CHAPTER II

LITERATURE REVIEWS

2.1 Failure Mode and Effects Analysis (FMEA)

Failure mode and effects analysis (FMEA) is a method that determines potential failures in products or processes. According to Johnson and Khan (2003), process failure mode and effects analysis (PFMEA) technique was first reported in the 1920s. However the use of FMEA has only been significant by the US military in 1949 to classify failures "according to their impact on mission success and personnel/equipment safety". In the 1960s National Aeronautics Space Agency (NASA) used it as a means of addressing a way to improve the reliability and safety of military equipment. It has been used in the automotive industry since the early 1970s. In the 1980s it was used by Ford to reduce risks after one model of car, the Pinto, suffered a fault in several vehicles causing the fuel tank to rupture and subsequently burst into flames after crashes. In the 1990s its use has been accelerated to address the major quality and reliability challenges caused by the Far Eastern car manufacturers. In addition, the recent changes in the law on corporate responsibility have led to companies reviewing their product design safety through the use of the PFMEA methodology (Johnson and Khan, 2003).

2.1.1 Definitions of FMEA

There are several definitions given to FMEA. Juran (1989) refers to FMEA as "failure modes and criticality analysis (FMECA)" and defines it as a methodical way to examine a proposed design for possible ways in which failure can occur. In FMECA, potential failures are identified first in terms of failure modes. For each mode, the effect on the total system is then studied. Finally, a review is made of the action being taken (or planned) to minimize the probability of failure or to minimize the effect of failure.

According to Sankar and Prabhu (2001), FMEA represents a powerful and documented method for engineers to present in a structural and formalized manner with their subjective thinking and experience in terms of three main questions: what might go wrong? What might cause it to wrong? And what effect would it have? In another words, FMEA is a technique that identifies, first, the potential failure modes of a product during its life cycle; second, the effects of these failures; and, third, the criticality of these failure effects in product functionality (Teng and Ho, 1996).

According to Chang et al. (2001), FMEA provides an effective tool for improving product design and process planning by discovering potential product and process failures so that preventive measures can be taken in early stages. 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" (BS 5760 Part 5, 1991). Moreover, it is a systematic process meant for reliability analysis (Elliott James, 1998). It improves operational performance of the production cycles and reduces their overall risk level. This task is achieved by means of preventing the system potential failures that have been identified through the preliminary analysis and the collection of plant historical data (Neville, 1993).

IEEE Std 352-1975: Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems, defines the purposes of an FMEA as being to:

- assist in selecting design alternatives with high reliability and high safety potential during early design phase
- ensure that all conceivable failure modes and their effects on operational success of the system have been considered
- list potential failures and identify the magnitude of their effects
- develop early criteria for test planning and the design of the test and check-out systems
- provide a basis for quantitative reliability and availability analyses
- provide historical documentation for future reference to aid in analysis of field failures and consideration of design changes

- provide input data for trade off studies
- provide basis for establishing corrective action priorities
- assist in the objective evaluation of design requirements related to redundancy, failure detection systems, fail-safe characteristics and automatic and manual override

Risk priority number (RPN) is a factor used in FMEA for setting up the priorities of the identified failures. RPN regards the severity, occurrence, and detection relatively impacted on the product or process. Typically RPN is calculated from the multiplication of the score of these three factors as shown in equation (2.1). Severity (S) is a rating according to the seriousness of an effect of a potential failure mode. Occurrence (O) is a rating corresponding to the rate at which a first level cause and its resultant failure mode will occur over the design life of product or process, or before any additional process controls are applied. Finally detection (D) is a rating corresponding to the likelihood that the detection methods or current controls will detect the potential failure mode before the designed product released for production, or for process before it leaves the production facility.

$$RPN = S \times O \times D \qquad (2.1)$$

Where

S = score for the severity of failure to the customers or the succeeding processes.

O = score for the chance of occurrence

D = score for the chance of undetection and is used to measure the possibility that the problems occurred can be detected by the quality control system

2.1.2 FMEA Procedure

FMEA is typically carried out by a team of people with direct knowledge of the products and processes concerned (Gilchrist, 1993). The elements of FMEA are: the identification and listing of modes of failure and the consequent faults; assessing the chances that these faults occur; assessing the chances that the faults are then detected; assessing the severity of the consequences of the faults; calculating a

measure of the risk; the ranking of the faults on the basis of the risk; taking action on the high-risk problems; and checking the effectiveness of the action, using a revised measure of risk.

According to Teng and Ho (1996), there are two phases in the FMEA process. The first phase is to determine the potential failure modes and their effects. The second phase is to criticality analyse the severity of the failure modes. The first phase has to be done concurrently with the detailed product design. It should also include defining the possible failures of the product's components, sub-assemblies, final assembly, and its manufacturing processes. At the end of the first phase, the detailed design is completed, and the design drawing is created. At the second phase of FMEA, engineers in the FMEA team determine and rank the criticality of each failure, and then revise each design detail and make required modifications. The most serious failure has the highest rank and is considered first in the design revision. The design is revised to ensure that the probability of occurrence of the highest ranked failure is minimized.

Figure 2.1 reveals the typical procedure of the FMEA process. The first phase starts from information collecting to the calculation of risk priority numbers (RPN). The actions in the second phase contain the ranking of RPNs, the recommendation of corrective actions, and the modifications of the design. At the end of the procedure, an FMEA report can be obtained, and the required modifications are completed to reduce the number of the potential failure modes to the minimum.

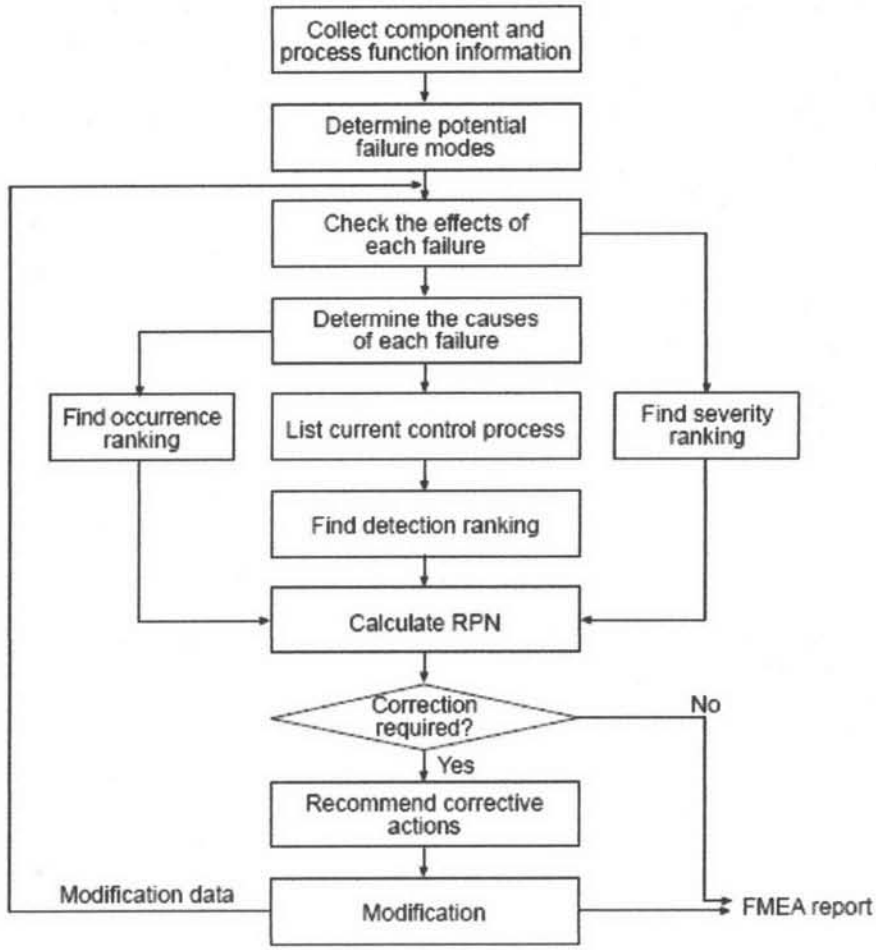

Figure 2.1: FMEA procedure (Teng and Ho, 1996)

According to Johnson (2002) and www.oahhs.org, an effective FMEA can be carried out following the below procedures:

(1) Defining the FMEA: First the process and its boundaries have to be described. Then individual and team responsibilities should be defined.

