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An evaluation of failure modes and effect analysis for a battery manufacturing industry

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Abstract

Failure mode and effects analysis (FMEA) is one of the well-known analysis methods where the potential failure modes usually are known and the task is to analyze their effects on system behavior. This thesis paper aim to identifies and eliminate current and potential problems from assembly lines in a battery industry. Feasibility test using control chart aim to find out the error and process performance. This thesis provides work sheets for problems identification and guide lines for recommending corrective actions. This thesis paper also analyzes Risk Priority Number (RPN). The different types of information are very difficult to incorporate into the FMEA by the traditional risk priority number (RPN) model. In this thesis paper we present an FMEA using the evidential reasoning (ER) approach, a newly developed methodology for multiple attribute decision analysis. The proposed FMEA is then illustrated with an application to a fishing vessel. As is illustrated by the numerical example, the proposed FMEA can well capture FMEA team members' diversity opinions and prioritize failure modes under different types of uncertainties.

Keywords: Failure mode and effects analysis, evidential reasoning (ER) approach, risk priority number.

1. Introduction

In the present era, there has been tremendous pressure on manufacturing and service organizations to remain competitive and provide timely delivery of quality products. The managers and engineers have been forced to optimize the performance of all systems involved in their organizations. The deterioration and failure of these systems might incur high costs due to production losses and delays, unplanned intervention on the system and safety hazards. In order to avoid such situations, an appropriate maintenance policy strategy is necessary in order to repair or replace the deteriorated system before failure. Deciding on the best policy is not an easy matter, as the maintenance program must combine technical requirements with the management strategy. A good quality program must define maintenance strategies for different facilities. The failure mode of every component must be studied in order to assess the best maintenance solution, in accordance with its failure pattern, impact and cost on the whole system. The management of large number of tangible and intangible attributes that must be taken into account represents the complexity of the problem. Several techniques have been discussed in the literature for planning maintenance activities of industrial plants. The most commonly used technique to evaluate the maintenance significance of the items failure modes and categorizing these in several groups of risk is based on using Failure Mode Effect and Analysis FMEA. This methodology has been proposed in different possible variants, in terms of relevant criteria considered and/or risk priority number formulation. Using this approach, the selection of a maintenance policy is performed through the analysis of the obtained priority risk number. The FMEA discipline was originally developed in the United States Military. The generic nature of the method assisted the rapid broadening off MEA to different application areas and various practices fundamentally using the same analysis method were created. The rest of this paper is organized as follows; section 2 represents literature review, section 3 represents problem statement & methodology, Section 4 represents data collection and result analysis. Section five represents the discussion and conclusion and finally references are mentioned after the conclusion portion.

2. Literature Review

Procedures for conducting FMEA were described in US Armed Forces Military Procedures document MIL-P-1629(1949); revised in 1980 as MIL-STD-1629A). During the 1970s, use of FMEA and related techniques spread to other industries. The automotive industry began to use FMEA by the mid-1970s.Although initially developed by the military, FMEA methodology is now extensively used in a variety of industries including semiconductor processing, battery industry, food service, plastics, software, and healthcare. There is relatively little information published on the use of FMEA for battery manufacturing systems. Documenting and analyzing potential risks proactively are essential for improved patient safety. Accomplishing this goal requires an effective method to identify risks and an easily understood approach to manage risks [3]. In situ simulation occurs in a patient unit at the microsystem level and involves inter disciplinary teams and organizational processes. Unlike simulations that occur in a laboratory setting, in situ simulation is a strategy that takes place on a patient care unit [5]. The authors [9] proposed a method to combine multiple failure modes into a single one, which opens the possibility for us to analyze a system considering multiple failure modes at the same time. Unfortunately, although they proposed such method, the detailed procedure such as which multiple failures need to be combined was not given. This paper aims to develop a new FMEA method that enables us to combine multiple failure modes into single one, considering importance of failures and assessing their impact on system reliability. FMEA is a tool for identifying, analyzing and prioritizing failures. It is a design technique which systematically identifies and investigates potential system weakness. It consists of a methodology for examining all the ways in which a system failure can occur, potential effects of failure on system performance and safety, and all seriousness of these [12]. effects A safety system used to monitor a nuclear power plant may have a logic error that allows a failure to dampen an overloaded reactor to go undetected. Risk prioritization produces a ranked ordering of risk items that are identified and analyzed. [4] Collected and analyzed a number of key risk factor and their impact on the system. An error in a spacecraft program for controlling re-entry angle could cause skip-out and loss of mission. The authors [8] proposed that this study was carried out considering the specific processes implemented at CNAO, therefore, the detailed definition of failure modes and the assignment of RPN scores, strongly depend on the specific process under investigation and on the current strategies/solutions locally applied. However, the process and fault trees here delineated can be easily adapted by other users to their local scenario or, at least, be useful as a starting reference point, thus minimizing the workload impact of the FMEA analysis on the involved team. P. C. [11] proposed a method for FMEA generation for a generic application using minimum information during the conceptual design stage. Prototype software has been created for the proposed method. It has been evaluated using case studies from the design and manufacture of two way radios. The evaluation revealed the feasibility of the proposal, as well as some weaknesses that need further improvement. Generally, the capability of the method to generate FMEA report with minimum information is demonstrated. According to BS 5760 FMEA is a method of reliability analysis intended to identify failures, which have consequences affecting the functioning of a system within the limits of a given application, thus enabling priorities for action to be set. In the paper [1] draw attention a new technique based on modified FMECA along with TOPSIS is proposed to determine the Maintenance Criticality Index (MCI) and to over- come the limits of the conventional RPN, as cited above. This technique permits to take into consideration the several possible aspects concerning the maintenance selection problem (failure chances, detect-ability, etc.).

