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Integrating Statistical Techniques with the Reliability Engineering Methodology of 'Failure Mode and Effects Analysis' for Continuous Improvement of Manufacturing Processes

Zalina Abdul Aziz, Chee Peng Lim, Yin Leong Cheow

School of Electrical and Electronics Engineering
Universiti Sains Malaysia, Engineering Campus
14300 Nibong Tebal, Pulau Pinang, Malaysia

Abstract

'Failure Mode and Effects Analysis' (FMEA) is a reliability engineering methodology for increasing the level of customer satisfaction in a company's products and services. This is achieved by identifying and eliminating or reducing known or potential problems in the case of existing products, processes, or services or in the case of when new products, processes or services are being designed. Statistical techniques can also be used to increase the level of customer satisfaction by detecting problems, verifying the root causes of the problems, and monitoring the effectiveness of corrective actions for both of the above cases. In this paper, it is proposed that the manufacturing industry in Malaysia use statistical techniques in conjunction with FMEA in their manufacturing processes. A methodology for introducing these techniques to the manufacturing companies as well as for developing their employees' knowledge and skills in the use and in the integration of these techniques into the companies' improvement activities has been designed and is being tested in the manufacturing industry in Malaysia. The methodology and its requirements are described in this paper. The requirements were formulated based on the results of testing the methodology in two of the manufacturing companies in Malaysia.

Introduction

This paper focuses on the research work that has been initiated by the School of Electrical and Electronics Engineering, University Science of Malaysia (USM) in its effort to promote the integrated use of statistical techniques with the reliability engineering methodology of 'Failure Mode and Effects Analysis' (FMEA) among manufacturing companies in Malaysia. Although statistical techniques and FMEA offer engineers in the areas of design, manufacture, and service efficient means of studying the causes and effects of both known and potential failures, its use among manufacturing companies in Malaysia is low. The results of a recent survey on the use of modern quality practices among such companies in Malaysia (Abdul- Aziz *et. al.*, 2000) showed that only around 20 % and 40% of the survey respondents use FMEA and statistical techniques (in particular, 'control charts') respectively at their manufacturing operations, thus the motivation for this research work.

Currently, two manufacturing companies in Malaysia; i.e. an industrial printing company and an electrical manufacturing company are collaborating in this research work. From these companies, we have obtained valuable insights for improving our methodology for introducing these techniques to the manufacturing companies as well as for developing their employees' knowledge and skills in the use and integration of these techniques into the companies' improvement activities. Ultimately, we plan to notify manufacturing companies in Malaysia regarding the methodology by means of the World Wide Web.

Overview of FMEA and Statistical Techniques

The improvement of a company's products and services can be achieved by focusing on the identification and analysis of the risks involved in the company's products and services. A recommended technique for such identification and analysis is known as 'Failure Mode and Effects Analysis' (FMEA). FMEA, which has its origin in the 1960's in the American aerospace and defense industries, has now been adopted by other industries throughout the world such as the automotive and electronic industries. In FMEA, all of the ways in which each component of a product, process, service, or design might fail to fulfill its intended function are examined based on expert opinions, historical information on similar components, and any other appropriate information. Each potential failure mode (a failure mode is a physical description of the manner in which a failure can occur) is assigned a relative ranking on a numeric classification scale. Such ranking represents one of the most unique and powerful aspects of FMEA, and basically involves the assignment of relative measures of occurrence, severity, and detection. These three measures are then multiplied together to provide an overall relative risk factor for the particular failure mode (also known as risk priority number or RPN value). Features of the existing or new product, process or service that are most likely to cause safety, reliability, or quality problems can then be quickly identified. Stamatis (1995) and McDermott *et .al.* (1996) are recommended for more information on FMEA.