(2) Assembling the FMEA: An assignment of team leader with adequate team members' qualification, particularly a cross-functional team with various job responsibilities and levels of experiences, should be carried out.

(3) Reviewing the process: A copy of the process' blueprint should be given to each member of the team. A clear and specific description of the process undergoing FMEA must be articulated. FMEA tables should be generated.

(4) Brainstorming potential failure modes: The team analyses each component and subsystem of the product or process for the failure modes by identifying ways it could potentially fail.

(5) Listing potential effects of each failure mode: The team lists the potential effects of each failure next to the failure. If a failure has more than one effect, each effect should be written in a separate row. A failure effect is what the customer will experience or perceive once the failure occurs. A customer may either be internal or external, therefore, effects to both must be included. Examples of effects include inoperability or performance degradation of the product or process, injury to the user, damage to equipment, etc.

(6) Assigning a severity rating for each potential effect: The team gives each effect its own severity rating (i.e. from 1 to 10, with 10 being the most severe). If the team cannot agree on a rating, a vote has to be carried out.

(7) Identifying the potential cause(s) of each failure mode: at this point provides some insight into probability throughout why-why analysis.

(8) Assigning an occurrence rating for each failure mode: The team collects data on the failure of the product's competition. The team can quantify the frequency of occurrence of potential causes based on statistical data or the participants' experiences. By using this information, the team can determine how likely it is for a failure to occur and assign an appropriate rating (i.e. from 1 to 10, with 10 being the most likely)

(9) Assigning a detection rating for each failure mode and effect: The team lists all controls currently in place to prevent each effect of a failure from occurring and assign a detection rating for each item (i.e. from 1 to 10, with 10 being a low likelihood of detection). In addition the detectability must imply whether the present control plans are effective to prevent the process from each failure mode.

(10) Calculating the risk priority number (RPN) for each effect: The team multiplies the severity rating by the occurrence rating by the detection rating. RPN is a decision factor based on the product of three ratings: severity, occurrence, and detection.

(11) Prioritizing the failure modes for action: The team decides which items need to be worked on right away. Any improvement plan would be based on the indications from the RPN. Failure modes with high RPN values are selected. For example, if the team ends up with RPNs ranging from 20 to 200, the team might want to work first on those with RPN of 100 or higher.

(12) Taking action to eliminate or reduce the high risk failure modes: The team determines what action to take with each high risk failure and assign a person to implement the action. The corresponding current controls (i.e. the solutions) are implemented for these high RPNs. The actions might include inspection, testing, monitoring, redesign, re-rating, conduct of preventative maintenance, redundancy, process evaluation, etc.

(13) Calculating the resulting RPN as the failure modes are reduced or eliminated: The team is reassembled after completing the initial corrective actions and calculates a new RPN for each failure. The new RPN will indicate whether the corrective actions are effective in reducing risk. The team will decide they have taken enough action or they want to work on another set of failures.

(14) Keeping FMEA tables updated. The FMEA tables should be updated regularly or every time the product design or process changes.

2.1.3 Classification of FMEA

In general there are four types of FMEA: system FMEA, design FMEA, process FMEA, and service FMEA.

2.1.3.1 System FMEA

System FMEA is used to analyse the potential failure occurred in the systems and subsystems during conceptual design process. It focuses on potential failure modes between the functions of the system caused by system failure, and safety issues in order to forestall the system-based failures. It provides an optimum system design alternative and the basis for system level

diagnostic procedures. Moreover the interaction between systems and elements of the systems is included in the system FMEA. The output of the system FMEA typically consists of:

- A potential list of failure modes ranked by the RPN
- A potential list of system functions that could detect potential failure modes
- A potential list of design actions to eliminate failure modes, safety issues, and reduce the occurrence.

Since several researchers (Spath, 2003; Teng and Ho, 1996; Teoh and Case, 2004) have emphasized the importance of design FMEA and process FMEA more than system FMEA and service FMEA (FMEA is classified into 2 types: design and process FMEA), the details of system FMEA and service FMEA will not be fully given in this chapter.

2.1.3.2 Design FMEA

Design FMEA involves design activities, for example, product design, machine or tooling design. It is used to analyse the part of design to prevent the design-based failure before they are released to manufacturing. Design FMEA is a procedure to identify that the right materials are being used, to conform to customer specifications, and to ensure that government regulations are being met, before finalizing the product design. Product/design engineers are usually the leaders of the design FMEA team. The action plan from this type of FMEA will help eliminating the failures affected to operation of the process by specifying the appropriate tests to prove the design. As a result, development time and cost of manufacturing can be reduced.

According to Teng and Ho (1996), the information input to design FMEA consists of customer inputs and specifications. Based on customer requirements, the potential failure modes are created. For the development of the design FMEA report, all the possible functional failures in product design must be caught. Component by component evaluations are necessary in design FMEA. A supplementary FMEA table – the component FMEA table – can be

established to analyse the potential component failures as a part of the design FMEA process. A well-trained and balanced design FMEA team must be formed to initiate the FMEA process and to embed reliability concerns in the product design process. Reliability engineers should give the potential failure information about the current design concept/prototype to product designers/engineers. Design FMEA is known to be more difficult to handle than process FMEA. Therefore, the selection of personnel in the design FMEA team must be based on the ability to cover all aspects of product functions.

The design FMEA team checks the component problems, the functionality problems, the specification problems; and then lists all the possible failures and begins to communicate with customers and suppliers. The members of the team discuss with their customers about the potential failure modes in design in order to make the possible changes in the product specifications to improve its design. They also talk to product engineers to improve the product's manufacturability, and inform suppliers about the potential problems in components or possible improvement required for a better design.

To be more effective in product design control, the design FMEA report should be used to develop the receiving inspection procedure and the design verification (DV) check list. It should also be employed to perform fault tree analysis and to predict the reliability of the product (Teng and Ho, 1996). The procedure for the design FMEA is shown Figure 2.2. The benefits received from this procedure are that a company can recognize its suppliers' performance through the supplier PPM reports, and the probability of occurrence in the design FMEA table can be updated according to the supplier PPM report.

