Failure Analysis Methods in Critical Equipment

Seyed-Mohammad Seyed-Hosseini[1,*], Kamran Shahanaghi[2], Safar Shasfand[3,4]

[1]Professor, Iran University of Science and Technology, Tehran-Iran // [2]PhD, Iran University of Science and Technology, Tehran-Iran // [3]PhD student, Iran University of Science and Technology, Tehran-Iran // [4]Tabriz Petrochemical Company, Tabriz-Iran

*Corresponding Author:. **Seyed-Mohammad Seyed-Hosseini,** e-mail: seyedhosseini@iust.ac.ir

ABSTRACT

Protection of national capitals and physical assets in upstream and downstream companies of Iranian oil industry (oil, gas, refining, and petrochemicals) that worth more than 400 billion dollars is highly important. Repetition of failures and unwanted stops are one of the major challenges of production and maintenance managers. Stops cause reduction of reliability and availability as well as increasing total price of the product and decreasing business competitiveness. Thus, planning and adopting maintenance policies based on root cause failure analysis in critical equipment leads to increasing life cycle, reliability, availability, and productivity. In this paper, it is attempted to use fish bone technique for explaining major failure causes of equipment, fault tree analysis for identifying failure modes, and Parto technique for identifying percentage and frequency of failures on pump 101 and drier 301. In addition, regression method was used for studying behavioral model of this equipment within a twenty-year period. Research findings indicate that 81 percent of major failure factors in production equipment include poor in executive procedures (24%), human error (22%), poor quality of materials and parts (20%), and lack of personnel training (15%).

Key words: Root analysis, fish bone, fault tree, Parto, behavioral model

1. Introduction

Root cause failure analysis (RCFA) [1] is one of the major and basic methods for improvement of reliability in every industrial unit, leading to quick and considerable effectiveness. On the other hand, using root cause failure analysis methods has been originally used in the issues related to safety management, so that the accident or event is explored systematically when using RCA or RCFA methods. With focus on different parts of the accident, its all aspects are analyzed and influence of personal tastes and emotions of the individuals in root finding of the accident causes is prevented. When no specific method is used for analysis of root causes of the accident, the most apparent and external factors are recognized as the major factors of the accident. The users and personnel involved in the accident are mainly questioned, and they are often identified as the guilty, and the hidden layers, which are mostly the root causes, are not ever entered. Undoubtedly, the organizations always face barriers, problems, defects, failures, and unwanted situations that jeopardize their interests and position in the business market. Many of these companies always attempt to quickly resolve these problems and unfavorable conditions and seek to resolve them regardless of the root cause of the problem. While using the root analysis approach, it is possible to avoid occurrence of the same problems in order to avoid. In fact, the ultimate goal of using failure analysis techniques is to solve the root causes of problems, not just identifying them. Considering multiple effective factors, complicated and delicate nature of working

processes in industries, problem solving for preventing from repetition of many unpleasant accidents requires accurate, technical, and expert investigation using standard, efficient, and specialized methods in this regard. Root cause analysis is one of the standard and reliable methods in this regards. Studies indicate that most failures occurring in the company are those that occur more than once for similar causes. This class of failures is known as chronic failures. Although they account for 20 percent of total failures, they cause 80 percent of the damages[2], and it means that eliminating of these failures cause great benefit in short-term and it manifests significance of RCFA.

2. Literature review

They [3] concluded that the installation process, the skill of operators, trained personnel of maintenance, environment variables, and gas quality can create the difference on expected availability of the design and operation. The reliability of the gas turbine in influenced by the skill of gathering, the training of maintenance forces , environmental changes (temperature, humidity, particulate matter) and the quality of gas consumption [4].They [5] conducted and compared below studies on the reactor inlet pipeline: 1. the classic analysis of reduced thickness (Degradation Analysis) 2- Analysis FORM (First -Order Reliability Method). Reliability is the probability that the machine or equipment can work continuously without failure at the time specified in the expected operating conditions [6]. The effectiveness of these approaches is assessed by the reliability indicators (MTBF) [7], availability (MTTR)[8], the percentage of implementation of PM programs and the rate of emergency maintenance [9], defined in the strategic management process [10] 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 [11]. Conditioning monitoring includes: Vibrations analysis (Mobley,1999 [1], [12] , ISO − 17359 ,2011 [13], ISO − 13373 -1 ,2002 [14] , ISO − 13373 -2 ,2016 [15], ISO − 13373 -3 , 2015 [16]) , Oil Analysis (ISO − 4406, 1999) [17] , Sound, RCFA/FEMA [18] ,Condition Based Maintenance [19].

