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Developing an information system to integrate a manufacturing firm and its supplier base

Abhishek Padiyar
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Abhishek Padiyar entitled "Developing an information system to integrate a manufacturing firm and its supplier base." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

Rapinder Singh Sawhney, Major Professor

We have read this thesis and recommend its acceptance:

Kenneth E. Kirby, Dukwon Kim

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Developing an information system to integrate a manufacturing firm and its supplier base

A thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Abhishek Padiyar
May 2005

DEDICATION

This thesis is dedicated to my parents, M. Balakrishana Padiyar and Kavitha B. Padiyar for always believing in my abilities, encouraging me through the challenging times, and helping me in realizing my dreams.

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When completing a work such as this, you realize that you did not do it alone, and that we all stand on the shoulders of other men and women. There are people who either gave you a chance or an avenue to create, encouraged or exhorted you along the way, or supported you so that you might have the opportunity to pursue your dreams. I have been very blessed to be surrounded by these types of people on this piece of my life’s journey, and I would like to take this space to acknowledge some of them.

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ABSTRACT

A manufacturing firm is encouraging their suppliers to achieve the goal of zero-defects. However, due to the high expectations set by the manufacturing firm, the suppliers are finding it quite challenging to be able to immediately react to the quality requirements of the manufacturing firm. The manufacturing firm wants to ensure that the suppliers take the necessary actions to eliminate the reoccurrence of specific non-conformities. This thesis illustrates the application of an information system that integrates the manufacturing firm with their supplier base. The information system is developed based on the framework of Failure Modes and Effects Analysis (FMEA). It utilizes the concept of Grey theory and Defective Opportunities per Part (DOPP) to rank the non-conformities based on the priorities of the manufacturing firm. This will align the supplier's response to the requirement of the manufacturing firm. The information system will not only provide transparency in the flow of information between the manufacturing firm and its suppliers but will also ensure that the manufacturing firm will be able to easily monitor the effectiveness of supplier's action. A future worth cost analysis demonstrates the benefit of employing the new approach.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

H_o	Null Hypothesis
H_a	Alternative Hypothesis
S_o	Occurrence of the non-conformity
S_s	Severity ranking of the non-conformity with regards to customer
S_d	Ease of detection ranking
x_i	Decision factors of FMEA
x'_i	Comparative series
x_o	Objective series or standard series
γ	Grey relational coefficient
Γ	Degree of grey relation
β	Weighting coefficient of factors
μ_1	Mean of RPN numbers calculated by the traditional approach
μ_2	Mean of RPN numbers calculated by grey theory and DOPP approach
α	Significance level
δ	Difference in means
σ_2^2	Variance of RPN numbers calculated by the traditional approach
σ_1^2	Variance of RPN numbers calculated by Grey theory & DOPP

σ	Pooled Standard Deviation

Abbreviations

CPN	Critical Path Network
DBMS	Data Base Management System
DOPP	Defective Opportunities per Part
FMEA	Failure Modes and Effect Analysis
FTA	Fault Tree Analysis
ID	Identification number
IS	Information System
IT	Information Technology
KR code	A category of defect code specified by the manufacturing firm
MS	Microsoft
NC	Non-conformities
PDPC	Process Decision Program Chart
PERT	Program Evaluation and Review Technique
RPN	Risk Priority Number
SDLC	System Development Life Cycle
SEM	Supplier Evaluation Module
WBS	Work Breakdown Structure

CHAPTER 1

Introduction

1.1 Introduction

This introductory chapter begins with a quest to answer the question as to why there exists a requirement for an information system between the manufacturing firm and the suppliers, or in other words, the rationale behind the development of this thesis. It then proceeds to pin down the problem statement that outlines the objective of this research. Further the chapter provides a brief description regarding the proposed approach undertaken during the course of this research to achieve the objective as defined in the problem statement. The chapter concludes with a bird's eye view of the organization of this thesis in the subsequent chapters.

1.2 Requirement for developing an information system

Advancements in technology increased the capability of the manufacturing firm to produce a wide variety of products. This made it difficult to enforce higher standards of precision and tolerances associated with the manufacturing of a part (Womack, 1991). Hence, the increase in demand for variety in parts produced also increased the number of non-conforming parts. This forced manufacturing firms to outsource the fabrication activities of their production process. However there still existed a requirement to reduce and prevent the occurrence of non-conformities from the parts that were being delivered by the suppliers so as to achieve the objective of zero defects and to dampen the schedule variation occurring due to the identification of nonconforming parts (Crosby, 1995). This compelled manufacturing firms to focus on the elimination of non-conformities and institute the zero tolerance policy across the supplier base.

The suppliers on the other hand started facing a compounded problem due to the higher quality standards set by the manufacturing firms. To ensure good product quality suppliers had to establish an efficient and comprehensive quality system in every stage of the production and design process (Teng and Ho, 1996). However, the impact of a comprehensive quality system or audit can be appreciated only after an extended period of its actual implementation. The timeline to achieve the perceived benefits was more immediate at the manufacturer's end as compared to the longer perceived timeline at the suppliers end. As a result the suppliers were opting for containment of non-conformance as a strategy for achieving zero defects (Halpin, 1966). The containment of non-conformance did not seem like a valid strategy because neither were the suppliers capable of immediately responding to the demands of the manufacturing firm nor were they able to prevent the reoccurrence of the non-conformities. Hence, there exists a requirement to develop an information system to bridge the gap of non-conforming standards between the manufacturing firm and its supplier base, because both of them are striving to achieve a common goal of zero defects.

The information system should be a means through which the suppliers and the manufacturing firm should be able to effectively communicate with each other. This will enhance the transfer of information between the manufacturing firm and its suppliers. The information system should also offer a structured approach to determine the probable point of incidence of the non-conformity for the manufacturing firm. It should also be able to effectively rank the non-conformities into precise action items for the suppliers, based on the priorities of the manufacturing firm. This will allow the suppliers to quickly align themselves and react immediately to the quality standards of the manufacturing firm. It will also enable the suppliers to have appropriate controls in place to detect the non-conformities and hence prevent the non-conforming parts from reaching the manufacturing firm.