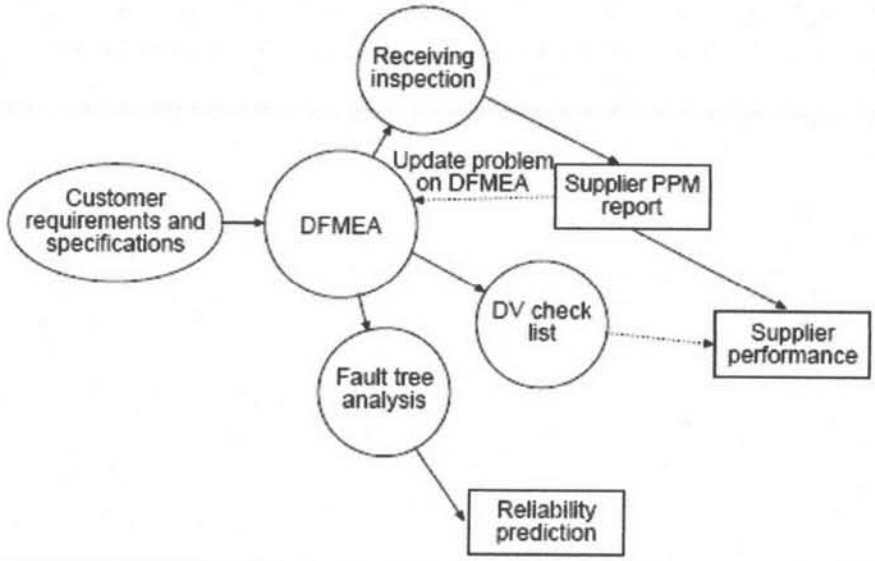

Figure 2.2: The procedure of the design FMEA (DFMEA) (Teng and Ho, 1996)

The output of the design FMEA typically consists of:

- A potential list of failure modes ranked by the RPN
- A potential list of critical and/or significant characteristics
- A potential list of design actions to eliminate failure modes, safety issues, and reduce the occurrence
- A potential list of parameters for appropriate testing, inspection and/or detection methods
- A potential list of recommended actions for the critical and/or significant characteristics.

2.1.3.3 Process FMEA

Process FMEA (PFMEA) is used to solve problems due to manufacturing processes. Process FMEA traditionally begins when the design FMEA report is available. It identifies any potential failures that could be caused by manufacturing/assembly processes, machines, fixtures, inspection points, and production methods. Process/manufacturing engineers usually lead the process FMEA team. The PFMEA is used to prevent the process-based failures before running in the production.

The procedure of the PFMEA starts with the input which is a process flow diagram. The diagram represents each of the manufacturing steps of a product. The potential failures in each of the manufacturing steps are listed in the PFMEA table as the potential failure modes. The step after determining the failure modes is to find the cause of each failure by utilizing various quality problem-solving techniques like design of experiments, Pareto analysis, and past experiences on similar products. Then the FMEA team should obtain the probability of failure occurrence, the severity with global effects, and the current detection/control method. The probability of failure occurrence is based on engineers' experiences, similar products/processes in the past, Weibull analysis, and other statistical analyses (Teng and Ho, 1996). The severity with global effects comes from various test results, field data, and engineers' experiences. At this stage, the FMEA team lists the possible effects caused by the failures and determines the detection methods to be used in the production process for each failure mode. One of very helpful detection methods which should be used is Visual Aids which can also help the operators to identify failures (Teng and Ho, 1996).

The risks of these effects are then evaluated accordingly. The ranking of the occurrence, the severity, and the detection method are based on a 1 to 10 scale. The numerical 1 to 10 scale does not have too much meaning to the FMEA team without a meaningful definition of these numbers. A good way is to utilize words to reflect the numerical system. For example, on the severity, 10 represents "catastrophic effect" (non-function or malfunction of the part may cause the death of a user); 9 and 8 mean "critical effect" (cause critical body injury); 7 and 6 denote "major effect"; 4 and 5 indicate "minor effect"; 2 and 3 depict "trivial effect"; and 1 means "no effect". The RPN is calculated by taking the multiplication of these three data. With the establishment of the process FMEA table, engineers can possess certain required information for process control.

Examples of the criteria for ranking the scale of severity, occurrence, and detection are shown in Table 2.1-2.3.

Table 2.1: Example of the ranking scale for severity (S) of potential failure mode

Effect	Criteria	Score
Hazardous Effect	Hazardous Effect. Safety-related—sudden failure. Non compliance with government regulation.	10
Serious Effect	Potential hazardous effect. Able to stop product without mishap; safety-related ; time dependent failure. Disruption to subsequent process operations. Compliance with government regulation is in jeopardy.	9
Extreme Effect	Customer very dissatisfied. Extreme effect on process; equipment damaged. Product inoperable but safe. System inoperable.	8
Major Effect	Customer dissatisfied. Extreme effect on process; rework/repair on part necessary. Product/process performance severely affected but functionable and safe. Subsystem inoperable.	7
Significant Effect	Customer experience discomfort. Product/process performance degraded, but operable and safe. Non vital part inoperable.	6
Moderate Effect	Customer experiences some dissatisfaction. Moderate effect on product/process performance. Fault on nonvital part requires repair.	5
Minor Effect	Customer experiences minor nuisance. Minor effect on product/process performance. Fault does not require repair. Nonvital fault always noticed.	4
Slight Effect	Customer slightly annoyed. Slight effect on product or process performance. Nonvital fault noticed most of the time.	3
Very slightly effect	Customer more likely will not notice the failure. Very slightly effect on product/process performance. Nonvital fault noticed sometimes.	2
No Effect	No effect on product or subsequent processes.	1

Table 2.2: Example of the ranking scale for occurrence (O) of potential failure mode

Occurrence	Rating	Failure Rate	Criteria
Almost never	1	1 in 30,000	Process inefficiency very unlikely.
Remote	2	1 in 10,000	Remote number of process inefficiencies.
Very slight	3	1 in 4,000	Very few process inefficiencies.
Slight	4	1 in 2,000	Few process inefficiencies.
Low	5	1 in 400	Occasional number of process inefficiencies.
Medium	6	1 in 80	Moderate number of process inefficiencies.
Moderately high	7	1 in 20	Frequent process inefficiencies.
High	8	1 in 10	High number of process inefficiencies.
Very high	9	1 in 5	Very high number of process inefficiencies.
Almost certain	10	1 in 3	Process inefficiencies almost certain to occur. History shows many process inefficiencies.

Table 2.3: Example of the ranking scale for detection (D) of potential failure mode

Effect	Rating	Criteria
Almost certain	1	Controls are in place and almost certain to detect the failure mode.
Very high	2	Very high likelihood current controls will detect the failure mode.
High	3	High likelihood current controls will detect the failure mode.
Moderately high	4	Moderately high likelihood current controls will detect the failure mode.
Medium	5	Medium likelihood current controls will detect the failure mode.
Low	6	Low likelihood current controls will detect the failure mode.
Slight	7	Slight likelihood current controls will detect the failure mode.
Very slight	8	Very slight likelihood current controls will detect the failure mode.
Remote	9	Remote likelihood current controls will detect the failure mode.
Almost impossible	10	No controls in place to detect the failure mode.

Owing to that the overall objective of this research is to improve the efficiency and productivity of an existing coating and drying processes, therefore, it is directly involved with process FMEA.

2.1.3.3 Service FMEA

Service FMEA is used to monitor and analyse service process or system that might be failed before the service reaching to customers. It focuses on failures caused by system or process deficiency. This type of FMEA can help improving service timing and efficiency. The output of the service FMEA typically consists of:

- A potential list of failure modes ranked by the RPN
- A potential list of critical and/or significant tasks, or processes
- A potential list of bottleneck processes or tasks
- A potential list to eliminate the errors
- A potential list of monitoring system/process functions

The objectives and goals of the all 4 types of FMEA and their focuses are summarized in Figure 2.3.