3. Root Cause Failure Analysis in Equipment

3.1. Using Fish Bone [20] Technique

Causal relationship is such that the cause of an effect can be affected by other causes. Therefore, in this research, it is attempted to select the most effective and most important "cause" or "causes" among the other existing factors, and put it in a shape to determine their importance toward other causes. Following specifying the effect or unexpected failures in the complex, cause and effect diagram is drawn, and relationship between relevant factors is specified so that the fault or defect, which is against the company's strategic approach to achieve zero error, is minimized aiming at optimization.
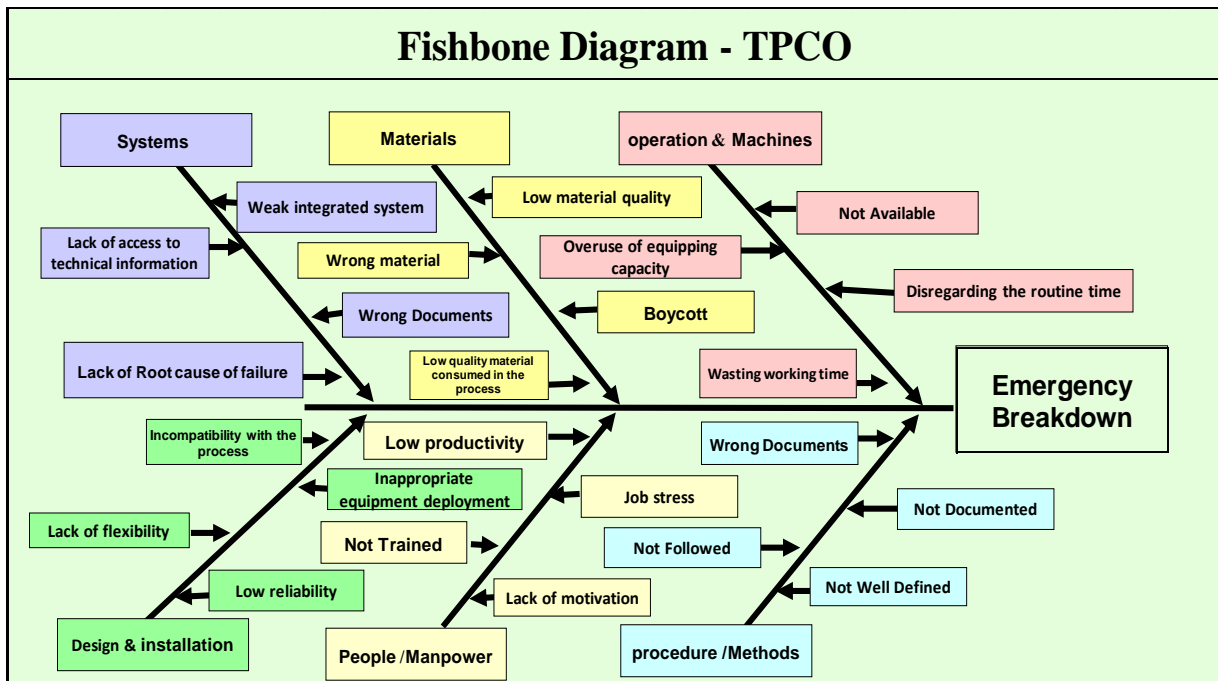
Figre1. Fish bone diagram for Tabriz Petrochemical equipment

3.2. Classification and Prioritization of Equipment

According to the determined criteria and scoring by the experts, all process equipment of the company is prioritized at sensitive, semi-sensitive, and non-sensitive levels. In this paper, drier 301 and pump 101 were selected as the study sample because of their high sensitivity and critical role in the production process, so that sensitivity degree is 97 / 100 in drier 301 and it is 84 /100 in the pump.

3.3. Failure History in Pump 101 and Drier 301

3.3.1. Pump 101

In order to specify feasibility of preventive scheduling program, PM reach rate index and emergency maintenance rate index were calculated so that deviation and distance to the standard program is determined. In fact, the purpose is to specify percentage of realization of preventive routines issued as regulatory preventive program. PM reach rate index for centrifuge pump (50 P 101 A) is about 82 percent, while emergency maintenance rate is about 37 percent for the same equipment.

Table1. Summary of pump P101 failure file

No.	Repair Type	Date	Defect Cause	Actions	Normal	Cumulative	MTBF
				TAG NO. 50-P-101A		Up -Time	
1	EM	1997/10/26	Electro Motor Vibration	Bearing Replacement	4900	4900	4900
2	EM	1998/06/06	Seal Leakage	Repair of leakage	5376	10276	5376
3	EM	1999/08/10	Seal Leakage	Repair of leakage	10296	20572	10296
4	EM	2000/07/03	Turned Around	Bearing Replacement	7896	28468	7896

No.	Repair Type	Defect Cause	Actions	Repair Date	Normal	Cumulative	MTTF
5	EM	Electro Motor high Vibration	Bearing Replacement	2000/08/17	1056	29524	1056
6	EM	Flow reduction	Bearing Replacement	2001/08/13	8664	38188	8664
7	EM	Abnormal Sound	Bearing Replacement	2003/08/30	17928	56116	17928
8	EM	Abnormal Sound	Bearing Replacement	2005/11/17	19440	75556	19440
9	EM	Electro Motor high Vibration	Bearing Replacement	2007/02/04	10704	86260	10704
10	EM	Abnormal Sound	Bearing Replacement	2007/09/16	5328	91588	5328
11	EM	Electro motor Abnormal Sound	Bearing Replacement	2007/09/24	168	91756	168
12	EM	Electro motor Abnormal Sound	Impeller modification and Bearing replacement	2014/10/19	61968	153724	61968
13	EM	Abnormal Sound	Replacement of Impeller , Shaft , O- ring & Gaskets	2015/11/08	9264	162988	9264
14	EM	Electro motor Abnormal Sound	Cleaning of Rotor and replacement of Bearing	2016/11/26	9240	172228	9240
15	EM	Abnormal Sound	Replacement of Impeller , Shaft , O- ring & Gaskets and Bearings	2017/2/08	1800	174028	1800
16	EM	High vibration of Bush	Repair of Case and Shaft	2017/03/17	888	174916	888

3.3.2. Drier 301

PM reach rate index for drier 32-DH-301 B is about 85 percent, while emergency maintenance rate is about 58 percent for the same equipment. The standard defined in this regard for PM reach rate index is about 90 percent or more, and the standard defined for emergency maintenance rate index for rotating equipment under preventive maintenance program is about 0.5 percent or lower. Lack of proper implementation of preventive maintenance and repair program is one of the causes for emergency failures in equipment that make them to be out of control. It may occur due to various causes such as failure to timely delivery of equipment from operation unit to perform preventive routine, increasing number of preventive routine conversions and reducing quality of repairs.