1.3 Problem statement

The research carried out in this thesis focuses on developing an information system to fulfill the following objectives:

1) To enhance the transparency of information between the manufacturing firm and its suppliers so that the suppliers will be able to immediately align and react to the quality standards of the manufacturing firm.
2) To develop a systematic approach to rank the non-conformities for the manufacturing firm and to provide the manufacturing firm with the ability to trace the cause of the non-conformity.
3) To facilitate the manufacturing firm's ability to drive the suppliers to take the control actions in the sequence of the non-conformity ranking, so that the non-conformity of a higher priority to the manufacturing firm will be addressed immediately.

1.4 Approach

The application (Information System) is developed on the platform of Microsoft Access, which acts as a database to store comprehensive information regarding all the non-conforming records. Microsoft Visual Basic 6.0 is used as a front end for this application. It acts as a means through which the manufacturing firm and its suppliers can input information into the MS access database. It also behaves as an interface for the manufacturing firm and its suppliers to effectively communicate between each other thereby, improving the transparency of the information regarding a particular non-conformity. The back end of the information system uses the concept of modified Failure Modes and Effect Analysis (FMEA) and an algorithm based on Grey theory to rank the non-conformities for the manufacturing firm and hence provide the supplier with a prioritized list of action items. A block diagram of the proposed information system is shown in Figure 1.1.

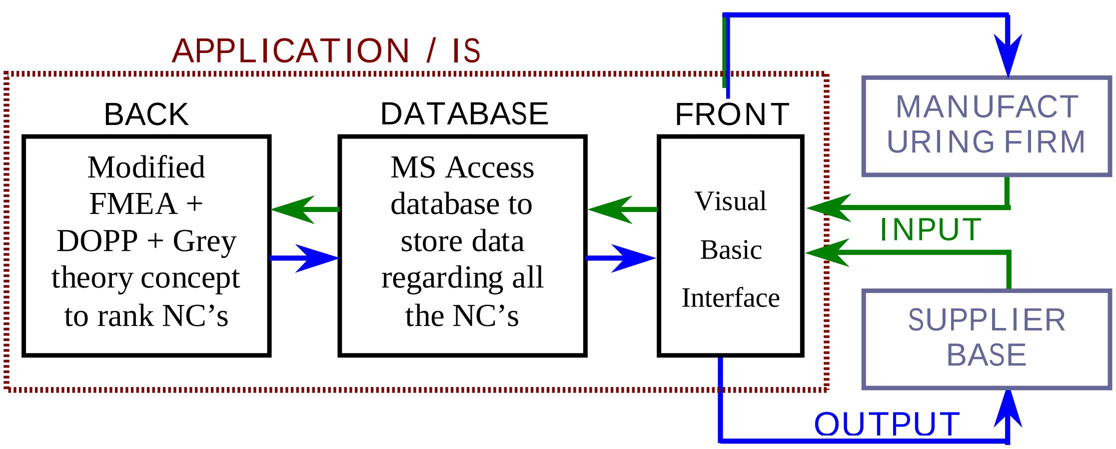
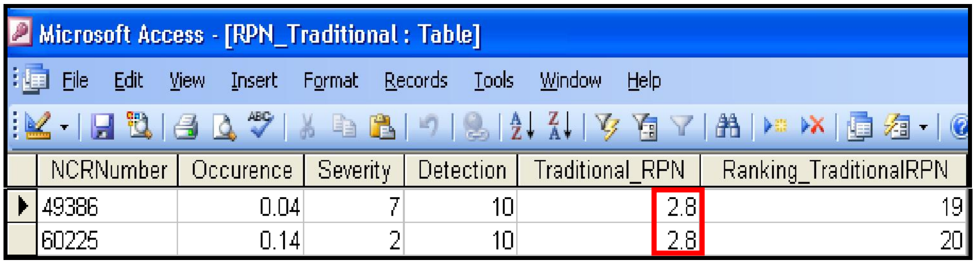


Figure 1.1: Block diagram of the information system

1.4.1 FMEA as a framework for developing the information system

One of the primary objectives of developing this information system is to provide the manufacturing firm with an ability to prioritize the non-conformities. A literature review indicates that of all the quality control tools that are currently in practice, the concept of FMEA has proved to be very successful to prioritize the non-conformities and hence create a list of control action items so as to prevent the reoccurrence of the non-conformity (Aldridge et al., 1990). Hence, the back end of the Information System was built on the concept of FMEA. FMEA involved listing of the potential failure modes which in this case would be the non-conformities originating from various suppliers and then evaluating the risks associated with the nonconformities in terms of the likelihood of their occurrence (S_o), severity with regards to customer (S_s) (Refer Figure A-1), and ease of detection (S_d) (Refer Figure A-2). As a non-conformity is identified, the occurrence, severity and detection associated with it is recorded in the database of the information system. This information is then utilized to calculate the Risk Priority Number (RPN), which is a product of S_o, S_s and S_d (Figure 1.2). The non-conformities are then ranked based on the decreasing order of the RPN number. This ranking is then employed to provide the suppliers with a prioritized list of action items. This will enable the suppliers to immediately align themselves and react to the requirements of the manufacturing firm. The effect of the control action, taken by the supplier, is monitored by the manufacturing firm.



NCRNumber	Occurence	Severity	Detection	Traditional_RPN	Ranking_TraditionalRPN
49386	0.04	7	10	2.8	19
60225	0.14	2	10	2.8	20

Figure 1.2: Drawback in calculating RPN (Traditional approach)

1.4.2 Drawbacks of traditional FMEA approach

Literature indicates that several researchers (Sankar and Prabhu, 2001; Ben-Daya and Raouf, 1993; Gilchrist, 1993; Pillay and Wang, 2003; Chang *et al*., 1999) have criticized the traditional FMEA, especially in association to the method in which the RPN number is calculated. The debates that were consistently raised by each of these authors included the following points:

1) The RPN number does not take into account the complexity of a non-conforming part or in other words the three factors that are used for calculating the RPN number (S_d, S_s and S_o) do not consider the number of opportunities for defects in a given part. This is a very critical factor that needs to be taken into account when we are ranking the non-conformities originating from wide variety of parts (as in this case) on the basis of a common ranking system.