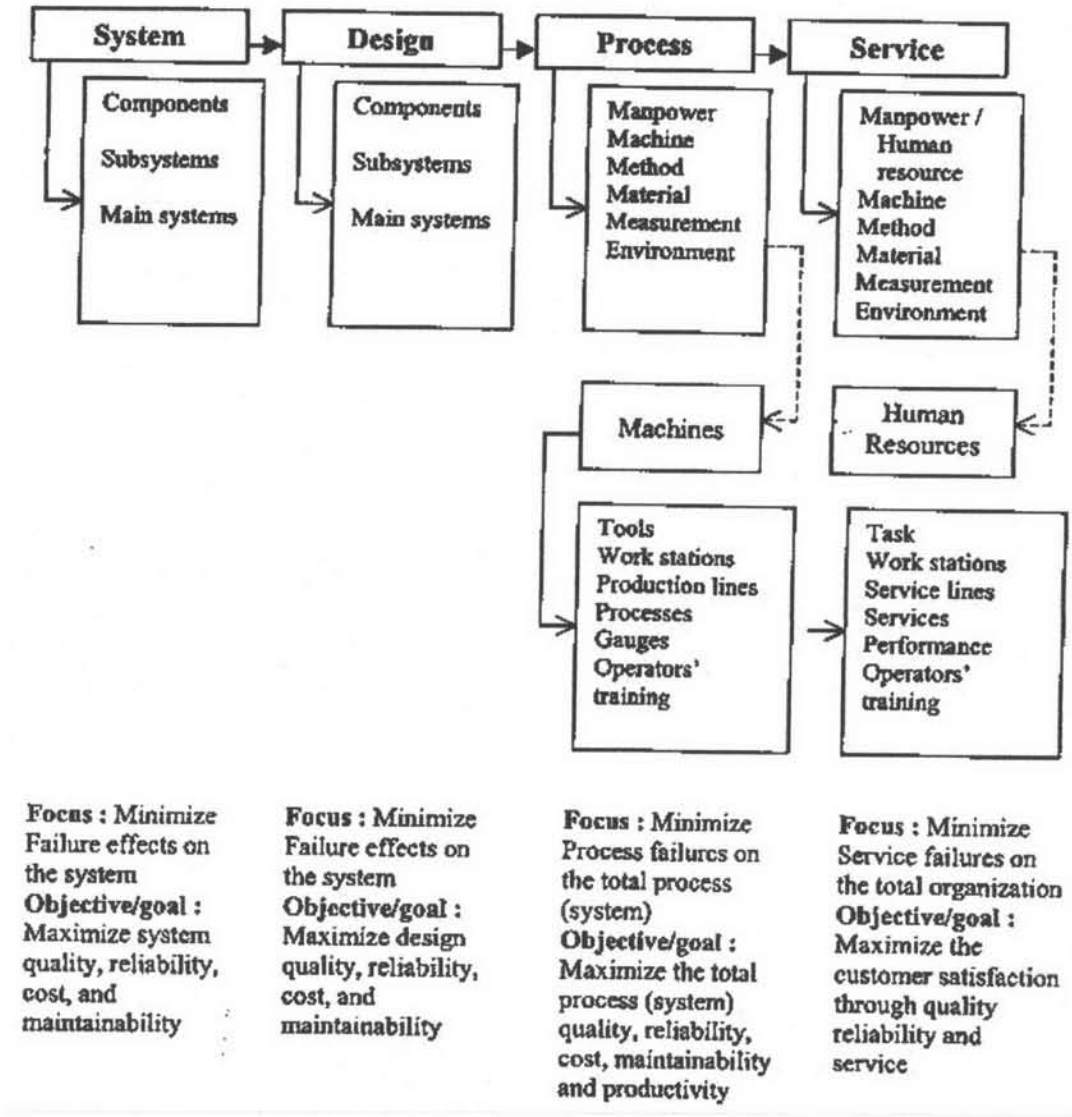

Figure 2.3: Type of FMEA (Stamatis, 1995)

2.1.4 Key Factors for The Success of The FMEA Process

2.1.4.1 Time to Start The FMEA Process

FMEA can begin whenever needed although information is not complete yet. According to Stamatis (1995: 29), the starting time for an FMEA program can be:

- "When new systems, designs, products, processes, or services are designed

- When existing systems, designs, products, processes, or services are about to change regardless of reason
- When new applications are found for existing conditions of the systems, designs, products, processes, or services
- When improvements are considered for the existing systems, designs, products, processes, or services"

It is important to note that after FMEA is implemented, it should be continuously conducted and periodically updated to reflect changes in design or application. The FMEA will be terminated only when the system, design, product, process, or service is considered complete, and/or discontinued.

2.1.4.2 Teamwork

Teamwork is critical to the success of the FMEA process. It is hardly to perform FMEA successfully by individual because the result of FMEA may be bias since it is caused by single individual perspective. Therefore team must be set up appropriately for a specific problem or project. Cross functional and multi-discipline team is necessary as members of the team can share their knowledge and experience in different points of view, i.e. to identify potential failure and find out ways to prevent them from reaching to customers.

The team to perform FMEA should include customers, manufacturing engineers, test engineers, quality engineers, reliability engineers, product engineers, and sales engineers. The potential failure modes listed in the FMEA report include the failures at different stages of internal and external customers such as the manufacturing department in the company, the customer – another manufacturing company – and their customers – the end users. The information used in the FMEA process should come from the company's own production lines, the customers, and the field data of similar products.

Therefore, the FMEA team has to work with the customers to gather the required information to develop an effective FMEA report.

2.1.5 Advantages and Disadvantages

According to Teng and Ho (1996), FMEA provides basic information to reliability prediction, and product and process design. FMEA helps engineers find potential problems in the product earlier and thus avoids costly changes or reworks at later stages, such as at the manufacturing stage and at the product warranty stage. In the FMEA process, product functions must be carefully evaluated, and the potential failures must be listed. This analysis process provides a thorough analysis at each detailed functional design element. It allows FMEA to be a very useful tool in quality planning and reliability prediction.

When an FMEA was performed properly, it actually quantifies design or process risk so high risk can be easily identified. This is important because in the field of quality, the right thing to do is not always intuitive-in fact, it can actually be counterintuitive (Reid, 2005). This is particularly true with characteristic management, dealing with selection of the characteristics to be controlled (Reid, 2003). Once an FMEA is completed, the result is usually the evaluation of some high risk characteristics that would not have otherwise been identified. Using this information, the organization can and should take corrective and preventive action to escape the potential failures in the subject design or process. These actions should be deployed across the organization to similar products, services and processes and the result should be improvements in quality, safety and cost, which should also positively impact customer satisfaction (Reid, 2005). In addition, the FMEA also give process documentation and organizational memory.

Despite advantages described above, problems associated with FMEA implementation include the timing of the FMEA process at the product/process design stage, the establishment of a well trained and balanced FMEA team, the co-ordination of individual departments in generating an accurate FMEA report, and agreement on the FMEA report to improve product/process designs by all departments. Similar to the concurrent engineering procedure, the purpose of the FMEA application is to shorten the time length for the design of product and process. Reliability concerns must be used in the design, and it must be verified that all requirements are met before the completion of the design. Therefore, more effort is required at the design stage.

The full co-operation of all departments is necessary for initiating the FMEA study. Since concurrent engineering is generally received by most companies, the objective then will be to develop an FMEA procedure which runs parallel to the concurrent engineering process. The FMEA report must supply valuable information for product/process improvement in the concurrent engineering process.