The improvement of a company's products and services can also be achieved by using statistical techniques such as control charts and 'Design of Experiments' (DOE) techniques. DOE provides a powerful means to achieve breakthrough improvements in product quality and process efficiency. Montgomery (2000), Peace (1993), and Wu and Hamada (2000) contain readable material on the subject of DOE. Many companies tend to ignore this tool because it requires the provision of proper training, and the running of experiments. The latter requires proper planning, discipline, and the use of statistics. Unfortunately, fear of statistics is widespread, even among highly educated scientists, engineers and managers. DOE includes a wide range of techniques but most commonly used is 'factorial design'. The latter can be used to investigate the effect of multiple variables including their interactions on the performance of a given system. For example, in the study of the problem of color variation or color inconsistency of printed material in the printing company, many variables can contribute to this problem. Among the variables are the printing speed, plate pressure, concentration of fountain solution, concentration of IPA (alcohol), and tank temperature. Both the individual and joint effects of these variables on the manufacturing cost and quality of the printed product can be investigated using a factorial design in which the variables are varied simultaneously in predetermined combinations.

A control chart is a plot of important process parameters and performance measures on a real-time basis with control limits added to show the range of values that would be typical of the process. Control charts enable you to distinguish between sources of variability which are inherent in the process and sources of variability, which are unpredictable. The control limits are calculated from statistical formulas. Points on the charts that fall randomly inside the control limits show the presence of inherent sources of variability. Nonrandom points within the control limits and points that occur outside the control limits would be expected to be due to some unpredictable cause(s). It is important to distinguish between the two types of occurrences. The cause(s) of points outside the control limits are relatively easier to track down and fix. The cause(s) of points that occur inside the control limits can only be improved by making fundamental improvements in training, information systems, equipment or procedures. These charts can also show the effects of process improvement efforts, which are aimed at reducing the sources of inherent process variability or at eliminating the sources of unpredictable process variability.

Methodology

This section contains the steps of our proposed methodology.

(1) Securing Top Management Commitment

As is usually the case of any new endeavor, securing the top management's buy-in and support is essential. To achieve this, briefing sessions were held for top management on the following topics: an overview of FMEA and statistical techniques, the benefits of such methods, actual case studies, and how to implement FMEA and statistical methods (specially control charts and DOE).

(2) Setting-Up of Project Teams

Teams, consisting of middle-level managers, engineers, technicians, and operators were established. The reason for the multi-level nature of the team members is to facilitate the brainstorming sessions since different staff levels will have different improvement ideas. A team leader will also be selected in order to co-ordinate the activities of the team and to keep the team focused on the project.

(3) Defining the Project Scope

This includes a statement of the problem, a definition of the boundaries, the magnitude of the improvement goals, a target date for completion, and the resources needed (such as training in problem-solving skills and team-building skills). Statistical techniques such as control charts, line graphs, etc. should be used to understand the current level of the problem. One of the fundamental approaches of our FMEA and SPC project is to look at the process from the customers' point of view. The starting point should be to find out what the customers and the end users want. Firstly, the team will talk to the customers and find out how they use the product or service, what problems they have with it, and how it can be enhanced. The information obtained from these interviews should be analyzed to determine which aspects of the product or service should be improved and the extent to which the product or service meets the needs of the customer. For the case of the 2 companies that collaborated in our research, this was already done by the companies before the project started. Based on this analysis the team will define the project goals.

(4) Understanding the Process

The next step is to understand how the process presently works. Before one can attempt to improve the process, one must understand how it currently works and what it is supposed to do. There are two approaches to understanding the present process. One is descriptive, the other is graphic. A good way to understand the process is to describe it. One benefit of describing the process is that it sometimes leads to the discovery of obvious problems and solutions that can be fixed quickly. A flow chart of the process is particularly helpful in obtaining an understanding of how the process works. It provides a visual picture. A top-down flow chart shows only the essential steps in a process without any details. It is particularly useful in helping the team members focus their minds on those steps.

(5) Identifying the Root Causes

Members can use brainstorming, cause-and-effect diagrams or the structure tree to develop a list of possible causes. When the team has figured out what it thinks the root causes are, it should verify the root causes with data. It is easy to draw conclusions from incorrect data. Use statistical techniques (such as DOE) to collect and analyze the data so that objective conclusions regarding what the possible causes are can be obtained.