2) The RPN should measure the probability of the customer receiving a faulty part. However, different scores and probabilities of S_d, S_s and S_o can be combined to give the same RPN, yet the associated probabilities of the fault reaching the customer are different. Hence,

there is no rationale as to why S_d, S_s and S_o are to be multiplied to arrive at the RPN number. An illustration of this case can be seen in Figure 1.2. Two different non-conforming records (49386 and 60225) have different set of associated probabilities yet arrive at the same RPN (2.8). This makes it difficult to rank or prioritize these non-conformities on the basis of RPN number.

3) One of the critical disadvantages of the FMEA is the method that it employs to calculate risk ranking. The RPN number is just a multiplication of factor scores and it fails to consider the relative importance of each of these individual factors.

1.4.3 Defective opportunities per part (DOPP)

Arguments in the previous section reinforce the fact that it is very essential that we make a conscious effort to reduce the impact of the above mentioned drawbacks of a traditional FMEA before applying this concept for calculating the RPN number in the proposed model. One of the first steps to achieve this objective is to include an additional factor called defective opportunities per part (DOPP) along side the other factors, S_d, S_s and S_o that are currently used for calculating the RPN number. This would enable us to standardize the prioritization of non-conformities originating from different types of non-conforming parts and hence rank the non-conformities on a common platform. In other words while calculating the RPN number the

DOPP will act like a weighting factor that accounts for the complexity associated with a part.

1.4.4 Integrating grey theory into the proposed model

Grey theory provides a measure to analyze relationship between discrete quantitative and qualitative series provided all the components of the series are existent, countable, extensible and independent (Chang *et al.*, 2001). Since all the factors (DOPP, S_d, S_s and S_o) in the proposed model fulfill these characteristics, therefore, it is suitable to apply grey theory to this model. Researchers (Pillay and Wang, 2003; Chang *et al.*, 1999; Chang *et al.*, 2001) have demonstrated the use of grey theory within the FMEA framework to calculate the RPN number. They have indicated that the major advantage of using the grey theory method to calculate RPN number lies in its capability of assigning different weighting coefficient to the factors (in our case DOPP, S_d, S_s and S_o). Thus, ensuring that different score and probabilities of DOPP, S_d, S_s and S_o when combined together result in a unique grey relation coefficient (equivalent to RPN number of traditional FMEA). Pillay has also established that grey theory calculates the grey relation coefficient on a comparative scale which increases the rationality behind using grey relation coefficient as a metric to quantify the impact of the control action taken. Thus, the use of grey theory and DOPP along with the concept of FMEA negates all the drawbacks of a traditional FMEA approach.

The method of calculating the grey relational coefficient in the proposed model involves several steps. First, a comparative series is generated which is comprised of scores or probabilities of all the four factors DOPP, S_d, S_s and S_o representing each non-conformity. This comparative series is represented in the form of a matrix. Following which a standard series for the factors is formulated by determining the optimal level of all four factors that is required to be achieved to obtain the lowest value of risk priority number. The difference between the standard and comparative series is obtained and the results are used to determine the grey relation coefficient. The degree of grey relation for a non-conforming record is calculated using the grey relation coefficient and the weighting coefficient for all the factors. The degree of relation denotes the relationship between the non-conformities originating from different suppliers and the optimal value of the decision factors. The higher the value obtained, the smaller the effect of the identified non-conformity. Therefore, the increasing order of the degree of relation represents the risk priority for the identified non-conformities. It is demonstrated in Chapter 4 that the introduction of DOPP and Grey theory to the FMEA framework has provided a basis to better rank the non-conformities than the traditional method of RPN number.

The end result of designing this information system is the development of a systematic technique to rank the non-conformities that not only improves the operational performance of the manufacturing firm but also provides insight into the key problem areas originating from different suppliers. It also integrates the manufacturing firm with its suppliers so that they can together achieve the objective of zero-defects.

1.5 Organization of thesis

This thesis is comprised of five chapters including this introductory chapter. Chapter 2, “Literature Review”, provides a comprehensive review of various quality control tools to emphasize the fact that FMEA is the most appropriate tool for developing this information system. This chapter also throws some light on the various applications of FMEA in industry hence emphasizing the uniqueness of this thesis to use the concept of FMEA to develop an information system. Chapter 3, “Research Methodology” outlines the methodology that is followed in this thesis, in conjunction with the system development life cycle, to design this information system. It also provides a detailed description of how the different concepts (FMEA and Grey theory) work in tandem with each other to fulfill the purpose of this application. Chapter 4, “Case Study and Results”, consists of a practical example from industry that illustrates the application of the proposed model to demonstrate its viability. This chapter is comprised of a section on economic analysis to demonstrate the benefit of the proposed approach over the traditional one. Chapter 5 “Conclusion”, summarizes the major conclusions of this thesis. It also sheds some light on the scope for future research in this area.

CHAPTER 2

Review of quality control tools

2.1 Introduction

This chapter begins with a comprehensive review of all the quality control tools that are currently employed in the industry. The literature review intends to shed some light on the deficiencies of each of these tools to meet the requirements of the stated problem, as described in the introductory chapter. Thus, stressing on the fact that FMEA is the most suitable approach for developing the information system, as compared to the other quality control techniques that are identified during the literature search. Further, the extent of utilization of the concept of FMEA in different facets of the industry is discussed. Thus, emphasizing the uniqueness of this thesis to apply the concept of FMEA for developing an information system.

2.2 Review of quality control tools

2.2.1 Decision flow chart

A decision flow chart is a systematic approach to graphically represent and analyze the sequence of events associated with the flow of document, materials, and processes that affects the occurrence of non-conformance in the end product or its component parts. This makes it a very powerful tool for product inspection. However, this technique has the disadvantage of not providing clear visibility to identify those operations where the procedure itself is not a part of the sequence of events. It also fails to readily show the critical points where the particular decisions or dispositions were made which lead to the non-conformance and who was responsible for making them. This technique of analyzing the cause and the point of incidence of the non-conformance gets quite complicated during a multiple failure condition. It also does not provide a systematic technique to prioritize the non-conformities in case of a multiple failure condition (Layth C. Alwan, 2000). An example of a simplified decision flow chart is shown in Figure 2.1.