A major problem in FMEA implementation is to utilize the FMEA report in the overall quality system implementation to improve the product and the manufacturing operations (Teng and Ho, 1996). So the problem is not only to generate the FMEA report, but also to use the FMEA information in the overall quality system operation to achieve the goal – to improve the product/process design. It is crucial to define and to specify the interactions between FMEA process and quality control process. In general, the major puzzle in today's FMEA application is how to link FMEA procedure to quality control procedures (Teng and Ho, 1996).

According to Chang et al. (2001), the debates that have commonly been raised include:

- the evaluation of RPN is different from traditional concepts of quality measurement;
- the conversion of scores are linear for the chance of failure, but nonlinear for the chance of undetection;
- different sets of the three factors can produce exactly the same value of RPN, but, the hidden implications may be totally different;
- why use multiplication instead of other formulations;
- RPN ignores the effect of production quantity;
- RPN is unable to assign weight to the three factors, which may exist in the real world;
- RPN is unable to estimate the effectiveness of the improvement action.

In comparison to total quality management (TQM), FMEA have some weal spots as listed below (Devadasan et al., 2003):

- TQM envisages the integration of all functions in an organisation that is from design to service. Hence, failure occurrence, detection and

prevention should be applicable to all functions. However, conventional FMEA applies only to design and production processes (Alridge et al., 1991), thus making the TQM process incomplete.

- The success of FMEA lies on the effective retrieval of the tables and other relevant information to prevent further recurrence of failures. However, the traditional FMEA does not effectively support this process because of the absence of a simple codification and retrieval system.
- Although, team effort is suggested in the literature for creating FMEA tables, it is not effectively practised. This is due to the fact that, FMEA tables do not incorporate titles, which can be filled only through team effort.
- Conventional FMEA process involves the calculation of RPN. This calculation makes the FMEA process complex, but does not assure any accuracy in estimating the mode and effect of the failures.

Referred to the calculation of RPN, several points have been criticised by Gilchrist (1993) as follows:

- The RPN does not satisfy the usual requirements of measurement. As a result, the RPN cannot be used to evaluate the impact of remedial actions taken.
- There is no sensible rule of algebra to apply to S and D since the chance of a fault relates to the score in a non-linear fashion, while the chance of undetection and the corresponding score have a linear relationship.
- The RPN should measure the chance of a customer receiving a faulty part. However, with the given scores and probabilities different scores can be combined to give the same score, yet the associated probabilities of a fault reaching the customer are different.
- There is no rationale as to why S, O, and D should be multiplied to produce the RPN.
- The RPN ignores the number of items to be produced and calculates the risk to a customer from one item only.

2.2 Total Quality Management (TQM)

Total quality management (TQM) is a management strategy aimed at embedding awareness of quality in all organizational processes. TQM has been widely used in manufacturing, education, government, and service industries, as well as NASA space and science programs (Wikipedia, 2007).

2.2.1 Definition

As defined by the International Organization for Standardization (ISO), "TQM is a management approach for an organization, centered on quality, based on the participation of all its members and aiming at long-term success through customer satisfaction, and benefits to all members of the organization and to society."

Total quality is called total because it consists of 3 qualities: Quality of return to satisfy the needs of the shareholders, Quality of products and services to satisfy some specific needs of the consumer (end customer) and Quality of life - at work and outside work - to satisfy the needs of the people in the organization. This is achieved with the help of upstream and downstream partners of the enterprise.

In Japan, TQM comprises four process steps, namely (Wikipedia, 2007):

1. *Kaizen* – Focuses on "Continuous Process Improvement", to make processes *visible*, *repeatable* and *measurable*.
2. *Atarimae Hinshitsu* – The idea that "things will work as they are supposed to" (for example, a pen will write).
3. *Kansei* – Examining the way the user applies the product leads to improvement in the product itself.
4. *Miryokuteki Hinshitsu* – The idea that "things should have an aesthetic quality" (for example, a pen will write in a way that is pleasing to the writer).

TQM requires that the company maintain this quality standard in all aspects of its business. This requires ensuring that things are done right the first time and that defects and waste are eliminated from operations (Wikipedia, 2007).

To date there are several authors describing total quality management concept. These include Deming (1986), Juran and Gryna (1993), Crosby (1979), Feigenbaum (1991), and Ishikawa (1985).

2.2.2 TQM Approaches

2.2.2.1 Deming's Approach to TQM

The theoretical essence of the Deming's approach to TQM concerns the creation of an organizational system that fosters cooperation and learning for facilitating the implementation of process management practices, which, in turn, leads to continuous improvement of processes, products, and services as well as to employee fulfillment, both of which are critical to customer satisfaction, and ultimately, to firm survival (Anderson et al., 1994). Deming (1986) has stressed the responsibilities of top management to take the lead in changing processes and systems. Leadership plays in ensuring the success of quality management, because it is the top management's responsibility to create and communicate a vision to move the firm toward continuous improvement. Top management is responsible for most quality problems; it should give employees clear standards for what is considered acceptable work, and provide the methods to achieve it. These methods include an appropriate working environment and climate for work-free of faultfinding, blame or fear. Deming (1986) has also emphasized the importance of identification and measurement of customer requirements, creation of supplier partnership, use of functional teams to identify and solve quality problems, enhancement of employee skills, participation of employees, and pursuit of continuous improvement.

2.2.2.2 Juran's Approach to TQM

TQM is the system of activities directed at achieving delighted customers, empowered employees, higher revenues, and lower costs (Juran and Gryna, 1993). Juran has believed that main quality problems are due to management rather than workers. The attainment of quality requires activities

in all functions of a firm. Firm-wide assessment of quality, supplier quality management, using statistical methods, quality information system, and competitive benchmarking are essential to quality improvement. Juran's approach is emphasis on team (QC circles and self-managing teams) and project work, which can promote quality improvement, improve communication between management and employees coordination, and improve coordination between employees. He has also emphasized the importance of top management commitment and empowerment, participation, recognition and rewards.

According to Juran and Gryna (1993), it is very important to understand customer needs. This requirement applies to all involved in marketing, design, manufacture, and services. Identifying customer needs requires more vigorous analysis and understanding to ensure the product meets customers' needs and is fit for its intended use, not just meeting product specifications. Thus, market research is essential for identifying customers' needs. In order to ensure design quality, he proposed the use of techniques including quality function deployment, experimental design, reliability engineering and concurrent engineering.

2.2.2.3 Crosby's Approach to TQM

Crosby (1979) has identified a number of important principles and practices for a successful quality improvement program, which include, for example, management participation, management responsibility for quality, employee recognition, education, reduction of the cost of quality (prevention costs, appraisal costs, and failure costs), emphasis on prevention rather than after-the-event inspection, doing things right the first time, and zero defects.

Crosby (1979) has claimed that mistakes are caused by two reasons: Lack of knowledge and lack of attention. Education and training can eliminate the first cause and a personal commitment to excellence (zero defects) and attention to detail will cure the second. Crosby (1979)has also stressed the importance of management style to successful quality improvement. The key to quality improvement is to change the thinking of top managers-to get them

not to accept mistakes and defects, as this would in turn reduce work expectations and standards in their jobs. Understanding, commitment, and communication are all essential. Crosby (1979) presented the quality management maturity grid, which can be used by firms to evaluate their quality management maturity. The five stages are: Uncertainty, awakening, enlightenment, wisdom and certainty. These stages can be used to assess progress in a number of measurement categories such as management understanding and attitude, quality organization status, problem handling, cost of quality as percentage of sales, and summation of firm quality posture. The quality management maturity grid and cost of quality measures are the main tools for managers to evaluate their quality status.