3. Problem statement

In case of process improvement, at first one should know about the process whether the existing process is capable or not. Incapable process produces large number of defective items. In these case manufacturers should justify the process capabilities. In Rahimafrooz Globatt Ltd. the production of defective items in different stages of assembles line is well enough. But the failure in Open circuit voltage is serious. If this failure is occurred there is no way to rework except scrap. So this paper concentrates on the reasons of OCV failures and develops worksheet for individual reasons of failure. RPN is also important for ranking of seriousness of those failures. The objectives of this thesis work are (i) Find out the failure rate. (ii) Find out the failure reason. (iii) Proposed corrective action.

3.1 Methodology

- ❖ Statistical data collection methods for checking the quality percentage of errors and determining Process Capacity Ratio (PCR) of the process. Production process flow and Standard operation procedure is reviewed. We collect data from production engineer and Quality Assurance department of Rahimafrooz Globatt Limited.
- ❖ Identify potential design and process related failure modes. Ideally, the process is changed to remove potential problems in the early stages of development.
- ❖ Find the effects of the failure modes for each failure on system operation.
- ❖ Find the root causes of the failure modes. Barkai (1999) stated that an FMEA is designed to find the sources of the failures of a system.

- Identify, implement, and document the recommended actions. Pries noted that FMEA documents should be under formal document control. Kennedy stated that the recommended actions are to address failure modes with rankings that are considered unacceptable.

4. Data Collection and Results analysis

4.1 Control Chart: X bar R chart

From a day's a production, a sample of 4 batteries is selected randomly from the production line and their voltage are recorded. The average voltage of this sample are computed and recorder in a table. We collected this data in 20 days in the month of December. Thus, X bar and R values of 20 samples are recorded in the table.

Table 4.1: Voltages of battery in volt from four observations

SL	Voltages of battery for four observations				$\bar{X}$	R
	i	ii	iii	iv		
1	12.63	12.55	12.59	12.60	12.59	0.08
2	12.63	12.66	12.67	12.64	12.65	0.04
3	12.69	12.65	12.63	12.58	12.64	0.11
4	12.58	12.54	12.67	12.69	12.62	0.15
5	12.70	12.64	12.69	12.60	12.66	0.10
6	12.63	12.66	12.67	12.64	12.65	0.04
7	12.55	12.56	12.60	12.56	12.57	0.05
8	12.69	12.64	12.65	12.69	12.67	0.05
9	12.69	12.62	12.63	12.58	12.63	0.11
10	12.67	12.60	12.73	12.60	12.65	0.13
11	12.70	12.64	12.69	12.63	12.67	0.07
12	12.68	12.61	12.63	12.69	12.65	0.08
13	12.62	12.69	12.69	12.62	12.66	0.07
14	12.68	12.63	12.60	12.69	12.65	0.09
15	12.59	12.57	12.68	12.69	12.63	0.12
16	12.73	12.78	11.50	12.51	12.38	1.28
17	12.65	12.68	12.70	12.63	12.67	0.07
18	12.51	12.65	12.68	12.69	12.63	0.18
19	12.63	12.66	12.67	12.58	12.64	0.09
20	12.60	12.66	12.56	12.65	12.62	0.10
Average					12.63	0.151

4.1.1 R Chart development:

First, the R chart is developed.

$$\bar{R} = \frac{\sum_{i=1}^{m} R_i}{m} = \frac{3.02}{20} = 0.151$$

For samples of size n=4, from appendix: D_3=0&D_4=2.282

We know, the control limits Range (R) chart are found

$UCL_R = \bar{R} D_4$ = (0.151) * (2.282) = 0.343 $CL_R = \bar{R}$ = 0.151 LCL_R = (0.151) * (0) = 0

Hence, the R chart is constructed as below.