2.2.2 Critical path network (CPN)

The critical path network is a production control tool that has been adapted to analyze the flow of goods and services from a quality audit point of view (Milles A. Charles, 1989). CPN involves a chart showing each significant activities or critical operations in system that could lead to a non-conforming part. While conducting the product quality audits, the major advantage of this technique lies in its ability to use the existing set of documents for identifying the critical activities that could be the source of non-conformance. However, this technique hardly offers any visibility to the controls, procedures and standards that should be in place pertaining to the identified critical activities that contribute to the non-conforming part. This makes it difficult to evaluate the impact of the planned changes on the entire system. An example of a simplified CPN chart is shown in Figure 2.2.

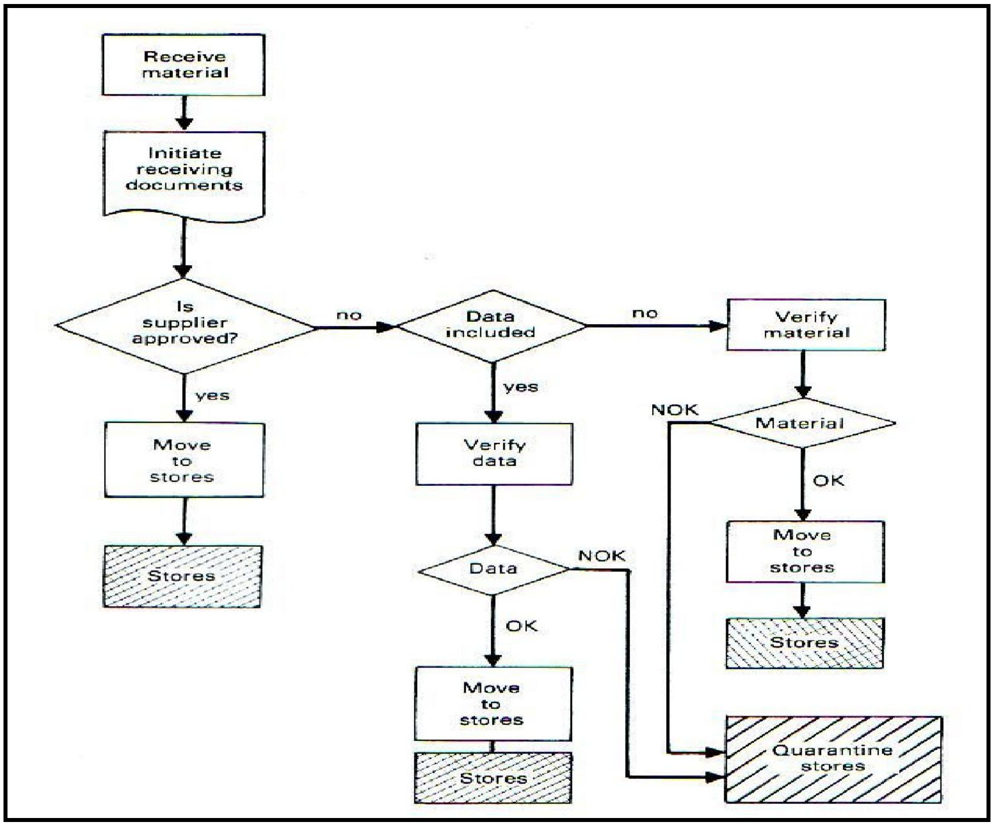


Figure 2.1: Decision flow chart (Mills A. Charles, 1989)

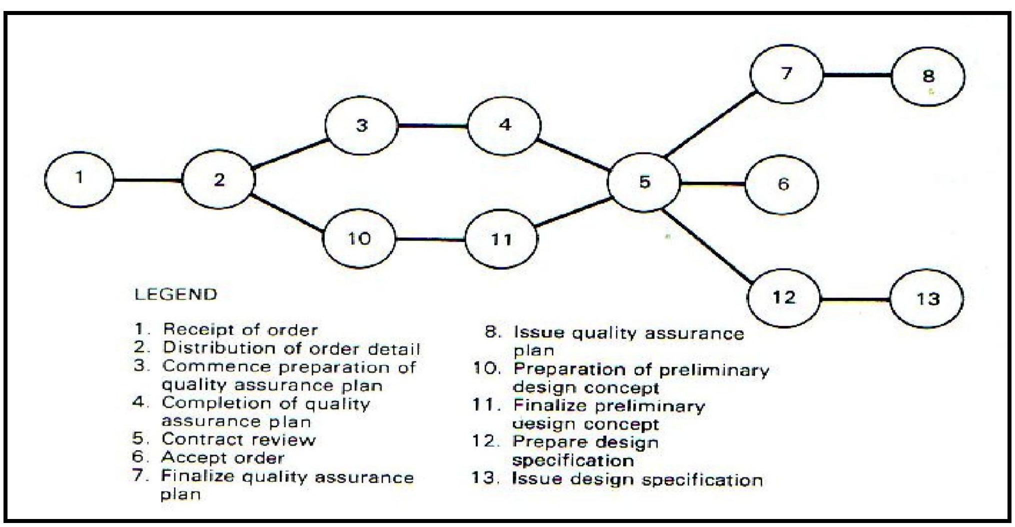


Figure 2.2: Critical path network (Milles A. Charles, 1989)

2.2.3 Process decision program chart (PDPC)

The frequent change in customer expectations limits our ability to act as we anticipate, so we are forced to alter our plans. Hence, in a dynamic manufacturing environment it is very critical to plan step by step to solve problems and reach our objectives. The PDPC method helps us to select the best processes to obtain the desired results by evaluating the progress of events in a chronological order and the various outcomes associated with the events. By tracking the impact of actions from a certain initiating event one can discover the causes of non-conformities. Thus, the PDPC method can be used as an effective technique to implement counter measures to minimize the impact of nonconformities in the system. The PDPC method comprehends the actions of a system as a whole; hence this technique is quite effective for identifying and preventing significant errors from occurring in the system. This technique definitely does a good job on doing a comprehensive summarization of the cause and source of a non-conformance but it fails to capture the individual details related to a non-conformity, which plays a significant role when the objective is the attainment of zero defects (Shigeru Mizuno, 1988). A schematic representation of a process decision program chart for NO_x reduction activities in the LPG combustion chamber is illustrated in Figure 2.3 (Eguchi and Kishimoto, 1978).