Table2. Summary of Drier DH 301 failure file

TAG NO. 32-DH-301 B				Up -Time (Hrs.)		MTTF (Month)
No.	Repair Type	Defect Cause	Actions	Repair Date	Normal	Cumulative	
1	EM	Abnormal Sound of Bearing	Bearing Replacement	2003/11/08	1488	1488	2.1

2	EM	Abnormal Sound of Bearing	Bearing Replacement	2004/12/08	9504	10992	13.2
3	EM	Abnormal Sound of Bearing	Bearing Replacement	2005/01/22	1080	12072	1.5
4	EM	Abnormal Sound of Bearing	Bearing Replacement	2005/03/29	1584	13656	2.2
5	EM	Abnormal Sound of Bearing	Rotor Balancing & Seal Replacement	2005/04/05	168	13824	0.2
6	EM	Abnormal Sound of Bearing	Rotor Balancing & Seal Replacement	2005/12/22	6168	19992	8.6
7	EM	Un-balancing	Rotor Balancing & Bearing replacement	2006/05/22	3600	23592	5.0
8	EM	Bearing defect and shaft corrosion	Buildup of rotor & Bearing replacement	2006/10/17	3456	27048	4.8
9	EM	Abnormal Sound	Bearing replacement of electro motor side	2006/10/28	264	27312	0.4
10	EM	Un-balancing	Rotor Balancing	2006/11/11	336	27648	0.5
11	EM	Vibration and abnormal Sound	Rotor Balancing & Seal Replacement	2007/02/02	1992	29640	2.8
12	EM	Flange erosion	Buildup of rotor & Rotor Balancing	2007/12/22	6912	36552	9.6
13	EM	Bearing abnormal sound	Seal & Bearing Replacement	2008/01/06	384	36936	0.5
14	EM	Coupling oil leakage	Seal & Bearing Replacement of Turbo coupling	2008/05/06	2904	39840	4.0
15	EM	Bearing abnormal sound	Seal & Bearing Replacement	2010/01/07	14520	54360	20.2
16	EM	Vibration and abnormal Sound	Rotor Balancing & Bearing replacement	2010/07/25	4392	58752	6.1
17	EM	Abnormal Sound	Bearing replacement of electro motor side	2010/08/04	240	58992	0.3
18	EM	Abnormal Sound	Bearing replacement of electro motor side	2012/01/03	8640	67632	12.0
19	EM	Turbo coupling oil leakage	Seal & Bearing Replacement of Turbo coupling	2012/02/08	864	68496	1.2
20	EM	Misalignment of electromotor shaft	Bearing greasing and Rotor cleaning	2012/03/26	1152	69648	1.6
21	EM	Defect of Turbo coupling and Gear box	Turbo coupling and conveyer repair	2012/03/27	24	69672	0.0
22	EM	Bearing abnormal sound	Rotor ,Seal and Bearing replacement	2012/04/09	312	69984	0.4

23	EM	Vibration and abnormal Sound	Rotor Balancing & Bearing replacement	2012/07/12	2160	72144	3.0
24	EM	Turbo coupling oil leakage	Gear box replacement	2012/12/16	3024	75168	4.2
25	C	Abnormal Sound	Bearing replacement of electro motor side	2014/03/06	10920	86088	15.2
26	EM	Shaft corrosion	Rotor and Oil replacement	2014/03/12	144	86232	0.2
27	EM	Bearing failure and Stop	Rotor and Oil replacement	2014/10/04	4824	91056	6.7
28	EM	Bearing failure	Rotor and Oil replacement	2014/10/12	192	91248	0.3
29	EM	Bearing failure	Rotor and Bearing replacement	2014/11/27	864	92112	1.2
30	EM	Bearing failure	Rotor replacement	2015/05/07	3456	95568	4.8
31	EM	Bearing failure	Rotor and Oil replacement	2015/05/10	72	95640	0.1
32	EM	High Vibration and abnormal Sound	Rotor replacement	2016/11/22	13128	108768	18.2
33	EM	Bearing failure	Rotor and Oil replacement	2017/01/07	1104	109872	1.5