(6) Developing Solutions

Ideas for solving the root causes should be evaluated against criteria to determine the best solution. The problem and the cause(s) of the failure are listed in the FMEA table. The team will define the characteristics of an ideal solution and identify the criteria that must be satisfied and the criteria that are desirable but not absolutely necessary. Constraints to a proposed solution will be identified. These constraints may take the form of budget limits, rules or practices that may make a solution difficult to carry out. The solution of the failure have to be prioritized based on the RPN value calculated in the FMEA table. Each possible solution will be evaluated against the criteria for selection. The team will seek to develop a solution which comes closest to solving the root causes, is the easiest to implement, satisfies criteria for selection, and does not impact on the constraints. When the team has selected the best alternative, it should obtain feedback from those people who are most affected by the changes. Depending upon the nature of the changes it may be possible to implement them right away. Alternatively the solution will be present to the recommendations to the team members and the upper management to obtain approval before they can be implemented.

(7) Implementing the Solutions

The team should then use the Plan, Do, Check, Act sequence to implement the proposed solutions. The changes which are to be made need to be defined and the sequence of steps that are required to implement the changes as well as a schedule for the steps should be prepared. Milestones should be defined so that progress can be monitored. Responsibilities for each of the steps should also be defined.

(8) Reviewing the Results

Monitor the effectiveness of the changes and compare the results of the changes with the original goals of the team. Ask the following questions:

- Did the team achieve the expected benefits?
- Were there any unexpected benefits or problems?
- What can the team learn from these?
- What can be done to fine tune the solution so that it can be applied on a wider basis?

In order to realize the full benefits of the above methodology, several key elements are required. These elements are covered in the next section.

Testing of Methodology

The background of the two companies in which our methodology was tested are as follows. Both companies are locally owned and have been in operation since 1984. The first company is involved in industrial printing such as the printing of instruction manuals for equipments. This company has around one hundred employees. Most of its' customers are located in Malaysia, and are subsidiaries of multi-national companies. The second company manufacturers electrical fans, light fittings, and their components. Recently, the company started a new product line i.e. that of motor alarms. The number of employees is three hundred, and the company also exports its products to overseas markets such as the UK. Both companies are certified to the ISO 9002 Quality Management System standard.

Two pilot project teams were set up in each company i.e. at the printing and cutting operations of the first company, and the light fitting and motor alarm operations of the second company. Six months was spent at each company. Actual examples of FMEA tables, control charts, and Pareto Diagrams from some of these operations are shown below.

Figure 1: Pareto Chart for Transmitter PCB, Motor Alarm Operation

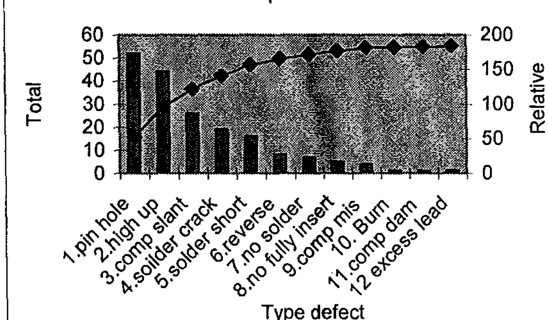
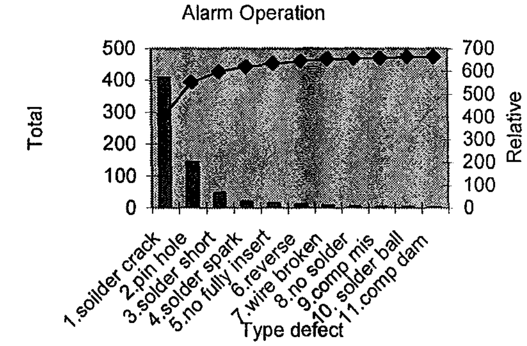