2.2.2.4 Feigenbaum's Approach to TQM

Feigenbaum (1991) defined TQM as: An effective system for integrating the quality development, quality-maintenance, and quality-improvement efforts of the various groups in a firm so as to enable marketing, engineering, production, and service at the most economical levels which allow for full customer satisfaction. He claimed that effective quality management consists of four main stages, described as follows:

- Setting quality standards;
- Appraising conformance to these standards;
- Acting when standards are not met;
- Planning for improvement in these standards.

The quality chain, he argued, starts with the identification of all customers' requirements and ends only when the product or service is delivered to the customer, who remains satisfied. Thus, all functional activities, such as marketing, design, purchasing, manufacturing, inspection, shipping, installation and service, etc., are involved in and influence the attainment of quality. Identifying customers' requirements is a fundamental initial point for achieving quality. He has claimed that effective TQM requires a high degree of effective functional integration among people, machines, and information, stressing a system approach to quality. A clearly defined total

quality system is a powerful foundation for TQM. Total quality system is defined as follows:

"The agreed firm-wide operating work structure, documented in effective, integrated technical and managerial procedures, for guiding the coordinated actions of the people, the machines, and the information of the firm in the best and most practical ways to assure customer quality satisfaction and economical costs of quality."

2.2.2.5 Ishikawa's Approach to TQM

Ishikawa6 (1985) has argued that quality management extends beyond the product and encompasses after-sales service, the quality of management, the quality of individuals and the firm itself. He has claimed that the success of a firm is highly dependent on treating quality improvement as a never-ending quest. A commitment to continuous improvement can ensure that people will never stop learning. He advocated employee participation as the key to the successful implementation of TQM. Quality circles, he believed, are an important vehicle to achieve this. Like all other gurus he emphasized the importance of education, stating that quality begins and ends with it. He has been associated with the development and advocacy of universal education in the seven QC tools (Ishikawa, 1985). These tools are listed below:

- Pareto chart;
- Cause and effect diagram (Ishikawa diagram);
- Stratification chart;
- Scatter diagram;
- Check sheet;
- Histogram;
- Control chart.

Ishikawa (1985) has suggested that the assessment of customer requirements serves as a tool to foster cross-functional cooperation; selecting suppliers should be on the basis of quality rather than solely on price; cross-functional teams are effective ways for identifying and solving quality

problems. Ishikawa's concept of TQM contains the following six fundamental principles:

- Quality first-not short-term profits first;
- Customer orientation-not producer orientation;
- The next step is your customer-breaking down the barrier of sectionalism;
- Using facts and data to make presentations-utilization of statistical methods;
- Respect for humanity as a management philosophy, full participatory management;
- Cross-functional management.

2.3 Cause and Effect Diagram

A cause and effect diagram is a tool that helps identify, sort, and display possible causes of a specific problem or quality characteristic. It graphically illustrates the relationship between a given outcome and all the factors that influence the outcome. This type of diagram is sometimes called an "Ishikawa diagram" because it was invented by Kaoru Ishikawa, or a "fishbone diagram" because it looks like the skeleton of a fish as shown in Figure 2.4.

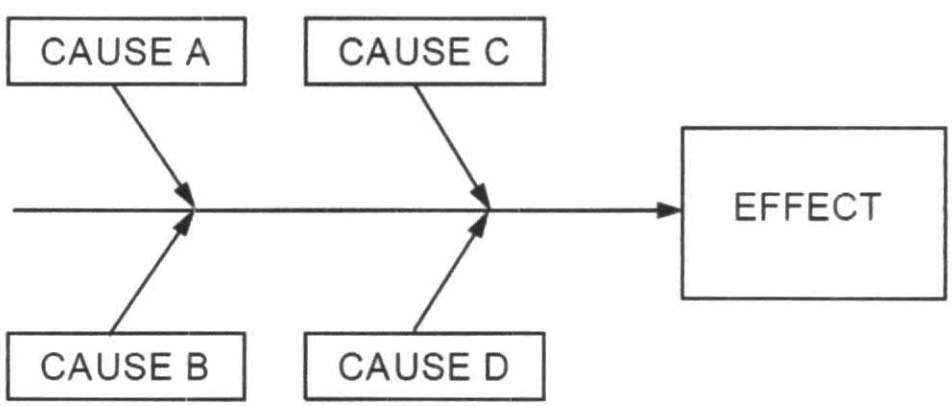

Figure 2.4: Basic layout of cause and effect diagram

Constructing a cause and effect diagram can help a team to do several things including:

- Identify the possible root causes, the basic reasons, for a specific effect, problem, or condition.
- Sort out and relate some of the interactions among the factors affecting a particular process or effect.
- Analyze existing problems so that corrective action can be taken.

A cause and effect diagram is a tool that is useful for identifying and organizing the known or possible causes of quality, or the lack of it. The structure provided by the diagram helps team members think in a very systematic way. Some of the benefits of constructing a cause and effect diagram are that it helps determine the root causes of a problem or quality characteristic using a structured approach, encourages group participation and utilizes group knowledge of the process, uses an orderly, easy-to-read format to diagram cause-and-effect relationships, indicates possible causes of variation in a process, increases knowledge of the process by helping everyone to learn more about the factors at work and how they relate, and finally identifies areas where data should be collected for further study.

2.3.1 Procedure for Developing A Cause and Effect Diagram

The steps for constructing and analyzing a cause and effect diagram are outlined below:

Step 1 - Identify and clearly define the outcome or effect to be analyzed

- Decide on the effect to be examined. Effects are stated as particular quality characteristics, problems resulting from work, planning objectives, and the like.
- Develop an operational definition of the effect to ensure that it is clearly understood.
- Remember that an effect may be positive (an objective) or negative (a problem), depending upon the issue that's being discussed.

- Using a positive effect which focuses on a desired outcome tends to foster pride and ownership over productive areas. This may lead to an upbeat

atmosphere that encourages the participation of the group. When possible, it is preferable to phrase the effect in positive terms.

- *Focusing on a negative effect can sidetrack the team into justifying why the problem occurred and placing blame.* However, it is sometimes easier for a team to focus on what causes a problem than what causes an excellent outcome. While it should be cautious about the fallout that can result from focusing on a negative effect, getting a team to concentrate on things that can go wrong may foster a more relaxed atmosphere and sometimes enhances group participation.

Step 2 - Using a chartpack positioned so that everyone can see it, draw the spine and create the effect box.

- Draw a horizontal arrow pointing to the right. This is the spine.
- To the right of the arrow, write a brief description of the effect or outcome which results from the process. Figure 2.5 shows an example of the causes relating to a car's getting poor gas mileage. Here the effect is poor gas mileage
- Draw a box around the description of the effect.

Figure 2.5: Drawing the spine and creating the effect box

Step 3 - Identify the main causes contributing to the effect being studied.

These are the labels for the major branches of the diagram and become categories under which to list the many causes related to those categories.

- Establish the main causes, or categories, under which other possible causes will be listed. Category labels that make sense for the diagram created should be used. Here are some commonly used categories:
  - 4Ms - methods, materials, machinery, and men (people)

- 4Ps - policies, procedures, people, and plant
- Environment - a potentially significant fifth category

- Write the main categories the team has selected to the left of the effect box, some above the spine and some below it.
- Draw a box around each category label and use a diagonal line to form a branch connecting the box to the spine.

Example of this step is shown in Figure 2.6 by using the 4Ms to start developing the diagram developed in Step 2.