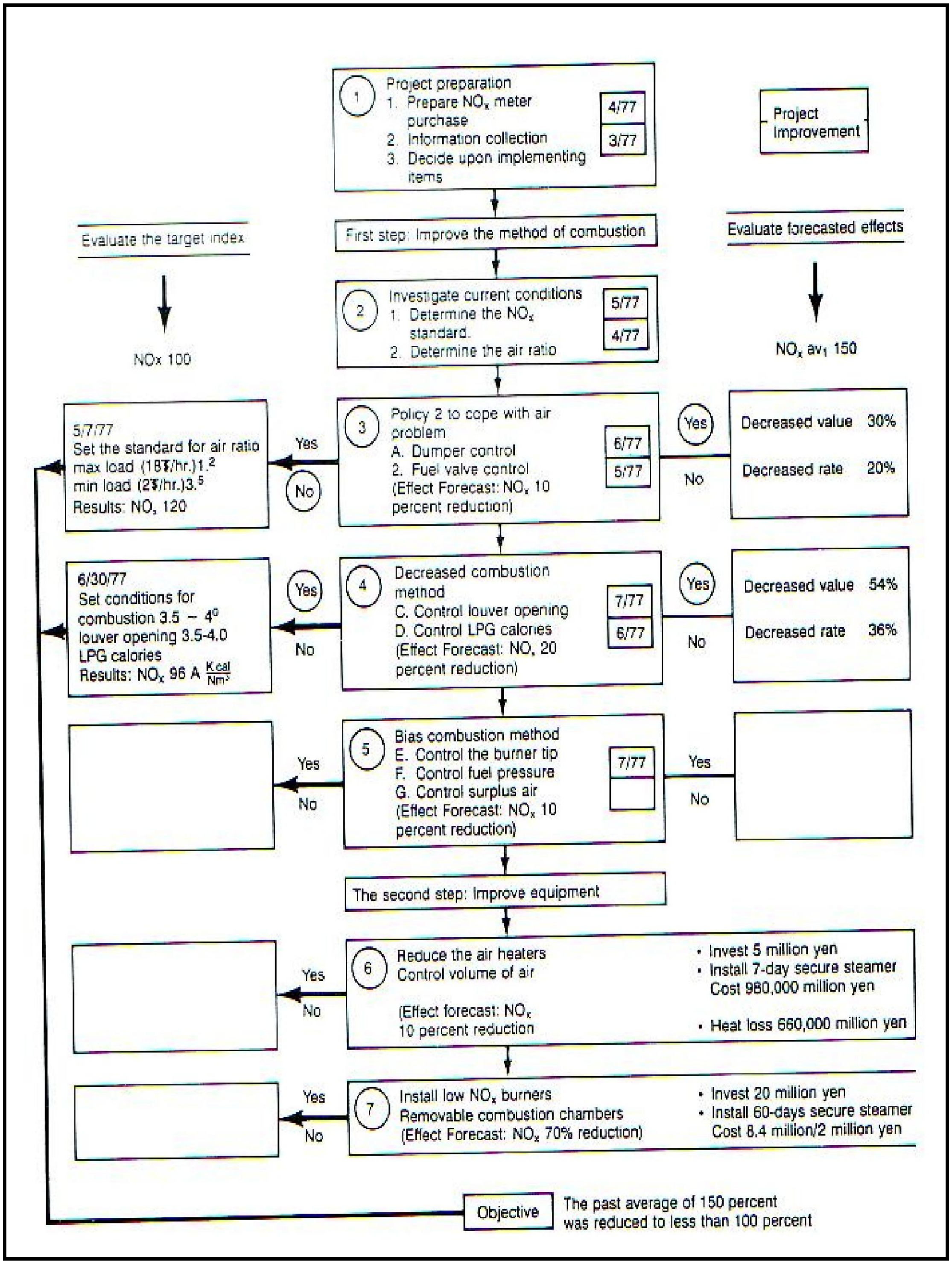


Figure 2.3: Process decision program chart (Eguchi and Kishimoto, 1978)

2.2.4 Fault tree analysis (FTA)

Fault tree analysis is logical and structured process to identify the potential causes of non-conformance. The FTA analysis starts with one "undesirable situation" and identifies the various possible combinations of faulty events that can result in the non-conformance in a top-to-bottom fashion, until it reaches the principle failure element to obtain a solution. The logical relationship between all the possible events that can lead to the non-conformance is represented graphically in form of a structural tree using different symbols. This process is continued successively for the next levels of events, until the basic cause of the non-conformance is identified. If estimates of failure rates are available for individual events, the probability of occurrence of the top events can be predicted. However, the failure rates cannot be used as a single criterion to prioritize the failures in the case of a multiple failure condition. FTA can also be used to identify multiple failure conditions when two or more events contribute to the occurrence of non-conformity. It however fails to provide a detailed action plan or a strategy to prevent the occurrence of non-conformity again in the future (DYADEM, 2003). Figure 2.4 illustrates a simple example of fault tree analysis applied to a fire warning system (Shigeru, 1975).