Figure 2: Pareto Chart for Receiver PCB, Motor Alarm Operation



Number	Component of process	Function purpose	Failure modes	Failure causes	Failure Effect	Failure prevention	S	O	D	RN	Measures
0001	Requesting material from store and set up machine	To get the correct material from the store	Wrong material provided	Paper does not meet specification	Wrong paper size printed Cause reject/scrap	Checking need to be done	8	3	3	72	
	Cut paper size according to specified job	To cut the paper as per the spec	Overcut	Careless mistake done by operator	Wrong paper size printed Cause reject/scrap	Check the provided jobsheet before cutting Identify the error from time to time	8	2	3	48	
	Check the paper size to ensure it is connect on every pallet	To stack the paper properly onto the pallet	Paper wrinkle Paper torn Page folded	Paper does not properly stack onto the pallet Wrong handling by the operator	Cause reject/ scrap	Inspection after stacking	8	4	3	96	Johnny/ 20th April
0002	Mount the plate on the plate cylinder	To transfer image within inks' roller and blanket.	No image printed on the papers Printing look dirty.	Forget to put on the plate Dirty blanket	Cause hickies Visual appearance inspection rejected	Prepare detail jobsheet Ensure the operators follow the steps provided.	8	3	4	96	Azlan/ 20th April
	Put the cardboard/paper onto the feeder pallet	To rise papers to the suction head.	Control switch broken	Short circuit.	Machine maintenance	Check the switch box and the wire frequently.	8	3	3	72	
	Set the feeder and deliver size	To ensure the papers in the right position corresponded to the image.	Pick up more than one sheet.	Incomplete set up on the suction head.	Papers rejected and wasted	Set up the feeder and delivery size according to the type of paper used	8	3	3	72	

Table 1 - FMEA for Manuals, Cutting Operation

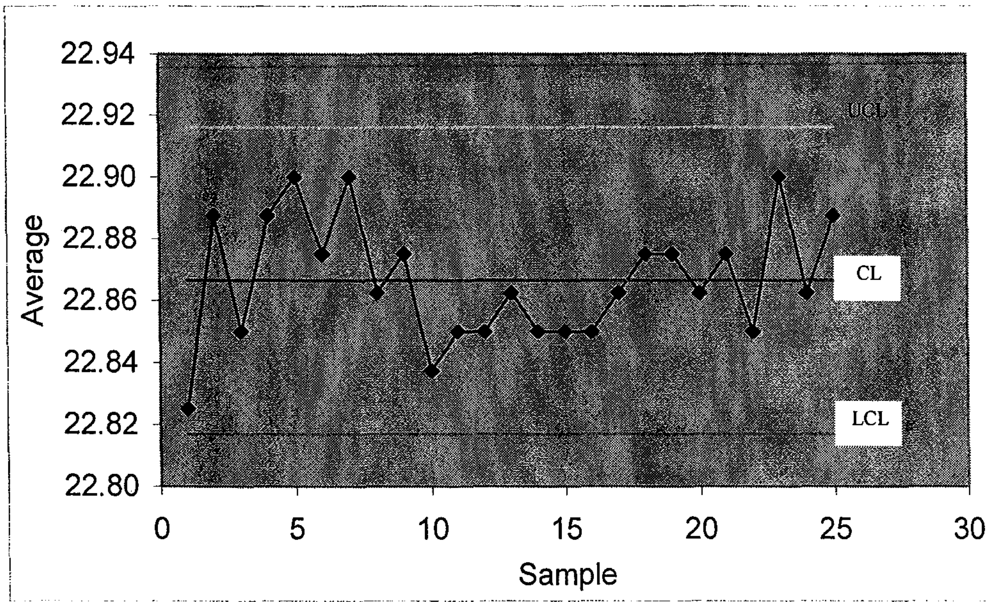


Figure 3 - X-bar control chart for length of manuals (in cm) for cutting operation