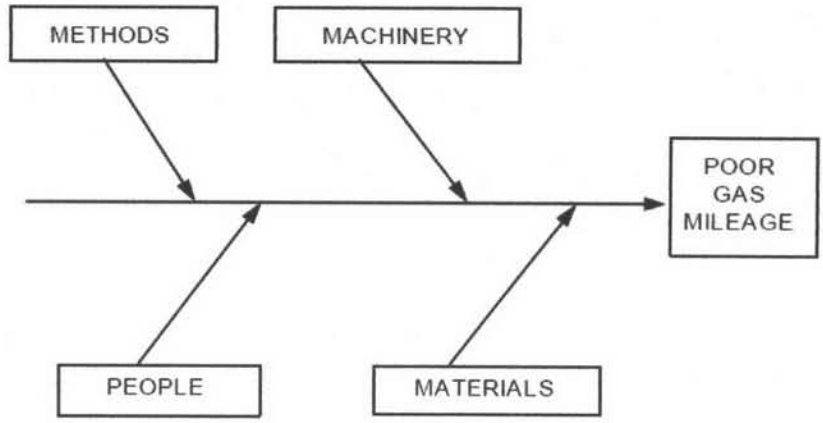

Figure 2.6: Identifying main categories

Step 4 - For each major branch, identify other specific factors which may be the cause of the effect (Ishikawa, 1968, p.20).

- Identify as many causes or factors as possible and attach them as subbranches of the major branches. Example of the possible causes for *Poor Gas Mileage* is listed under the appropriate categories as shown in Figure 2.7.
- Fill in detail for each cause. If a minor cause applies to more than one major cause, list it under both.

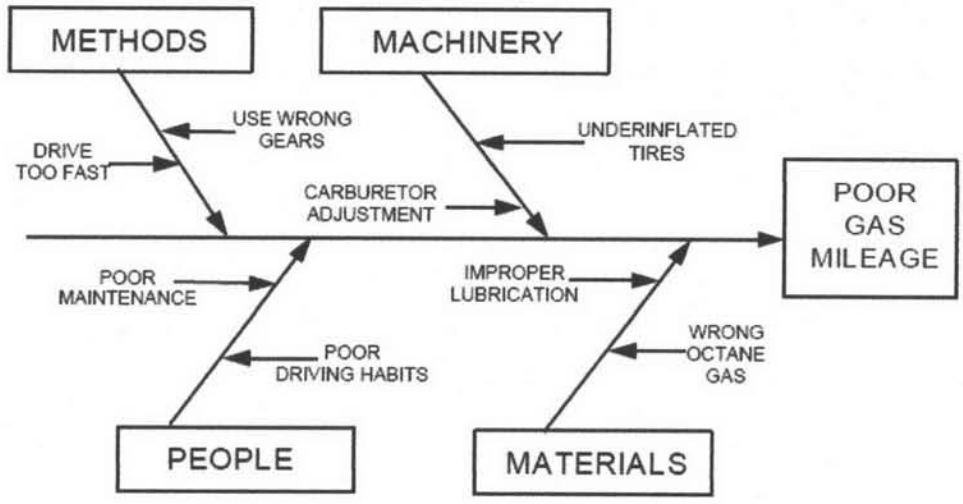

Figure 2.7: Identifying causes influencing the effect

Step 5 - Identify increasingly more detailed levels of causes and continue organizing them under related causes or categories.

This can be done by asking a series of why questions. A series of why questions to fill in the detailed levels for one of the causes listed under each of the main categories should be used. For example, why was the driver using the wrong gear? The answer is the driver couldn't hear the engine. Why couldn't the driver hear the engine? The answers are the radio was too loud and poor hearing. Figure 2.8 shows how the diagram looks when all the contributing causes that were identified by the series of why questions have been filled in. As can be seen, there may be many levels of causes contributing to the effect. It may need to break the diagram into smaller diagrams if one branch has too many subbranches. Any main *cause* (4Ms, 4Ps, or a category named) can be reworded into an *effect*.

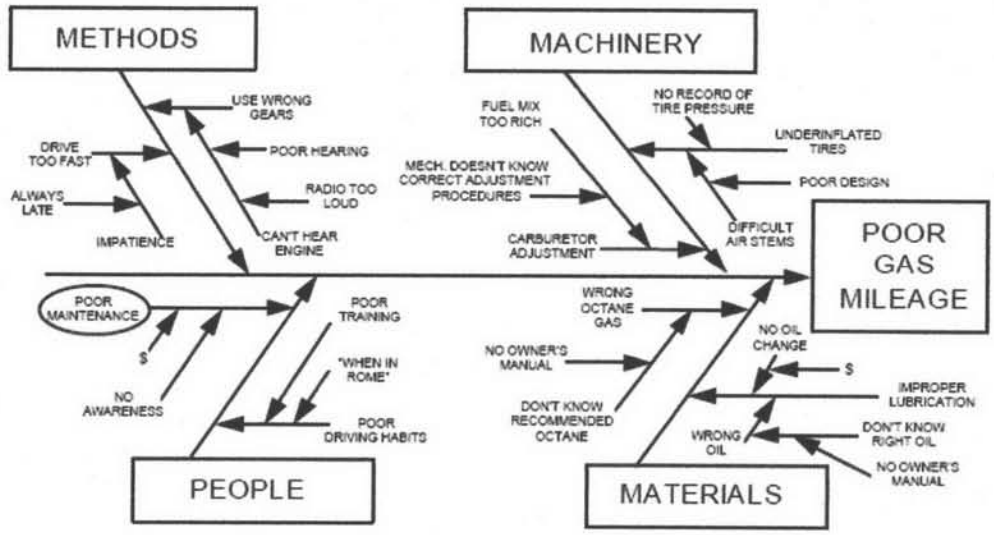

Figure 2.8: Adding detailed levels and analyzing the diagram

Step 6 - Analyze the diagram.

Analysis helps the team identify causes that warrant further investigation. Since cause and effect diagrams identify only possible causes, it may be necessary to use a Pareto chart to help the team determine the cause to focus on first.

- Look at the "balance" of the diagram, checking for comparable levels of detail for most of the categories.
  - ➢ A thick cluster of items in one area may indicate a need for further study.
  - ➢ A main category having only a few specific causes may indicate a need for further identification of causes.
  - ➢ If several major branches have only a few subbranches, it may need to combine them under a single category.
- Look for causes that appear repeatedly. These *may* represent root causes.
- Look for what can be measured in each cause so that the effects of any changes made can be quantified.
- Most importantly, identify and circle the causes that the team can take action on.

From Figure 2.8, it can be concluded that:

- The level of detail is pretty well balanced.
- No causes are repeated.
- *Poor Maintenance* appears to be a cause for which the team could develop measurements.
- Moreover, *Poor Maintenance* appears to be a cause that the team can take action on. It is circled in Figure 2.8 to earmark it for further investigation.

2.4 Pareto Diagram

Pareto analysis is a statistical technique in decision making that is used for selection of a limited number of tasks that produce significant overall effect (Wikipedia, 2007). It uses the Pareto principle - the idea that by doing 20% of work, 80% of the advantage of doing the entire job can be generated. Or in terms of quality improvement, a large majority of problems (80%) are produced by a few key causes (20%). Therefore, targeting these "major causes" for elimination results in the most cost-effective improvement scheme.

Pareto analysis is a formal technique useful where many possible courses of action are competing for attention. In essence, the problem-solver estimates the benefit delivered by each action, then selects a number of the most effective actions that deliver a total benefit reasonably close to the maximal possible one. Purposes of the Pareto diagram is to display the relative importance of data and to direct efforts to the biggest improvement opportunity by highlighting the vital few in contrast to the useful many. The Pareto diagram is similar to the histogram or bar chart, except that the bars are arranged in decreasing order from left to right along the abscissa.

