A
141	01 P 1	Rotary	10.1	9.1	10	8.7	8.1	9.1	7.7	8.9	6.6	7.7	86	A
142	01 P 2	Rotary	10.1	9.1	10	8.7	8.1	9.1	7.7	8.9	6.4	7.7	86	A
143	01 P 3	Rotary	10.4	8.9	10	8.1	7.4	8.6	7.7	9	6.3	7.7	85	B
144	01 P 4	Rotary	10.4	8.9	10	8.1	7.4	8.6	7.7	8.9	6.4	7.7	85	B
145	50 P 5	Rotary	9.6	8.7	10	8.1	7.4	9	7.9	8.4	6.6	7.3	83	B
146	50 P 6	Rotary	9.6	8.7	10	8.1	7.4	9	7.9	8.4	6.4	7.3	83	B
147	70 UPS 1	Electrical	10	9.1	10	8.1	7.6	7.9	7.6	8	5.7	8.4	83	B
148	01 P 7	Rotary	9.7	8.7	10	7.6	7.4	8.7	7.9	8.1	6.6	7.9	83	B
149	01 P 8	Rotary	9.7	8.7	10	7.6	7.4	8.7	7.9	8	6.7	7.9	83	B
150	50 P 9	Rotary	9.9	8.3	10	7.4	6.9	9.1	7.7	9.1	5.7	6.6	81	B
151	50 P 10	Rotary	9.9	8.3	10	7.4	6.9	9.1	7.7	9.1	5.7	6.6	81	B

Received 17/04/2018
Approved 10/06/2018

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Table3. Maintenance approach as type of equipment criticality

ECI	*Type*	*Maintenance approach*
85-100	A	RCM, RBI, CBM ,TPM
67-84	B	CBM ,TBM
47-66	C	TBM , PM
25-46	D	PM, Checking
0-24	E	RTF

TBM, CBM , and RTF are Time Based Maintenance ,Condition Based Maintenance and Run To Failure respectively.

Table4. RCM five Steps on Gas Turbine 501

Equipment Parts	***Function Definition***	***Failure Modes***	***Failure Effects***	***Failure Consequences***
Intake air filter	Filtered air supply of Compressor	Dirty filter Rupture of membranes	Reduce the amount of intake air Transfer of foreign bodies	Reduce air compressor discharge pressure Increase the exhaust temperature The lowering of turbine efficiency Limitation of the generator loading
Fuel nozzles	The supply of fuel injection into the combustion chamber	Nozzle clogging Leakage of relevant connections Changing the angle of spraying Burning the nozzle outlet	Heterogeneity of the spraying High fuel consumption Misfire	Trip of turbine Environmental pollution Stop loading
Ignition system	Sparks at the time of mixing fuel and compressed air	Fouling of igniter electrodes Failure and short circuit of the numbers of ignition Breaking insulated electrodes (electric leakage)	Lack of ignition Lack of flame	Turbine does not start
Lubrication system	Doing lubrication and cooling of turbine bearings and accessories as well as control devices	The clogging oil exchanger tubes Oil filter clogging / oil pump failure Rupture of piping oil transfer Perforation of exchanger tubes and mixing oil with water	Raise the temperature of bearings Reduce the speed of rotation of the rotor Create sediment and rotor imbalance Damaged bearings Faulty hydraulic system	Gyrpazh rotor / bearing Increase in the cost of repairs Stop Power Generation

Received 17/04/2018
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Still and moving turbine blades	Receiving thermal and kinetic energy of ignited gas and changing to rotational moving energy	Cracks in the blades Too loose spokes inbalanceBlades Burning and corrosion	Vibration in blades	Increased vibrations Fractures of all turbines and compressors Stop production Increase the cost of repairs

Table 5. RCM Steps on Compressor - 201

Com ponent	***Function Definition***	***Failure Modes***	***Failure Effects***	***Failure Consequences***
Rotor	Compressor rotating tools are installed on the rotor	Corrosion on the shaft Curvature	Imbalance and Impact loading Sudden Trip Bearings failure Seal failure	Reduced efficiency Increase d vibration Increase d leakage
Journ al Bearing	The function of guiding rotor motor and rotating equipment in radial direction	Corrosion Fracture	Abnormal vibrations Lack of proper lubrication Injection of oil impurities Oil pressure fluctuation	Increase d vibrations Axial movements Compres sor tripping
Trust Bearing	Motor guiding of compressor rotating tools in axial direction	Corrosion Fracture	Abnormal vibrations Lack of proper lubrication Injection of oil impurities Oil pressure fluctuations	Increase d compressor vibrations Reduces efficiency Probable serious damage to compressor rotating tools and fixed parts Compres sor tripping
Oil Seal	Sealing oil chamber	Corrosion	Long-term operation wear with rotating tools Vibrations	Oil leaking out or into the fluid Reduce oil level reduced efficiency pollution and reduced quality lubrication in severe leakage conditions
Seals	Sealing the fluid chamber	Corrosion	Wear and corrosion due to inadequate and prolonged operation Abnormal vibrations	Leakage of fluid out of the chamber Reduced compressor