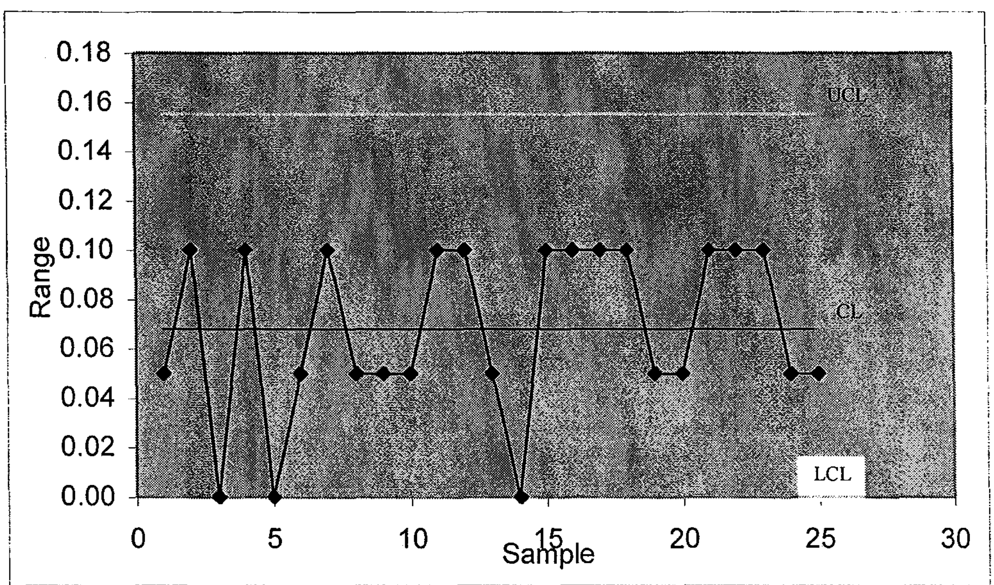


Figure 4 – R control chart for length of manuals (in cm) for cutting operation

As a result of testing the methodology in the two companies, several key elements were identified as being necessary for the success of the methodology. These key elements are teamwork, training, use of pilot project method, regular reporting to top management, and the use of relevant quality tools. These elements are described below.

(1) Improvement efforts usually require the collective thinking, decision, and action of groups or teams of individuals in a company. Thus, the importance of good teamwork among the team members. In order to establish the latter, it is necessary to provide training in team building skills.

(2) Training in statistical techniques, FMEA, and relevant quality tools (such as the Plan, Do, Check, Act Cycle, structure tree, etc.) to the team members are needed to enable the members to use the tools effectively. Training in the use of relevant softwares can also be carried out if the company is willing to invest in such softwares. Simple statistical techniques (such as control charts and simple DOE techniques) should be introduced to the companies if the companies are using statistical techniques for the very first time.

(3) The pilot project method should be utilized. The pilot projects should not be two complex since the members are utilizing the techniques for the very first time (and perhaps also working together as a team for the first time). Neither should the projects be too simple, since such projects may not yield significant improvements. It is recommended that the number of pilot projects be limited to between two or three. Later, the number of teams can be increased in order to involve more of the workforce in such activities.

(4) Top management should be regularly updated by the team leader on the teams' activities so that management will be aware of the teams' progress, or the problems faced by the teams. Such awareness will also facilitate top management's recognition of the teams' efforts.

(5) The use of quality tools such as brainstorming, cause-effect diagram, Plan-Do-Check-Act sequence, and structure tree were found to be relevant to the methodology such as in steps 6 and 7. The use of other quality tools will also be investigated.

Conclusions and Discussion

The two companies that participated in the testing exercise have indicated that the methodology is useful to them. However, other companies that are keen on adopting the methodology should be forewarned that extensive nurturing of the members of the pilot project teams in both the use of the techniques and in team-building skills are necessary. The support of top management is also necessary since the provision of the necessary resources to the team members (including time for team members to attend training sessions and for carrying out the projects) will require the full endorsement of top management. Such support is also necessary for the establishment of future project teams following the completion of the projects by the pilot teams. Companies should also be forewarned that the objective of the proposed methodology is not to produce good-looking FMEA tables or statistical control charts for purposes of displaying to the companies' customers or ISO 9002 auditors but to provide a systematic framework for companies to improve their products, processes, designs, or services.

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