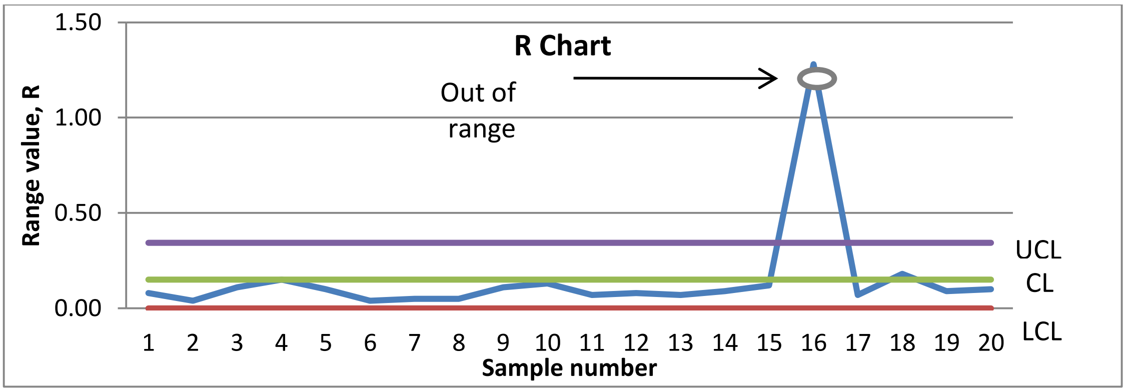


Fig 1: the R chart

We observed that one of the sample values go outside of the limits. They are not pretty random around the mean as well. Thus, the range chart can be considered as "out of control".

4.1.2 $\bar{X}$ Chart development

The $\bar{X}$ chart is constructed below

$\bar{\bar{X}} = \frac{\sum_{i=1}^{20} \bar{X}}{20} = \frac{\sum_{i=1}^{20} 252.5}{20}$ =12.625

For samples size n=4 then form appendix Table D, A_2=0.729

$UCL_X = \bar{\bar{X}} + A_2\bar{R}$ = 12.625+ (0.729)*(0.151) = 12.735 $CL_X = \bar{R}$ = 12.625

$LCL_X = \bar{\bar{X}} - A_2\bar{R}$ = 12.625- (0.729)*(0.151) = 12.516

Sample standard deviation:

$\hat{\sigma} = \frac{\bar{R}}{d_2} = \frac{0.151}{2.059}$ =0.073

Suppose that the stated speciation limits are: 12.50 V and 10.78 V, the centre line or the mean of the process has been found equal to 12.625.

Probability of the Voltages greater than the USL and less than LSL

P(X>USL) =1 - $\varphi\left[\frac{12.78-12.625}{.073}\right]$ =1 – φ (2.123) = 1-0.9831 = 0.0168= 1.68% & P(X<LSL) = 4.34%

Process Capability Ratio (PCR) is

PCR =$\frac{USL-LSL}{6\sigma} = \frac{12.78-12.50}{6*0.073}$ =0.639 < 1

This shows that the PCR value is less than 1, which indicates that a large number of products are nonconforming.