3.4. Using Fault Tree Technique

The other technique used in this research is fault error technique, which is used for identifying and determining possible causes for fault analysis. Figure 2 indicates all fault mechanisms in pump and non-pumping and fluid discharge. These mechanisms were drawn using previous experiences and holding various meetings with experts in this regards knowing occurrence of faults for determining their root causes. The figures draw them in the form of fault tree.
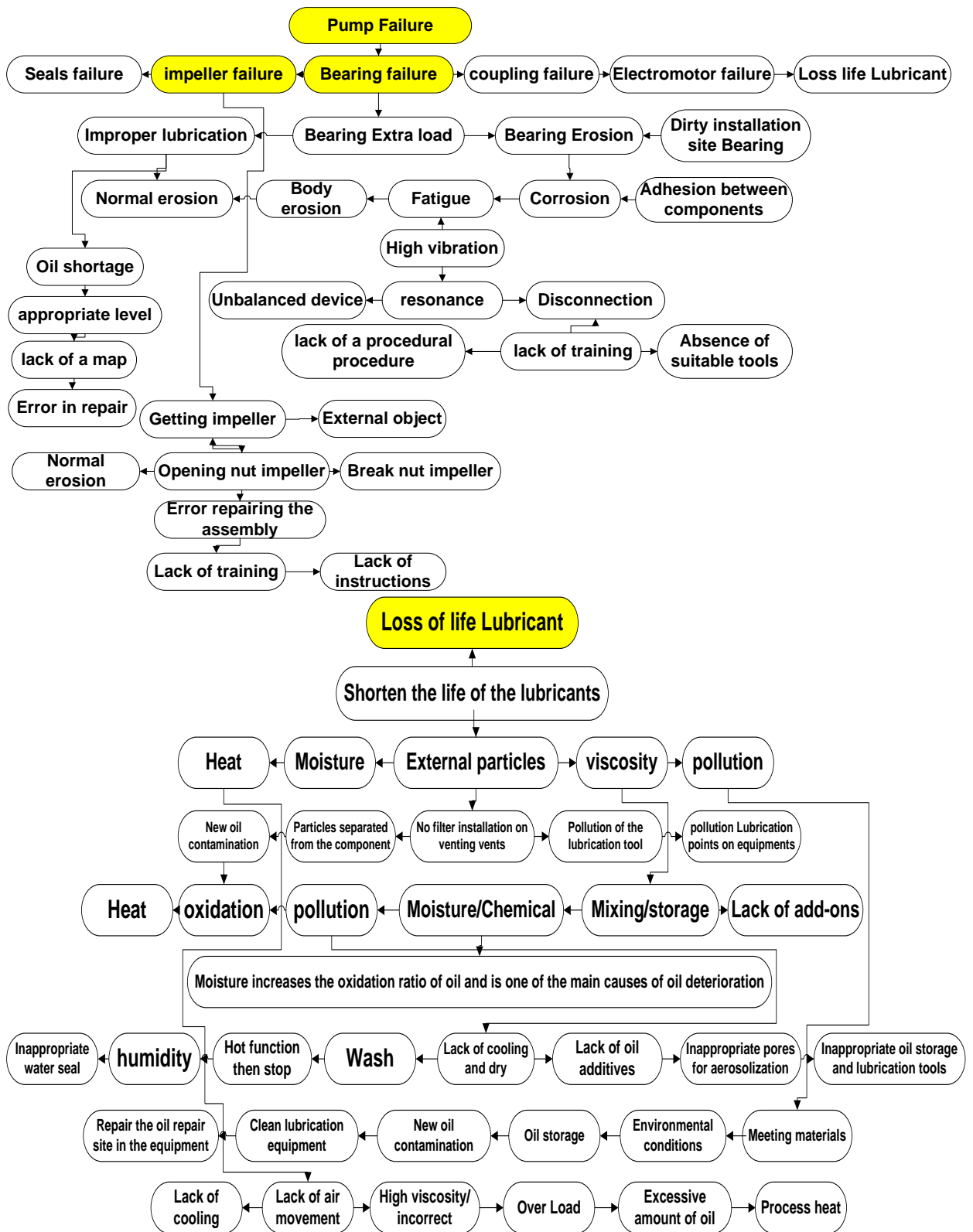
Figure2. Fault tree drawn for pump dysfunction

3.5. Twenty-Year Failure Analysis

3. 5. 1. Twenty-Year Failure Analysis for Pump 101

In order to analyze equipment behavior, those equipment was used that were more vulnerable to failure, and actually their average time interval was smaller. Maintenance and repair policy of the company is the preventive maintenance based on different check and inspection periods proposed by the equipment constructor. Thus, there are specific periods for inspection of equipment under study as the criterion standard, and then unexpected failure diagram is drawn based on function hours and number of emergency failures. Their lines are fitted in order to analyze equipment failure behavior analysis. Their behavioral model is studied and finally its function is obtained, their behavior is analyzed, and standard deviation is specified. In the following, two selected sensitive equipment of the complex are given according to Figures 3 and 4.
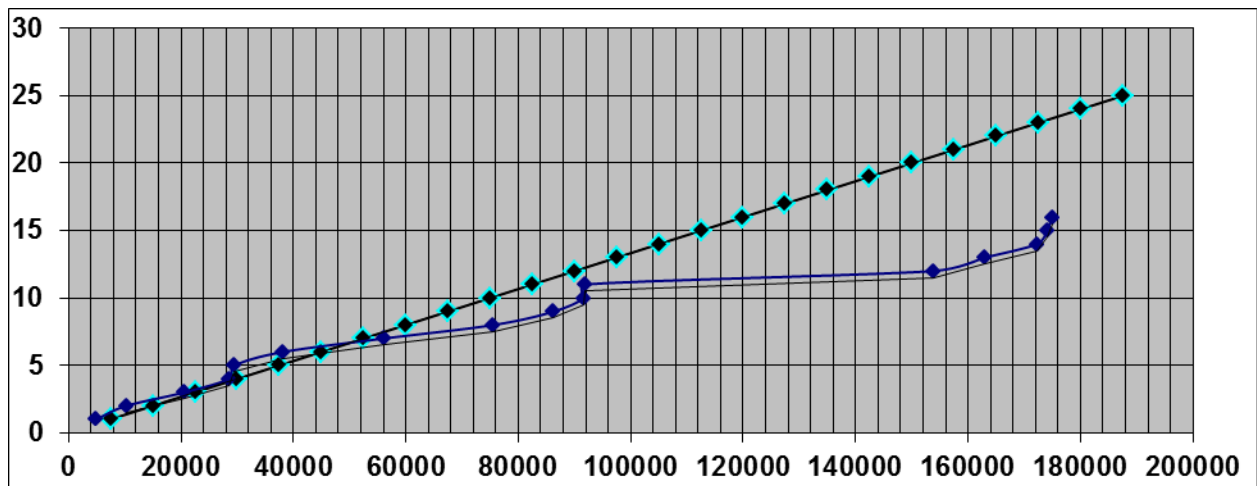

Figure3. Pattern of unexpected failures in pump 50 P 101 A

According to Figure 3, the standard and current status diagrams for centrifuge pump 50-P - 101A in area 1 was accurately analyzed based on above techniques, results of which are described in the following.