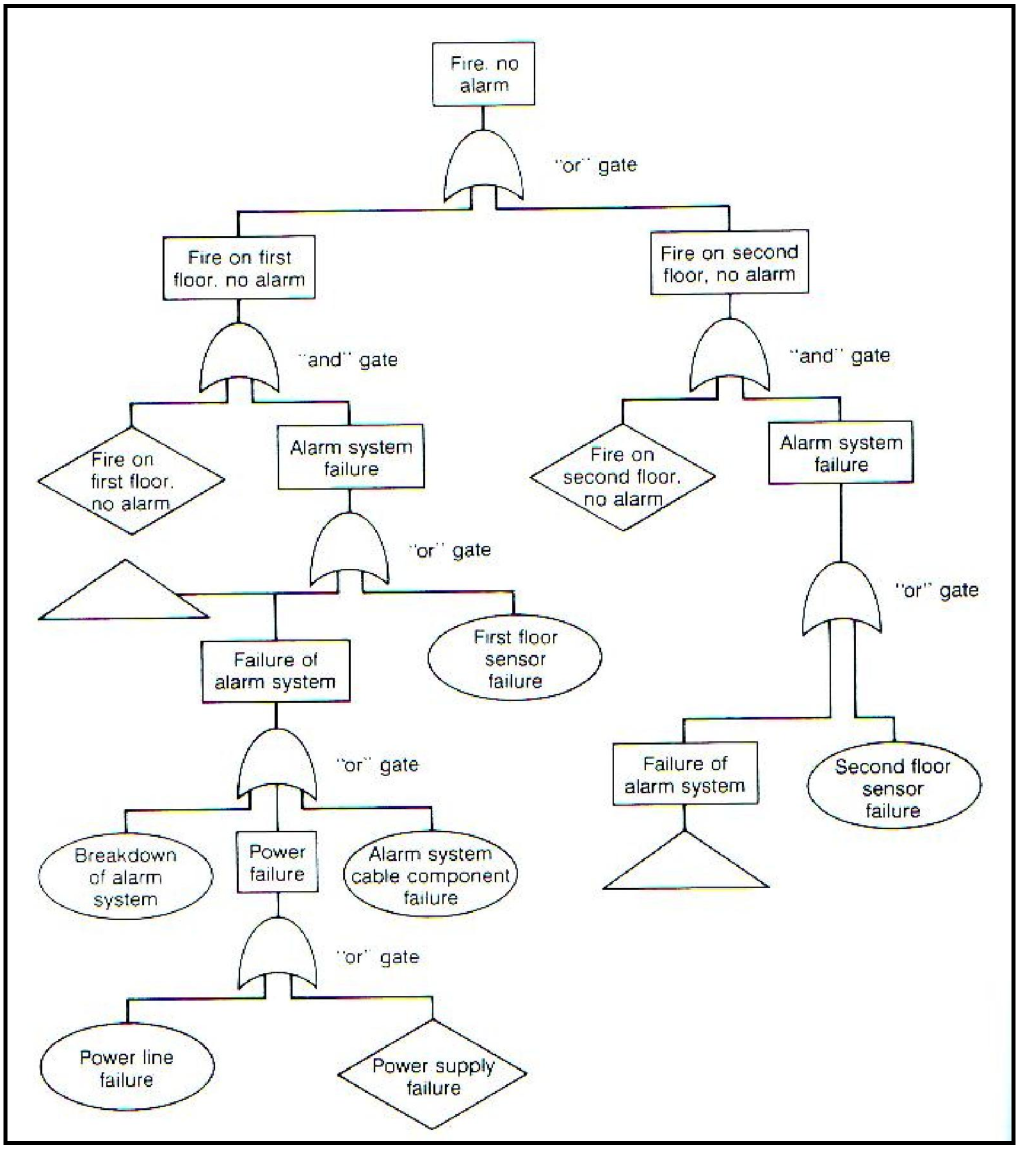


Figure 2.4: Fault tree analysis fire warning system (Shigeru, 1975)

2.2.5 Functional tree

Functional tree is a means of ensuring that each function of a system being audited is broken down into its most fundamental elements. The functional tree takes a major function of a non-conforming part and then subdivides it into secondary level functions that lead to the non-conformity. It is a means of ensuring that each activity being audited is broken down into its most fundamental elements so as to analyze the exact cause and the source of the non-conformance. This sequence is then repeated until all contributing activities have been identified. The number of levels depends on the complexity of the function being analyzed. A functional tree is powerful technique for identifying the various activities that comprise a quality audit and identifying the functional relationship between the various levels of the system. Hence, is quite effective in analyzing multi-point failure condition. It fails to identify the cause of non-conformance due to an improper manufacturing process or a procedure (Mills A. Charles, 1989).

2.2.6 Functional tables

Functional tables are tabular version of functional trees where a system is broken down into its major units. Each of these units is then subdivided into subsequent tiers of functions or activities for which it is responsible. In reviewing an area, first the productive function or activity is noted in the function column. The applicable specification and standards are then listed in the second column, followed by the assurance activities in the assurance column. Any relevant procedure pertaining to the assurance activities is entered in the reference document column. By using this format the system can be analyzed to determine its functional activities, control, and verification requirements. The greatest asset of functional tables is in providing clear visibility of the relevant documentation relating to the productive and assurance functions. This technique definitely scores points when it comes to identifying the reason behind a part not meeting the quality assurance requirements but fails to provide a guideline for ranking the non-conformities based on severity of their impact on the entire system (Mills A. Charles, 1989). Figure 2.5 provides an example of functional table that illustrates the use of this technique for the early phases of a quality audit project.

2.2.7 Quality audit check sheets

A quality audit check sheet is a method to collect data about a product, service or process in a simple and organized manner. It is strictly interpreted as a sheet designed for entry of data by entering checkmarks or tallies, hence the name quality audit check sheets. From a quality control perspective, it is an avenue to identify the presence or absence of non-conformities and record the pertinent information relative to non-conforming part, so that the quality audits can facilitate process improvements. One of the most significant deficiencies of check sheet is its inability to capture the source of all the

Function	Control documents	Assurance activities	Reference documents
1. Definition of customer needs	Product specification		
2.	Product quality plan	Definition of assurance activities	
3.	Product specification Product quality plan	Contract review	
4. Circulation of contract information	Work order		
5.		Quality audit	
6. Prepare design plan			
7. Preliminary design	Product specification		
8.	Preliminary design Product specification Product quality plan	Initial design review	
9. Detailed design	Product specification Product quality plan Product design plan Preliminary design Qualified parts lists etc.		
10.		Quality audit	
11.	Product specification Product quality plan Regulatory requirements Reliability analyses Maintainability analyses Availability analyses etc.	Verification tests	
12.	Product specification Product quality plan Product design documents Verification data	Design review	
13. Release for procurement and production			

Figure 2.5: Functional table (Mills A. Charles, 1989)

possible causes associated with a particular non-conformity. It also fails to monitor the control plan to prevent the occurrence of the non-conformity in the future (Layth C. Alwan, 2000).