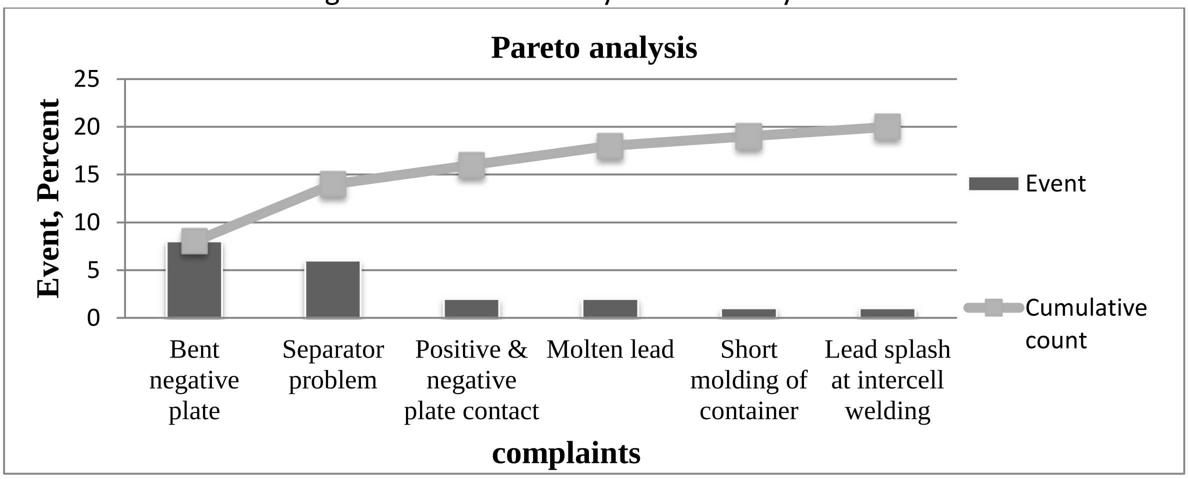
4.2 Pareto analysis for OCV failure

Table 4.2.1: Cumulative sum for various complaints

S. No.	Complaints	Event	Cumulative count	Percentage
1	Bent negative plate	8	8	40
2	Separator problem	6	14	30
3	Positive & negative plate contact	2	16	10
4	Molten lead	2	18	10
5	Short molding of container	1	19	5
6	Lead splash at inter cell welding	1	20	5
	Total	20		100

4.2.2 Graphical view:

Fig 4.2.2.1: Pareto analysis for battery defect



4.3 Worksheet for failure

Sub system name: OCV test, Model year: 2013

P=probability of occurrence, S=seriousness of failure

D=likelihood the defect will reach the customer, RPN= risk priority number

4.3.1 FMEA worksheet for OCV failure:

Table 4. 3.1: Function of OCV tester

SL	Part Name	Function	Failure Mode	Mechanism & cause of failure	Effect of Failure	Current controller	RPN	Recommended corrective action	Action taken
1	OCV tester	Check the open circuit voltage	Low output voltage	Less charging time & parameter Inter cell	The battery is scraped	Refill acid level then charging properly	40	Replace the wire check the charging	Wire changed Regularly inspect

4.3.1.1 FMEA worksheet for Negative plate bending:

Table 4. 3.1.1: Function of Negative plate bending

SL	Part Name	Function	Failure Mode	Mechanism & cause of failure	Effect of Failure	Current controller	RPN	Recommended corrective action	Action taken
1	Negative plate bending	Drop 2.1 voltage	Low output voltage	Thin grid than specification Low pasting	The battery is scraped	N/A	42	Maintain specific thickness Carefully insert cell	Improve grid casting m/c performance Train up labor

4.4 Potential failure cause with RPN for 20 defects Battery

For different potential failure the value of probability severity and detection are given bellow.

Table 4.4.1: Calculation of Risk Priority

Failure no.	Potential failure cause	Frequency	Probability (p)	Severity (S)	Detection (D)	RPN
1	Bent negative plate	8	7	3	2	42
2	Separator problem	6	6	3	3	36
3	Positive & negative plate contact	2	4	5	2	40
4	Molten lead	2	4	2	2	16
5	Short molding of container	1	3	5	2	30
6	Lead splash at inter cell welding	1	3	4	1	12

From the Table 4.4.1 it can be concluded that failure (1and 3) i.e. Bent negative plate and Positive & negative plate contact failures are of high risk, is catastrophic failure. The failures (2 and 5) i.e. Separator problem and Short molding of container failure, are classified as critical. The failures (4 and 6) i.e. Molten lead and Lead splash at inter cell welding failure are categorized as marginal failures. According to Table 4.4.1 Bent Negative plate failures and Positive & negative plate must be inspected when the failure occurs again and again.

5 Discussions and Conclusion

5.1 Discussion

By calculation the process capability Ration (PCR) is 0.639. This shows that the PCR value is less than 1, which indicates that the process is inappropriate. So the process is not good at all. This is due to a few products were taken as a sample. This paper finds out the products nonconforming or failures area to develop a worksheet or document to reduce products failure and smooth assemble line. FMEA worksheet is our main work which is very effective to increase product Quality and Productivity. Most of the machines are software based and automated so the implementation of recommended corrective action is hard enough.

5.2 Conclusion

EMEA is a team-oriented development tool used to analyze and evaluate potential failure modes and their causes in manufacturing process. It prioritizes potential failures according to their risk and drives actions to eliminate or reduce their likelihood of occurrence. FMEA provides a methodology for documenting this analysis for future use and continuous process improvement. It is structured approach to the analysis, definition, estimation and evolution of risks. This study shows that in battery production the process of manufacturing is very important which demonstrate the OCV (Open Circuit Voltage) failures. This paper checks the process capability and prioritizes reasons of failures using pareto analysis. This study tries to develop a FMEA documentation/worksheet for taking future action. This paper also calculated RPN for failure causes. The data was collected only from Rahimafrooz Globatt Ltd. Therefore, many possible future research works can be defined in this context. For example it is better to involve customers and suppliers in the preparation of FMEA. Involvment of customers and suppliers is a recommended part of TQM and FMEA for a battery industries is more cost effective at the earlier stage of design than at later stage when a design is almost at the final one.

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