Received 17/04/2018
Approved 10/06/2018

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				efficiency Environment pollution Oil pollution
Lube Oil Pump	Oil flow in the lubrication path and creating the necessary pressure in the oil path	Failure of bearings Corrosion and failure of screws	Long-term operation operating in inappropriate conditions Abnormal vibrations	Oil pressure drop in the path The failure of compressor bearings Compressor trip

Table6. Stages of RCM on Vacuum Pump - W301

Component	Function Definition	Modes Failure	Failure Effects	Failure Consequences
Rotor	Sucking Rotating tools are mounted on the rotor	Corrosion of rotors Wear of rotors	Bearings failure Seals failure Shell failure Coupling failure Gear timing failure	Stop of tool S / D Oxygen unit Lowering the tonnage of production
Ball & Roll Bearing	Task of axial and radial guiding of rotor	Corrosion of the balls Fracture of bearings Gripping Bering Bearing seizure	Rotor failure Gear timing failure Seal failure Shell wear	Stop of tool Rotor failure Increased tool vibration Increased abnormal sound
Seals	Oil chamber and vacuum chamber sealing	Corrosion of seals Tear of seals	Oil leakage to vacuum Nitrogen leakage into oil chamber	Oil leakage Environmental population
Coupling	Connecting the stage 1 vacuum to pump vacuum stage	Coupling tire failure Cuts in coupling screws	Failure of stages	Stop of tools Lowering the tonnage of production SH / D Oxygen unit
Timing Gear	Adjustment of axial movement of rotors	Corrosion of gears Fracture of gears In appropriate oil Imbalance of rotors	Rotor seizure Rotor failure	Stop of rotor Rotor failure & increased maintenance costs SH / D Oxygen unit

Table 7.Four critical equipment and related criticality type

Received 17/04/2018
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No.	Equipment	Type Of	Quality	Production	Safety	Environment	Operational Risk	Reliability	Availability	Maintainability	Energy	Cost	Sum	Criticality Type
		Equipment	Primary Criteria											
			11	10	12	10	9	10	9	10	8	11	100	
1	11-C1	Comprossor	10	10	10	8.8	9	9.5	8	9.8	8	11	94	A
24	22-W1	Rotary	11	10	11	6.5	8.8	9.5	8.5	9.8	8.5	10	93	A
123	71-T1	Rotary	11	9.7	11	9.1	9	9.7	8.6	9	7.7	11	95	A
129	71-UPS1	Electrical	10	10	11	9.3	8	9.3	8	9	7.7	10	93	A

Table8. Stages of RCM on UPS-201

Component	Function Definition	Failure Modes	Failure Effects	Failure Consequences
Fan	Cooling sensitive and vital parts of UPS	Bearing failure fan burning coil	Warming up and failure of important parts of UPS	Warming up and burning all the elements of power UPS failure probability SH/D of unit
Electronic cards	UPS general function controller	Burning electronic tools like capacitors, resistors, diodes, and transistors internal disconnection of tools	UPS dysfunction Problems in other tools	UPS malfunction UPS failure probability SH/D of unit
Electrical relays	establishing internal connections of UPS control	Burning solenoid Failure of contactors	UPS dysfunction Problems in other tools	Non- start of turbine
Contactors and keys	Disconnecting and connecting the inputs and outputs Initiating UPS Transferring in different modes	Burning solenoid Failure of contactors failure in internal connections of the contractors and keys Failure of relays protecting the keys	Dysfunction of different parts of UPS lowered power and maneuvering operations	Failure of a part of UPS Failure of the entire UPS Battery consumption and SH / D to DCS