A Pareto diagram can be constructed by the following procedure:

- Determine the categories and the units for comparison of the data, such as frequency, cost, or time.
- Total the raw data in each category, then determine the grand total by adding the totals of each category.
- Re-order the categories from largest to smallest.

- Determine the cumulative percent of each category (i.e., the sum of each category plus all categories that precede it in the rank order, divided by the grand total and multiplied by 100).
- Draw and label the left-hand vertical axis with the unit of comparison, such as frequency, cost or time.
- Draw and label the horizontal axis with the categories. List from left to right in rank order.
- Draw and label the right-hand vertical axis from 0 to 100 percent. The 100 percent should line up with the grand total on the left-hand vertical axis.
- Beginning with the largest category, draw in bars for each category representing the total for that category.
- Draw a line graph beginning at the right-hand corner of the first bar to represent the cumulative percent for each category as measured on the right-hand axis.
- Analyze the chart. Usually the top 20% of the categories will comprise roughly 80% of the cumulative total.

It is important to note that Pareto charts both before and after improvement should be prepared in order to show impact of improvement efforts. Different measurement scales, frequency, cost or time should be used in creating Pareto charts. Using objective data to perform Pareto analysis is better than using team members' opinions. If there is no clear distinction between the categories - if all bars are roughly the same height or half of the categories are required to account for 60 percent of the effect - consider organizing the data in a different manner and repeating Pareto analysis should be carried out.

2.5 Researches About Thai Rice

According to International Rice Research Institute (IRRI) report (2000), Thailand was the world's largest exporter of rice, shipping out 5-6 million tons of milled rice each year. It had a reputation for producing high-quality, long-grain, white rice, which commanded a premium price in the world market. In 1996, Thailand exported 6.2 million tons of rice worth US$2002 million of foreign exchange. Rice exports accounted for 3.6% of the country's total export earnings.

Farm families were the backbone of Thailand where 52% of the population was agricultural and rice was still the staple food and the most important crop. The average annual per capita consumption of milled rice was about 114 kg. Rice was cultivated on around 9 million hectares and occupied more than half of the total cultivated land.

The majority of Thai farmers grew rice. The world's population continued to increase by 85 million a year. Although the population growth was expected to slow down from 1.6% per year for 1990-95 to 1.0% for 2020-2025, the absolute increase in population would still be 75 million per year for the later period (IRRI Report, 2000).

Four seasons were recognized in Thailand: the southwest monsoon from May to September; a transition period from the southwest to the northeast monsoon during October; the cool, dry northeast monsoon from November to February; and a pre-monsoon hot, dry season from March to April.

Only about one-fourth of the total rice land in Thailand was irrigated. Thus, the rainfed lowland farm was the typical planting environment in Thailand especially on the nutrient-poor soils of the northeast, where 90% of the farms depended on rain for crop production.

Upland rice was grown in hilly areas while deepwater rice was cultivated on flooded areas of the central plain. Administratively and geographically, Thailand was divided into four regions: northern, central, northeastern, and southern. Each region had a different rice-growing environment.

Vejpas et al. (2003) have studied the systems of rice varieties and seed management through systems modeling with a participatory approach, and proposed models for managing rainfed lowland rice varieties and seed system in lower northeast Thailand. Rice varieties and seed management involve a complex system dealing with various problems such as variety adoption, agro-biodiversity conservation, and quality seed supply. A participatory modeling experiment on rainfed lowland rice variety and seed management in lower northeast Thailand has been launched to better understand the system and its problems. Conceptual modeling

was done through inter-institutional research team meetings, stakeholder analysis, surveying of stratified randomly sampled farmers and seed supply agents in Ubon Ratchathani Province, and by conceiving and using role-playing games (RPGs) with stakeholders. The system to be analyzed was divided into three subsystems, i.e. farmers' decision making regarding the choice of rice varieties, farmers' management of rice seeds, and the seed supply sub-system. A first RPG focusing on the first two subsystems was used with 25 farmers in two different gaming sessions. Observations and findings from the RPG helped to validate and to improve the conceptual model prepared by the research team. It also builds a shared understanding of farmers' rice varieties and seed management. Limited access to information about varieties and seeds, the need for early maturing varieties, and the scarcity of quality seeds were identified as current constraints of the system. A second RPG representing the seed supply subsystem is being conceived. Later on, a multi-agent system model of the whole system will also be developed and used to simulate scenarios identified by stakeholders and to discuss their results to facilitate collective learning and improvement of the current situation.

Varanyanond et al. (2005) have studied the effects of water soaking on gamma-aminobutyric acid (GABA) in germ of different Thai rice varieties namely, Khao Dawk Mali 105, Pathum Thani 1, Chai Nat 1, Suphan Buri 1, Leuang Pratew 123 and Plai Ngahm.. The research has found that Plai Ngahm had the highest percentage of germ weight while Patum Thani 1 had the lowest. Percentage of germ weight showed no relation to the GABA content. High GABA content of germ was found in 3 rice varieties: Khao Dawk Mali 105 (186.2 mg/kg of germ) Pathum Thani 1 (154.6 mg/kg of germ) and Chai Nat 1 (144.5 mg/kg of germ). Plai Ngahm, on the other hand, contained GABA 116.9 mg/kg of germ. Water soaking can enrich GABA content in the germ of all rice varieties. The GABA accumulation differed among rice varieties and according to soaking time.

Limpisut and Jindal (2002) have compared the properties of rice flour pasting using Brabender Viscoamylograph and Rapid Visco Analyser for evaluating cooked rice texture. Pasting properties of ten Thai rice varieties, with amylose contents in the range of 16 to 33% and stored at 10, 30 and 40 °C for six months were compared using the Brabender Viscoamylograph (VAG) and the Rapid Visco Analyser (RVA)

for evaluating the texture of cooked rice. Linear correlations between pasting temperature and viscosity parameters based on RVA showed a different pattern than those based on VAG with high negative correlation coefficients between the peak and breakdown viscosities. Both RVA and VAG indicated peak viscosity to be positively correlated with breakdown viscosity, and negatively with the setback viscosity. Setback and consistency viscosities correlated with each other in both instruments but indicating a negative correlation with breakdown viscosity in VAG only. Pasting temperature determined by VAG and RVA did not show good correlations for rice sample stored at different temperatures neither for individual nor for combined data. Only peak, breakdown and setback viscosities showed significant correlations in the overall data ($r > 0.496$). The VAG measurements performed better than the RVA in the development of predictive models for evaluating the hardness and adhesiveness of cooked rice based on instrumental texture profile analysis. The springiness and cohesiveness of cooked rice could not be estimated from the pasting properties of rice flour determined by both VAG and RVA. Results showed that both VAG and RVA could be used for evaluating the texture of cooked rice despite the differences in the measurements of the pasting properties of milled rice flours.

Krasachat (2003) has measured and investigated technical efficiency in rice farms in Thailand. This study decomposes technical efficiency into its technical and scale components. In past studies, efficiency analyses have involved econometric methods. In this study, the data envelopment analysis (DEA) approach and farm-level cross-sectional survey data of Thai rice farms in 1999 are used. A Tobit regression is used to explain the likelihood of changes in inefficiencies by farm-specific factors. The empirical findings indicate a wide diversity of efficiencies from farm to farm and also suggest that the diversity of natural resources has had an influence on technical efficiency in Thai rice farms.