1. Delay in issuing preventive routine, failure to observe the issuing intervals, or non-implementation of preventive routine caused increasing intervals between two curves.
2. At point 3, routine of current status, which is trivially functionally different from routine 7 of standard status, both suggest basic repairs of the equipment. In current trend with 500 hours fewer function and 4 routines fewer than in equipment compared to emergency routine was repaired. That is, failure in the equipment was so that there was no option other than stop and repair of the equipment, while the equipment was working when issuing routine C, indicating its service. Implementation of routine C is merely for prevention from occurrence of unpredicted failures and avoiding sudden stops in the production process.
3. In routines 5 and 6 of the current trend, two emergency repairs were done within 14 months of time intervals. Considering the function table, which suggests 350 hours of functioning between two emergency failures, and according to the list of changed pieces in two routines, it is found that there is fault in repair operations. Routines 5, 6, and 7 of the current trend give a steep slope to the trend leading to decreasing in the distance between the two diagrams.
4. At point 9 in current trend, and point 14 in standard status, the same current as clause 2 is exactly repeated.

5. Routine C is recommended at point 21 in standard status, while according to this point at current status (routine 12), routine C is transformed to B. it leads to implementation of emergency maintenance (EM) at point 13 after 200 hours of functioning. In case of non-transformation of routine C to B, occurrence of an emergency maintenance could be prevented.
6. Implementing emergency maintenance after routine cat point 18 in current trend indicates existence of fault in qualitative operation of the repair.

3. 5. 2. Twenty-Year Failure Analysis for Drier 301

As observed in Figure 4, the bold line indicates trend of unplanned failures in terms of different periods since operation of this equipment. Its trend is ascending by increasing function of the equipment. Its line equation and correlation coefficients of the points are fitted. The faded line in fact indicates trend of periodic inspections of the equipment based on the Based on manufacturer's recommendations. Although in this method, repair activities were implemented after occurrence of failures, since there is readiness for coping with such failures among repair forces in the repair office of the Company X, the experiences and taken measures are recorded in the equipment file, and they are analyzed in the repair planning office. Following drawing the diagrams, analytical tools would be required, so that the weaknesses and strengths of the system are identified and weaknesses are corrected and strengths are enhanced and effective maintenance and repair approach is realized. In other words, the most important analytical methods used in effective maintenance and repair system are used in this step, including root cause analysis (RCA) and root cause failure analysis (RCFA). The basic causes of failure in equipment and machines are smartly searched in these methods. Five Whys and Fish-Bone Diagram are the most practical and simplest methods. The goal of these methods is finding quick, efficient, and economical cause of failures and correcting the failure causes, rather than just finding the effect, as well as collecting information in order to help to prevent from re-occurrence of the failure.
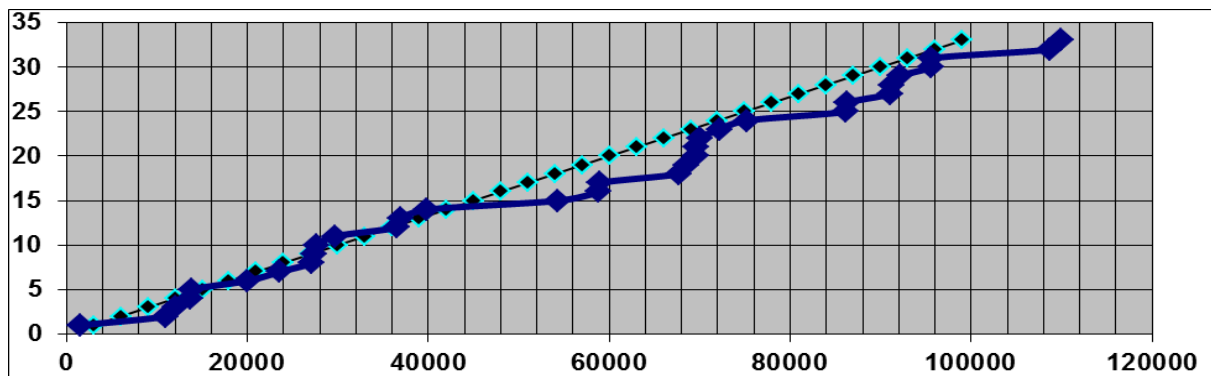

Figure4. Pattern of unexpected failures in Drier 32 DH 301 B

Spot analysis related to failures of 32 DH 301 B is presented in the following:

1. As observed, the first emergency failure occurred after 1488 hours of working due to abnormal sound, which led to replacement of bearing. It will be discussed in its place, because it occurred about 2 months after launching the equipment. Therefore, different factors may be effective including inadequate expertise in operation, inappropriate establishment in the location, etc.
2. Regarding preventive routines 2, 3, and 4, it should be noted that the first one was issued with a 816 h delay, the second one was issued earlier than due time, and the third one was

issued 1000 h earlier. Thus, Routine C (basic repair of equipment) had to be issued and implemented, because implementation of preventive routine C, especially in such sensitive equipment, is highly economical than emergency failures, and our preventive system is essentially aimed at reducing emergency failures. Thus, preventive routine C had to be issued and implemented at its due time.

3. As observed, because of non-implementation of preventive routine C at its due time, the second emergency failure occurred after about 1000 hours at point 5 because of unusual sound of bearing, and the bearings were replaced. However, despite replacement of the bearings, again the next emergency failure occurred after 1000 hours at point 6 with the same cause. The interesting point in this regard is similarity of replaced equipment code.

4. The next preventive routine B (point 9), which occurred after emergency failure, was issued much earlier than the due time, and not only lacked the necessary efficacy, but also it can be stated that it led to emergency failure at point 8, 700 hours after implementation of preventive routine. The interesting point is occurrence of the next emergency failure exactly 168 hours after repair, or in other words, replacement of its bearings, which is contemplative.