Received 17/04/2018
Approved 10/06/2018

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Power transistor and power diodes (Converter)	The key role in UPS function	Burning and failure of tools	Dysfunction of rectifiers and inverters	UPS failure DCS voltage cutoff Probability of SH / D unit
UPS batteries	Supports UPS in case of power failure ensuring stable power	Sulfated batteries Failure of electrolytes Failure of battery cells	Lowering the strength of energy and power storage	SH / D UPS in case of power failure SH / D Unit Sending to filler Environmental pollution Rising cost and lost opportunity

3. BUSINESS OF COMPANY & MAINTENANCE FROM THE BSC PERSPECTIVE

One of the key issues in business of companies is having a strategic approach to maintenance. In other words, maintenance is one of the main strategic and strategic actors in the business of each company. As a sample, one company's strategic table and its maintenance from the perspective Balanced Score card (BSC)[22] has been presented in tables 9 and 10. The goal of a BSC-based petrochemical company, in which maintenance plays a major and strategic role .

Table 9. Tabriz Petrochemical Business from the BSC perspective (2017)

Strategy : Sustainable business development with diversity approach					
Perspective	Macro goals	Defined indicator			
		Indicator	Indicator definition	Measurement unit	Quantitative goal of indicator per year
Financial	Development and continuity of business	Average cost of per unit of product	Total cost of production to the tonnage of goods sold	Rials /kg	10% Reduction
		Income	Total amount of resources obtained from of production and non-production	Milliard Rials	15% increase per year

Received 17/04/2018
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		Increasing the allocation of financial resources to development projects with technical and economic justification	Total financial resources received for implementation of development projects	Milliard Rials	155% Increase per year compared to one year
Customer	Increasing the stakeholders' satisfaction	Satisfaction level of customers	Ratio of customers' expectations met of total customers' Expectations	%	2% Increase per year
Internal processes of business	Quantitative, qualitative and diversity development of production and completion of the value chain	Waste rate	The ratio of total losses related to the process of product realization and its support to the total production tonnage	Ton	20% Reduction per year
		Intensity of energy consumption	Total consumption of energy carriers / Total product produced	Gj / Ton	1% Reduction per year
		Intensity – a Frequency of incidents	√coefficient of intensity * repetition coefficient /1000	Number	50% reduction compared to
		Production ratio of special grade products	proportion of tonnage of special grade polymeric products to the total	%	2% increase per year
		proportion of incidents caused by human errors	Total number of incidents / incidents caused by human errors	%	10% reduction compared to one year before
		Lost production of polymeric products	Reduced production of polymer products compared to design	%	zero
		Reduced total production	Total amount of reduction of total productions of company compared to design	%	zero
Growth and learning	Reforming the financial and administrative structures	Total Productivity	Output to input	%	2% Increase per year
		Innovation level of employees	Number of innovative experts to the whole experts	%	4% Increase per year
		Progress of comprehensive informatics plan of complex	The number of processes covered by IT to the whole process	%	5% Increase per year

Table 10.Manintenance from the BSC perspective

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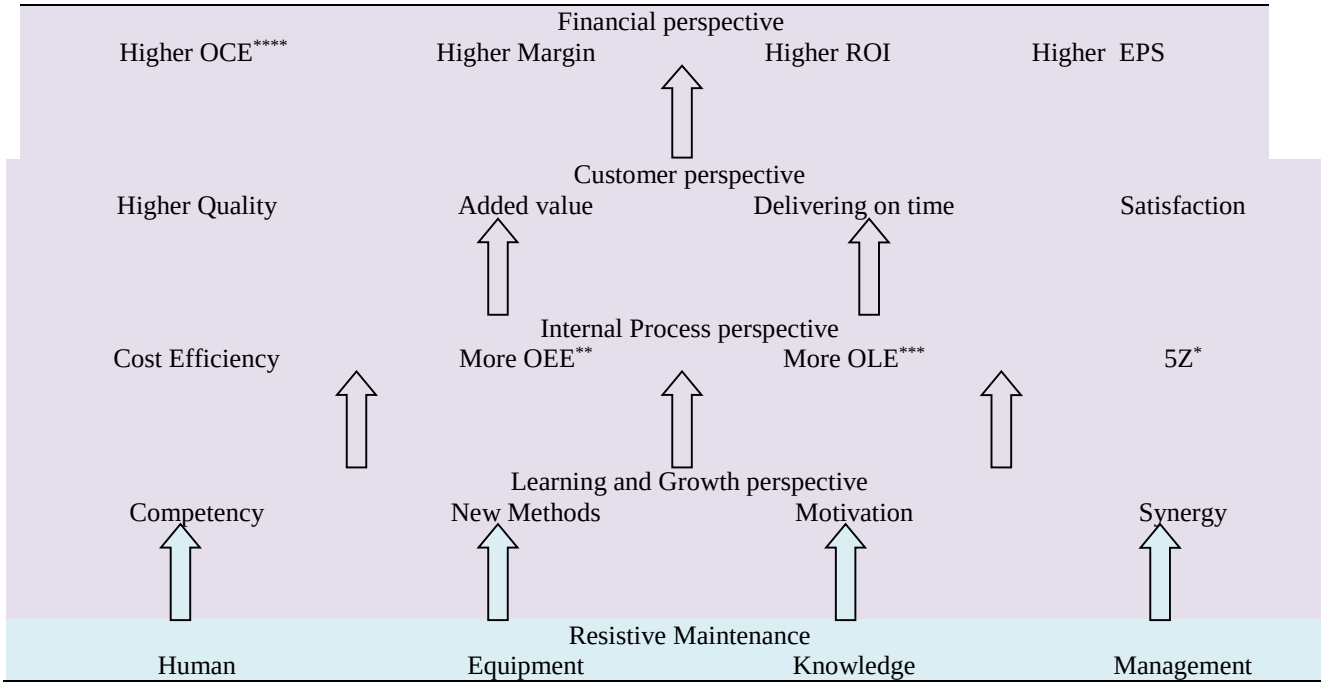