2.2.8 Pareto chart / diagram

Pareto chart draws its name from an Italian economist Vilfredo Pareto, but it was J.M. Juran who is credited for being the first to apply it to industrial problems. Pareto analysis is basically a two-step process: (1) collect data on the contributing factors and (2) display the data in meaningful way. Pareto chart is a graph where the cause for non-conforming parts is listed along the x-axis with heights of the bars representing frequencies or percentage of occurrence of non-conformities along the y-axis. In other words, Pareto diagram is simply a bar chart in which the frequencies (or relative percentages) of various factors that contribute to a non-conforming part is plotted in rank order (from highest to lowest). It is thus an effective tool to prioritize non-conformities or causes associated with them to initiate problem solving. This technique can also be used to analyze the before and after impact of the corrective actions made to the system. By performing Pareto analysis, the causes of a non-conformance can be classified as issues with the greatest impact (the vital few) from the less significant ones (the trivial many). However, in order to achieve the objective of zero-defects once cannot ignore the less significant issues that lead to the production of a non-conforming part (Layth C. Alwan, 2000).

2.2.9 Scatter plot / diagram

A scatter plot or a scatter diagram is a graph of data of one variable against another variable with the intent of showing whether the two variables are related in any systematic fashion. In situations where there is a potential cause and effect relationship between the two variables, a scatter plot serves as the first step towards gaining fundamental insight into the statistical nature of the causation. It is to be noted here that a scatter plot merely reflects a relationship between the two variables this however does not imply that there is a causal relationship between the two variables. In other words, a scatter plot merely highlights the strength and the direction of relationship between the two variables. The concept of correlation is employed in conjunction with scatter diagram to decide if a significant relationship exists between the paired data and regression analysis is used to identify the nature of relationship (Layth C. Alwan, 2000).

2.2.10 Cause and effect diagram

The Ishikawa diagram also known as cause and effect diagram was developed in Japan by professor Ishikawa as an analytical tool to identify all the activities that contribute to the incidence of non-conformity. In a cause and effect diagram the effect represents a particular type of non-conformity and the causes are the potential underlying factors that influence the occurrence of the non-conformity. This is achieved by subdividing the process or non-conforming part into various components, sub process or factors that can be individually controlled to ensure the preclusion of a product or process failure. From a quality audit point of view, the Ishikawa diagram is a valuable problem-solving tool and can be used effectively to identify all of the contributory elements of the system, process or product that is under review. However, this technique becomes quite cumbersome when we are analyzing a multiple failure condition in a system. It also fails to quantify the impact of varying the individual factors or causes on the non-conforming part on the system (Mills A. Charles, 1989). A simple example of a cause and effect diagram demonstrating process analysis for steel pipe scars is shown in Figure 2.6 (Ishikawa, 1982).

2.2.11 Relations diagram method

The occurrence of non-conformity predominantly involves certain hidden interrelated causal factors. The relations diagram assists to clarify these intertwined causal relationships in a complex system and hence figure out the reason for non-conformance. It employs arrows to show the cause-effect relationships among a number of problems within the system and the factors that influence these problems. With this understanding a factor

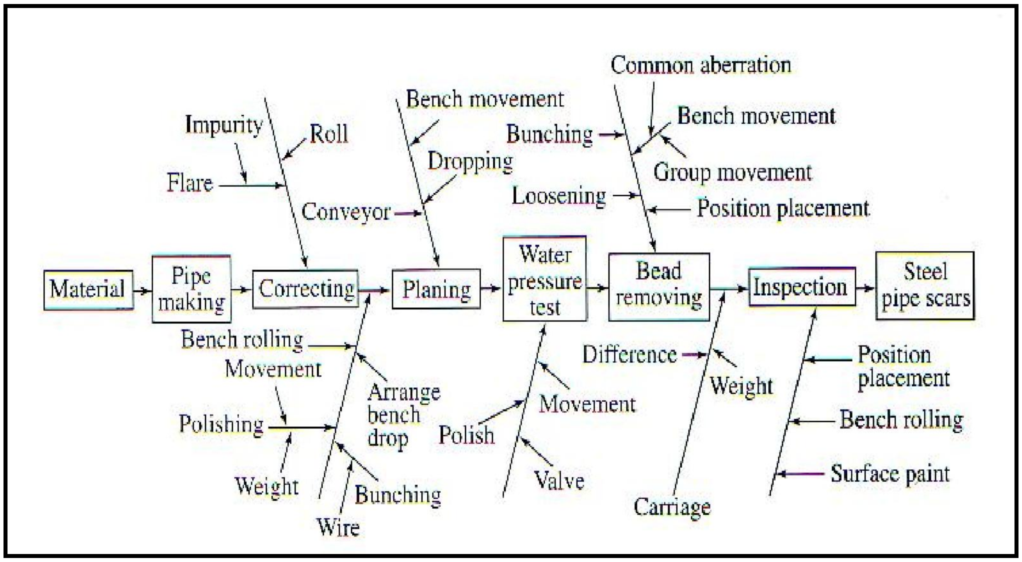


Figure 2.6: Cause and effect diagram (Ishikawa, 1982)

analysis can be conducted and control procedures identified. The biggest advantage of this technique lies in its ability to simplify problems into several major points, and this greatly assists the development of improvement measures. However, at times the relations diagram gets too complicated and it becomes difficult to understand it. When this occurs it is likely that the important factors will be overlooked in drawing conclusions. Also, it is necessary to redraw the diagram in response to changing situations, a process that can be time-consuming and very tedious (Shigeru Mizuno, 1988). A schematic representation of a relationship diagram for improving operations within the administrative department is shown in Figure 2.7 (Seigo, 1970)