5. Two cases of preventive routines of type B were issued at points 10 and 11; however, they lacked the required efficacy and led to the subsequent emergency failures 525 hours after preventive routines. Nevertheless, rotor balance was also added to the implemented repair actions at point 12.

6. Again, preventive routine B was issued by mistake and much earlier than the due time at point 13, which occurred 1800 hours after the next emergency failure (point 14). It was due to severe unbalance and led to a rotor balance. It was the same cause observed in the previous emergency failure, but it had been neglected.

7. Two cases of failures occurred 700 hours after preventive routine at points 16 and 17. Interestingly, the interval between these two failures is 600 hours, and they are due to the bearing failure and severe rotor corrosion, leading to rotor welding and turning, and replacement of turbo coupling bearing and balancing of the rotor.

8. Again, preventive routine B was issued by mistake and much earlier than the due time at point 18, which occurred 348 hours after the next emergency failure (point 19). It was due to abnormal sound and severe shaking that led to the rotor balancing and bearing replacement. It was the same cause observed in the previous emergency failure.

9. Three cases of preventive routines, which were issued at points 20, 21, and 22, either were issued earlier than the due time or lacked required efficacy because of incorrect transformations at wrong times. It is approved at point 22, where the preventive

10. routine C was transformed to routine B. it is clearly observed that three cases of emergency failures consecutively occurred (at points 23, 24, and 25) one week after these transformations and implementation of routine B. these failures occurred mainly due to the causes observed in the previous failures, and incurred great costs, which will be accurately discussed at financial phase.

11. Preventive routine was issued by mistake and in a very short interval to the emergency failure at point 26, that is, 300 hours after it. It was not necessary at all to issue such routine at this time in an interval much shorter than 3000-hour time interval.

3.6. Formulas of behavioral model

As shown in figures 3 and 4, studying the drier - 301 break down pattern and fitting it based on the liner trend of Excel software with a correlation coefficient to predict future failures of this equipment is obtained from function 1.Accordingly, for the pump -101, this calculation is made and the formula 2 is obtained, whose coefficient of correlation is $(R_p{}^2=0.9707)$

$$Y = 7E - 11x^2 + 0.0003x + 0.4543 \quad \textbf{(1)}$$
$$Y = -2E - 10x^2 + 0.0001x + 0.9469 \quad \textbf{(2)}$$

3.7. Using Parto Technique

The analysis shows that a specific cause of a different set of failures occurs. Hence we determined these failures and determined their number over the 20-year for two studied equipment. Then, we combine these data together and then place the failures of the highest value to the lowest value in a horizontal row. As shown in figure 5 for drier 301and figure 6 for pump 101, a histogram exists in which its columns represent a variety of failures and, on the other hand, there cumulative values are used to indicate the priority of improvement. At this point, the points that represent the 80% cumulative line are determined and the focus on the types of failures that are on the left side of this line will be of particular important.
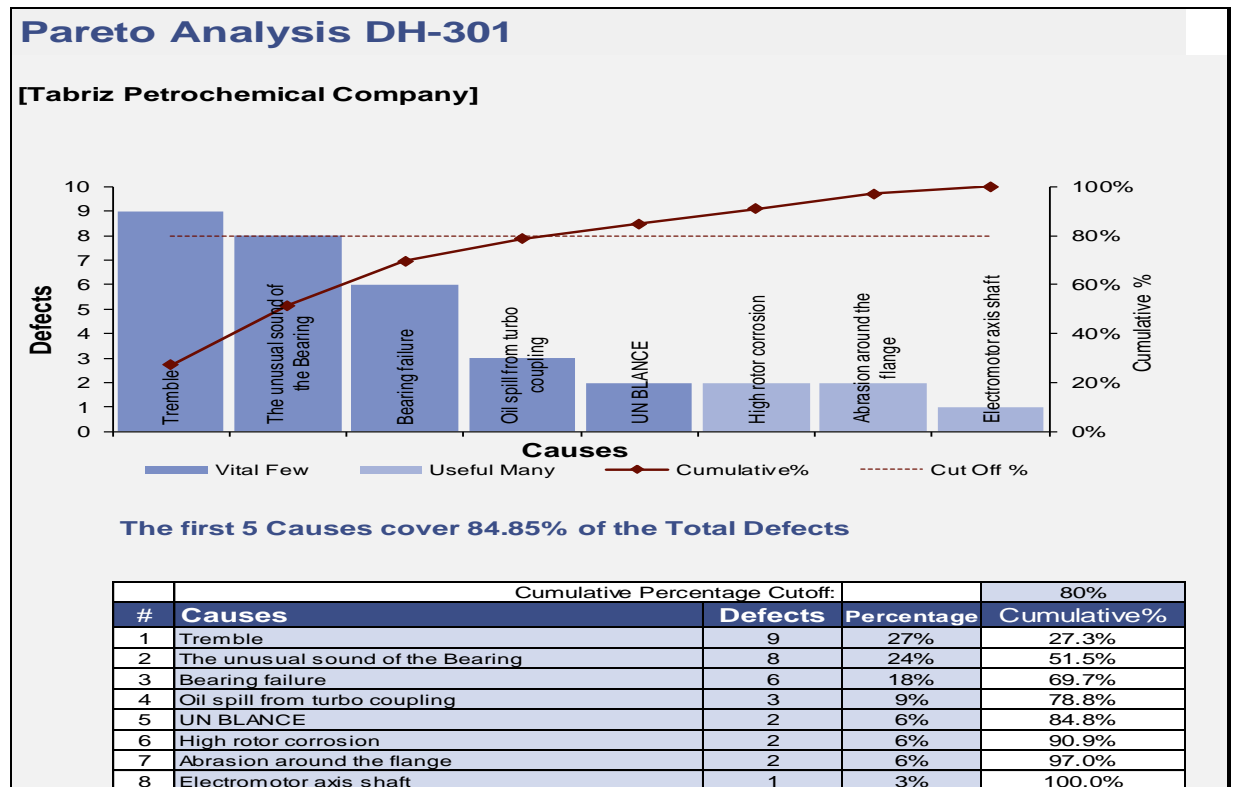