*5Z (Zero Break down, Zero Defect[23], Zero Incident[24], Zero Pollutant, Zero Unhealthy),

**OEE : Overall equipment effectiveness [25]and[26] ,

***OLE: Overall labor effectiveness [27] , ****OCE : Overall Cost Efficiency [28]and[29]

4. ASSESSMENT AND INTERVIEW QUESTIONS:

In the assessment models in the first stage, assessment is performed in the form of self-reporting (development of statements such as EFQM[30],IRMA_AWARD[31],IR-HRM[32], written response to questions based on the Likert spectrum, such as IPAM –AWARD[33]. The assessors study it and in order to confirm the statement, they usually examine it from site, and in addition to scoring, they report the strengths, improvable [34], [35], [36] points, and their recommendations. In visiting the site, in addition to examining the evidence, people are interviewed. The logic of assessment is based on radar logic. The scoring method of the excellence model is based on the RADAR[37] logic, which includes the elements on table11.

Received 17/04/2018
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Table11.RADAR logic

R	*A*	*D*	*A&R*
Result	Approach	Deploy	Assessment & Refine

In the presence interview, special conditions should be considered for the interviewee. For the effectiveness of the interview, a sense of trust should be created between the parties so that the interviewee feels secure so that he can express his ideas without any concern. The assessor team, usually between 2 and 5 people, should ensure that their data will remain confidential and will not use them against individuals. The managers' dignity should be considered in the interviews. Strategic questions should be asked from senior managers. As interviews cover different levels of organization and 50 resistive maintenance elements, better and accurate results will be achieved. In the interview, time and time should be managed. Typically, between 45 minutes and one hour is adequate for an interview.

For recording, the interviewee must be allowed to ask, never to be photographed from interviewing the film without any permission, should be avoided of anything that is to be discouraged and worried. For note-taking, the consent of interviewee should be obtained and the interview should not be videotaped, and everything causing distrust and concern should be avoided.

Normally, questions are documentary and classified based on organizational positions, so that they cover the main elements of the resistive maintenance excellence model [38]. The focus in each unit may be on some of the main elements of the excellence model. The resistive maintenance model has three sections (roots, methods, and results), which are as follows.

3.1 Questions related to the first section (Roots)

3.1.1 Human Resources:

3.1.1.1 What is your plan to develop your human resources?

3.1.1.2 How are educational per capita and its effectiveness assessed?

3.1.1.3 Which criteria do you apply to assess the competence and skills of individuals?

3.1.1.4 How is the process of delegating the authorities for employees fulfilled?

3.1.1.5 Do employees have sufficient financial and administrative authority to perform their tasks?

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3.1.1.6 How is the level of adherence of employees to ethics charter assessed?

3.1.1.7 What activities are being undertaken to increase the motivation of human resources?

3.1.1.8 Why employees' satisfaction is important to you?

3.1.1.9 Is the view of employees about the offered welfare services obtained?

3.1.1.10 How satisfied are employees with sporting and health services?

3.1.1.11 How is employees' commitment measured?

3.1.1.12 What is the work teamwork culture in performing activities?

3.1.1.13 Which activities are carried out to match the mental models of individuals?

3.1.1.14 Does organizational structure improve consistent with employee growth?

3.1.1.15 How many people are interested in working in their organization?

3.1.2 Management:

3.1.2.1 How does the management fulfill its leadership role?

3.1.2.2 Are mission, ideal, and strategy of organization announced by senior management?

3.1.2.3 How does the management ensure that the mission, ideals and strategy of the organization are understood and managed by employees?

3.1.2.4 Have the tasks and responsibilities of employees been defined correctly according to organizational structure?

3.1.2.5 What are the management plans to empower employees?

3.1.2.6 How resources are planned in an organization?

3.1.2.7 How are activities, resources allocation, and organization's function controlled?

3.1.2.8 On what base the basic organizational structure has been designed?

3.1.2.9 How are human resources equipped?

3.1.2.10 Are resources and organizational structure adequate and appropriate for the mission and strategies to achieve the organization ideal?

3.1.2.11 How does the management monitor and manage the works?

3.1.2.12 How are corrective actions managed?

3.1.2.13 How are reports and feedback of the activities delivered to management?

3.1.2.14 How does the CEO or the head of the organization perform the task of leadership and management?

Received 17/04/2018
Approved 10/06/2018

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3.1.2.15 On what process managers make decision?

3.1.3. Knowledge:

3.1.3.1 Is knowledge management applied in your organization?

3.1.3.2 How data and information are collected and monitored?

3.1.3.3 How is the accuracy of the obtained data obtained?

3.1.3.4 Are technical and managerial standards used in performing the company's activities?

3.1.3.5 How much do managers and employees pay attention to observe the legal requirements and rules?

3.1.3.6 Are working methods defined for the activities and relationships of the relevant offices?

3.1.3.7 Are working instructions prepared and used to perform the work?

3.1.3.8 Are software and manual procedures adequate and appropriate to access accurate and updated data?

3.1.3.9 How is the history of activities recorded, stored, and used?

3.1.3.10 What are the activities of research and development to create knowledge?

3.1.3.11 Is the company's knowledge provided to academic centers?

3.1.3.12 How is the intellectual property of the company's registered knowledge kept?

3.1.3.13 How is organization's explicit knowledge used?

3.1.3.14 How does the updated knowledge enter to the company?

3.1.3.15 What mechanism is used to transform the implicit knowledge of employees into explicit knowledge?

3.1.4 Equipment:

3.1.4.1 Does equipment has identification cards in your organization?

3.1.4.2 Have requirements and standards been observed in the design and construction of equipment?

3.1.4.3 What working conditions and environment govern to equipment?

3.1.4.4 Has the function of equipment been defined?

3.1.4.5 Can material required for stationary equipment be prepared?

3.1.4.6 Are there any spare parts needed for the equipment in stock?

3.1.4.7 Are required materials supplied timely and available for performing the work?

Received 17/04/2018
Approved 10/06/2018

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3.1.4.8 Is there a proper and adequate private and public tool for performing the activities?

3.1.4.9 Are special machines and tools available for ease of operation?

3.1.4.10 Are there appropriate workshops and space at site for performing the working activities?

3.1.4.11 Are the facilities necessary for the transportation of equipment used safely and by observing the technical points?

3.1.4.12 How is equipment classified in terms of risk and sensitivity?

3.1.4.13 What are criteria used for replacing the equipment?

3.1.4.14 How is the health of the equipment monitored?

3.1.4.15 How much maintenance is important for business?

3.1.5. Criteria:

3.1.5.1 What model is used to assess the organization?

3.1.5.2 How indicators are assessed?

3.1.5.3 Is radar process used in the assessment?

3.1.5.4 In SWOT method is used in examining the internal and external conditions?

3.1.5.5. Is the BSC used in the development of a strategy map?

3.1.5.6 How is benchmarking performed in organization?

3.1.5.7 How are internal and external superior experiences used to improve the function?

3.1.5.8 Which steps are taken in process of determining the micro and macro goals in the company?

3.1.5.9 How goals become operational and budgeted?

3.1.5.10 How are key performance indicators determined and measured?

3.1.5.11 How are the fulfillment of the goals and indicators monitored?

3.1.5.12 How are the efficiency and effectiveness of activities measured?

3.1.5.13 How is effectiveness of key activities and indicators assessed?

3.1.5.14 How is the process of reforming goals and indicators carried out?

3.1.5.15 How do the new criteria enter into the system and the existing conditions?

3.2 Questions related to the second part of the methods and tools (method):

3.2.1 Is autonomous maintenance performed by operation?

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3.2.2 Is attention paid to 5Z approach (zero defect, zero incident, zero pollution, zero un- healthy, and zero Breakdown)?