Pareto Analysis DH-301

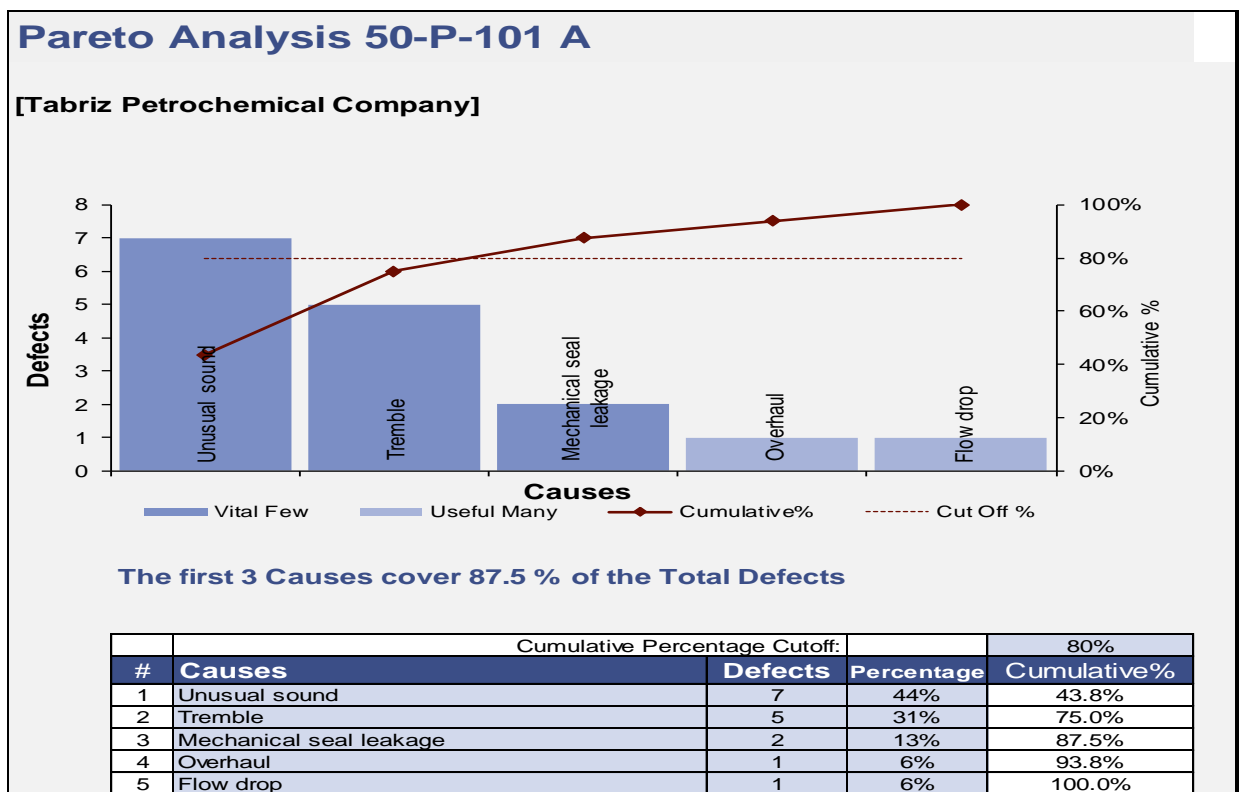**[Tabriz Petrochemical Company]**

The first 5 Causes cover 84.85% of the Total Defects

	Cumulative Percentage Cutoff:			80%
#	Causes	Defects	Percentage	Cumulative%
1	Tremble	9	27%	27.3%
2	The unusual sound of the Bearing	8	24%	51.5%
3	Bearing failure	6	18%	69.7%
4	Oil spill from turbo coupling	3	9%	78.8%
5	UN BLANCE	2	6%	84.8%
6	High rotor corrosion	2	6%	90.9%
7	Abrasion around the flange	2	6%	97.0%
8	Electromotor axis shaft	1	3%	100.0%

Figure5. Pareto Analysis DH-301

Pareto Analysis 50-P-101 A

[Tabriz Petrochemical Company]

The first 3 Causes cover 87.5 % of the Total Defects

	Cumulative Percentage Cutoff:			80%
#	**Causes**	**Defects**	**Percentage**	**Cumulative%**
1	Unusual sound	7	44%	43.8%
2	Tremble	5	31%	75.0%
3	Mechanical seal leakage	2	13%	87.5%
4	Overhaul	1	6%	93.8%
5	Flow drop	1	6%	100.0%