3.2.3 Are employees involved in decision making?

3.2.4 Is the general effectiveness of the equipment measured?

3.2.5 How is equipment classified in terms of sensitivity and importance?

3.2.6 Are maintenance and technical inspections planned according to the degree of sensitivity?

3.2.7 Is the RCM method used for equipment?

3.2.8 Is FMEA Method used?

3.2.9 Is the RBI method used in stationary equipment?

3.2.10 Is the risk of equipment being investigated?

3.2.11 Is corrosion control management used?

3.2.12 Is the RCA method used for errors and stops?

3.213 Are the Run to Failure, Preventive, Predictive and Proactive (R3P) techniques used?

3.2.14 What are tools used in predictive maintenance?

3.2.15 How are Monitor, Repair, Replacement and Redesign Monitoring, Repair, Replacing and Reengineering (M3R) operationalized?

3.2.16 On which approach does activities focus?

3.2.17 At which level and equipment does SIL used?

3.2.18 Is LCC method used in the process of decision making and selection of equipment?

3.2.19 How effective are visits and five senses in the demand for repair work?

3.2.20 Are CMMS and ERP used in organization?

3.2.21 Are reports and analysis of failures taken from CMMS?

3.2.22 How are Smart Software and Data checkers used?

3.2.23 Is Industry 4.0 method used in the company?

3.2.24 Are suitable hardware and software available for using methods and tools?

3.2.25 How are tools and methods upgraded?

3.3 **Questions related to the results section (results):**

3.3.1 How is reliability index defined, targeted and calculated?

Received 17/04/2018
Approved 10/06/2018

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3.3.2 Is equipment availability is defined, targeted and calculated?

3.3.3 What is the service level for equipment maintenance?

3.3.4 How are minimum and maximum determined?

3.3.5 How is optimal order value determined?

3.3.6 How are many specialists available for maintenance?

3.3.7 What is the ratio of planned maintenance to total maintenance?

3.3.8 What is the contribution of each of the R3P techniques?

3.3.9 What is the efficiency of overhaul?

3.3.10 Is equipment efficacy indicator (OEE) targeted and calculated?

3.3.11 Is human resources efficiency indicator (OLE) targeted and calculated?

3.3.12 How is the integrity of the elements measured?

3.3.13 Are safety indicators (repetition rate and severity of incidents, risk and study HAZOP) measured?

3.3.14 How are environmental indicators (air, water and soil) monitored?

3.3.15 What is the process of EPS and ROI?

3.3.16 What is the ratio of sales to production and what is its trend?

3.3.17 What is the cost of maintenance to investment?

3.3.18 What is the ratio of product quality and its trend?

3.3.19 What is the efficiency of production capacity and its trend?

3.3.20 How much is value added and how is created?

3.3.21 How is energy saving indicator defined, targeted, and measured?

3.3.22 What is the employee satisfaction level?

3.3.23 How is employees' commitment measured?

3.3.24 What is the continuous improvement trend of indicators?

3.3.25 How is the sustainability of the results monitored?

3.3.26 What is the level of R & D indicator?

3.3.27 How is resistive maintenance coefficient measured?

3.3.28 What is the ratio of executed projects to exported ones?

3.3.29 What is the wrench time in maintenance?

3.3.30 What proportion of corrective communication projects will be completed according to the plan?

Received 17/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 752-774. ISSN 1390-9304

5. CONCLUSION

In this paper, four functional maintenance concepts have been investigated. 1. Determining the criteria and determining the sensitivity of the equipment. 2. Performing RCM stages on four critical equipment. 3. Using a balanced scorecard in the company and maintenance 4. Developing the resistive maintenance assessment questions.

The questionnaire and the mean score of 80 industry and university experts were used to determine the criteria and determination coefficients of the sensitivity of the equipment. The results of the studies in Tabriz petrochemical and similar petrochemicals indicate that the determining the indicators, determining the sensitivity of the equipment and the maintenance planning on them and reliable implementation of them and having strategic perspective to maintenance can reduce environmental impacts, reduce safety incidents, increase production, reduce costs, and increase profits. However, it is necessary to work on maintenance model based on domestic capability and as a knowledge-based local maintenance model, given the conditions of our country.

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