Figure6. Pareto Analysis P-101

3.8. Research Finding

According to the studies on failures within the last seven years in the complex equipment as well as the information collected in the form of cause and effect diagrams, fish-bone technique, and Parto technique regarding failure causes in equipment of Tabriz petrochemical Company denote that cause of over 60 percent of failures in equipment may occur in direct relationship with the human factors. In fact, the equipment is affected essentially by unexpected failures, because firstly we do not know how to maintain them. Secondly, the policy adopted for maintenance of the process equipment is applied uniformly, and finally, we do not have enough trained personnel with high motivation to implement maintenance programs and can improve the programs using proper feedbacks.
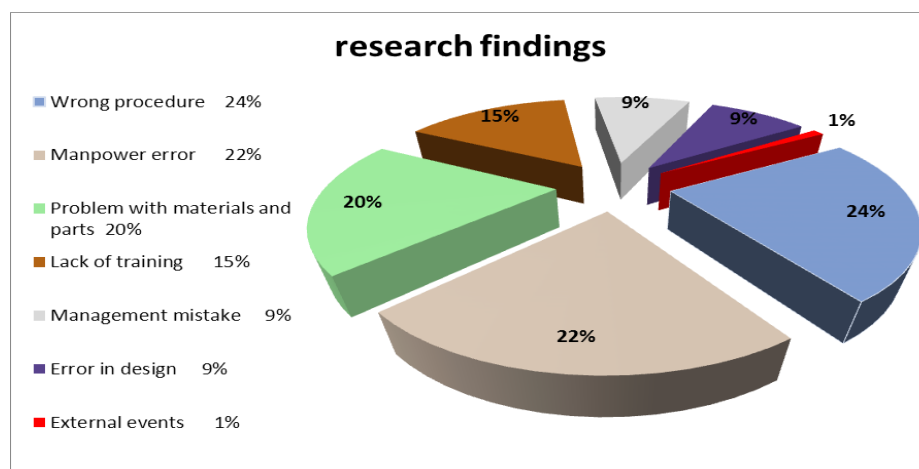

Figure7. Percent of failures in equipment

Following spot analysis and case analysis, the main causes of emergency failures in equipment were identified as follows:

1. Low quality of materials and spare parts used in the repair process
2. Lack of adequate knowledge for operation and inappropriate use of equipment in an excessive load
3. Disproportionation between the material purchased for replacement with the respective equipment
4. Improper deployment of equipment in its place
5. Weakness of repair unit in effective implementation of routines and not paying attention to the qualitative maintenance.
6. Failure to observe the specified intervals for routine issuance

4. Conclusion

Investigation of effects of current preventive maintenance program of the company on equipment reliability and availability as well as identification of their failure models and relationship between failure rate and PM and maintenance approach based on the status monitoring showed that major failures in this equipment are due to low quality of consumed bearings and lack of adequate education for proper lubrication of bearings. In fact, the consumed parts used for replacement lacked required quality in most cases, and poor education for proper lubrication or inappropriate establishment of the equipment at its place in some causes caused reduction of equipment reliability and availability. On the other hand, the extent of effectiveness was evaluated by analysis of relationship between PM, failure rate, reliability, and availability. To this end, it would be easy to estimate that how many of failures were resolved by the current preventive maintenance. Therefore, such activities should certainly be implemented according to proper and systematic planning and they should be based on statistical and mathematical computations and probability theory. Analysis of causes for increasing emergency failures in pumps of chemical tanks due to severe corrosion and behavioral analysis and identification of their failure model led to registration of patent in this regard.

Refrencence

1. Mobley R.K. Root Cause Failure Analysis, Butterworth-Heinemann, 271-276, 1999.

2. Dunford,R. et al. The Pareto Principle, the Plymouth Student Scientist, 7, (1), 140–148, 2014.

3. Carazas,F. J .G. and Souza, G. F. M . Availability Analysis of Gas Turbines used in power plants, Int.J. Of Thermodynamics vol.12 (No.1) pp 28-37, 2009.

4. Barringer, H. P. and kotlyer,M. Reliability of critical Turbo compressor Equipment, 5th International on Process plan Reliability Texas, USA, 1996.

5. Mokhtar, A. A. et al. Comparative study between Degradation Analysis and First order Reliability Method, IJET vol. 9 No: 10, 2010.

6. Stamatis, D H. The OEE Primer, CRC press, 2012.

7. Shasfand,S. OEE & Reliability in Petrochemical industries,*12th ICPAM- IPAMC*,14-15 November, Iran, 2017.

8. Charaf, K. and Ding, H. Is overall Equipment effectiveness (OEE) universally Applicable, International journal of Economics and Finance, Vol.7, No.2. 2015.

9. Assaf, S A., et.al. Performance evaluation and benchmarking for … at Petrochemical corporation using a DEA model, *Int. J adv. Manuf. Technol.*, Springer, London, 2014, DOI: 10.1007/s00170-014-6422-2.

10. Sivaram,N.M. Et.al. Implementing-total-productive maintenance through the ISO9001:2008, SAJIE*, vol24 (2)* pp33, 2013.

11. Stecki JS et al. The rise and fall of CBM, *KEM vol.588* (2014) pp 290 -301, 2014.

12. Behzad, M. et al .Vibration Analysis Case Studies, 10th CMFD, Sharif University, Iran, 2016.

13. ISO – 17359.Condition Monitoring and diagnostics of Machines, Second edition, 2011.

14. ISO – 13373 -1.Vibration Monitoring (General Procedures), First edition, 2002.

15. ISO – 13373 -2.Vibration Monitoring (Processing, Analyzing…), Second edition, 2016.

16. ISO – 13373 -3 .Vibration Monitoring (Guide lines for Vibration diagnosis), First edition, 2015.

17. ISO – 4406. Method for coding the level of contamination by solid particles, Second edition, 1999.

18. Shasfand S, Seyed Hosseini SM. Enlightening Resistive Production, MCSER, Vol. 7, No.4 S2, 2016, DOI:10.5901/mjss.2016.v7n4s2p82.

19. Sinha,P.Towards higher maintenance effectiveness, IJQRM, Vol.32, Iss7, 754-76, 2015.

20. Ilie G. and. Ciocoiu C.N. Application of fishbone diagram to determine the risk of an event with multiple causes management research and practice vol. 2 issue 1, 1-20, 2010.