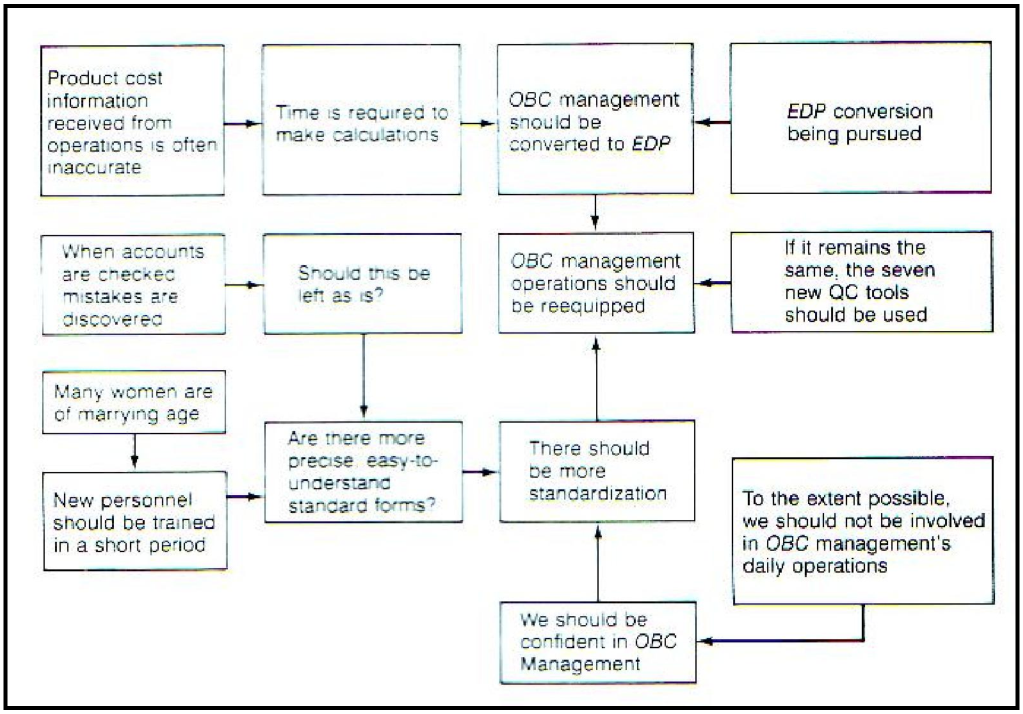


Figure 2.7: Relations diagram (Seigo, 1970)

2.2.12 Systematic diagram

The systematic diagram displays the means necessary to achieve specific goals and objectives, clarifies the essence of the problem by making the subject matter visible, and searches for the most suitable means of realizing the objectives which in our case would be the attainment of zero defects. This process enables in organizing the information in a systematic fashion to pursue the cause(s) of abnormalities, and then devise measures to counter the occurrence of non-conformities. In a systematic diagram first the quality characteristic or objective is clearly outlined, the means for reaching this objective is developed and examined. Next, the measures for reducing non-conformities are specified. The method is effective in not only clarifying key control points in quality control activities and developing effective improvement methods, but also in training business people to think in terms of means and objectives. This technique however gets complicated when there are several objectives and various means to achieve them. An application of systematic diagram for quality assurance activity is illustrated in Figure 2.8 (Mizuno, 1988).

2.2.13 Matrix diagram method

Matrix diagram method clarifies problematic spots through multidimensional thinking. It is designed to seek out the principal factors that contribute to the production of nonconforming items from a plethora of phenomena concerning a subject under study. However, when there are many factors the problem is easily resolved by clarifying the relationship between the defect phenomena and causes associated with the phenomenon. Matrix diagram method indicates the relationship of the two contributing factors at the point of intersection in the matrix. It also helps to expedite the process of problem solving by indicating the presence and degree of strength of relationship between the two set off factors. By using the intersection points as starting points, the matrix diagram allows us to explore the problem under study from two points of view and also build a base for further two dimensional problem solving. A systematic diagram clarifies a problem when the causes and methods can be explained in once dimension. However when

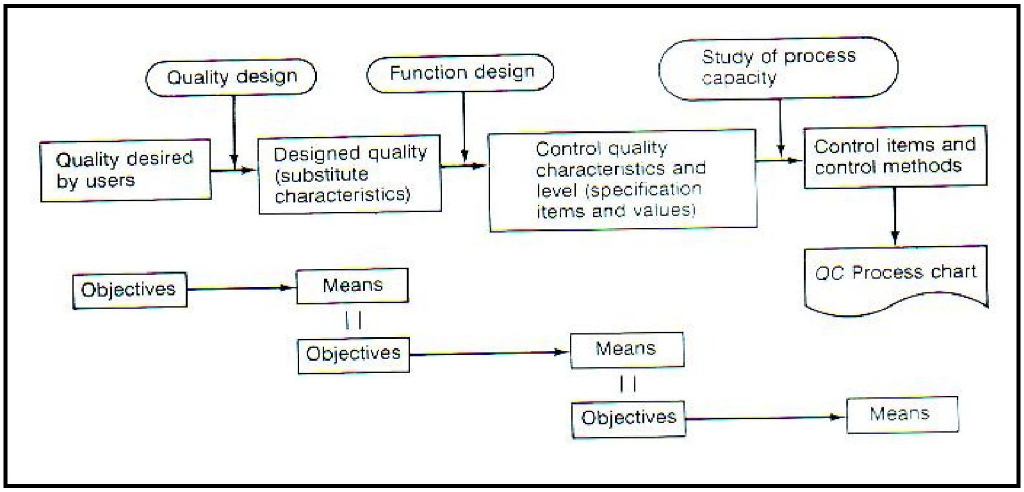


Figure 2.8: Systematic diagram (Mizumo, 1988)

there are two sets of factors and methods, the matrix diagram method can correlate these to each other, in a more effective manner. The matrix diagram uses symbols to show the degree of relationship between nonconforming phenomena and their causes. Hence the subjective opinions of the evaluators are likely to be involved, and hence the objective analysis possible with the numerical data can not be expected out of this technique. An example of a matrix diagram of car brake warranty, test items, and test equipment is shown in Figure 2.9 (Shigeru Mizuno, 1988).

2.2.14 Matrix responsibility table

The matrix responsibility chart is a method of summarizing the actions to be taken on various procedures that are used within an organization. It can also serve as a very effective index for procedures manual. In fact, it provides an excellent tool for conducting audits to determine compliance with procedures.

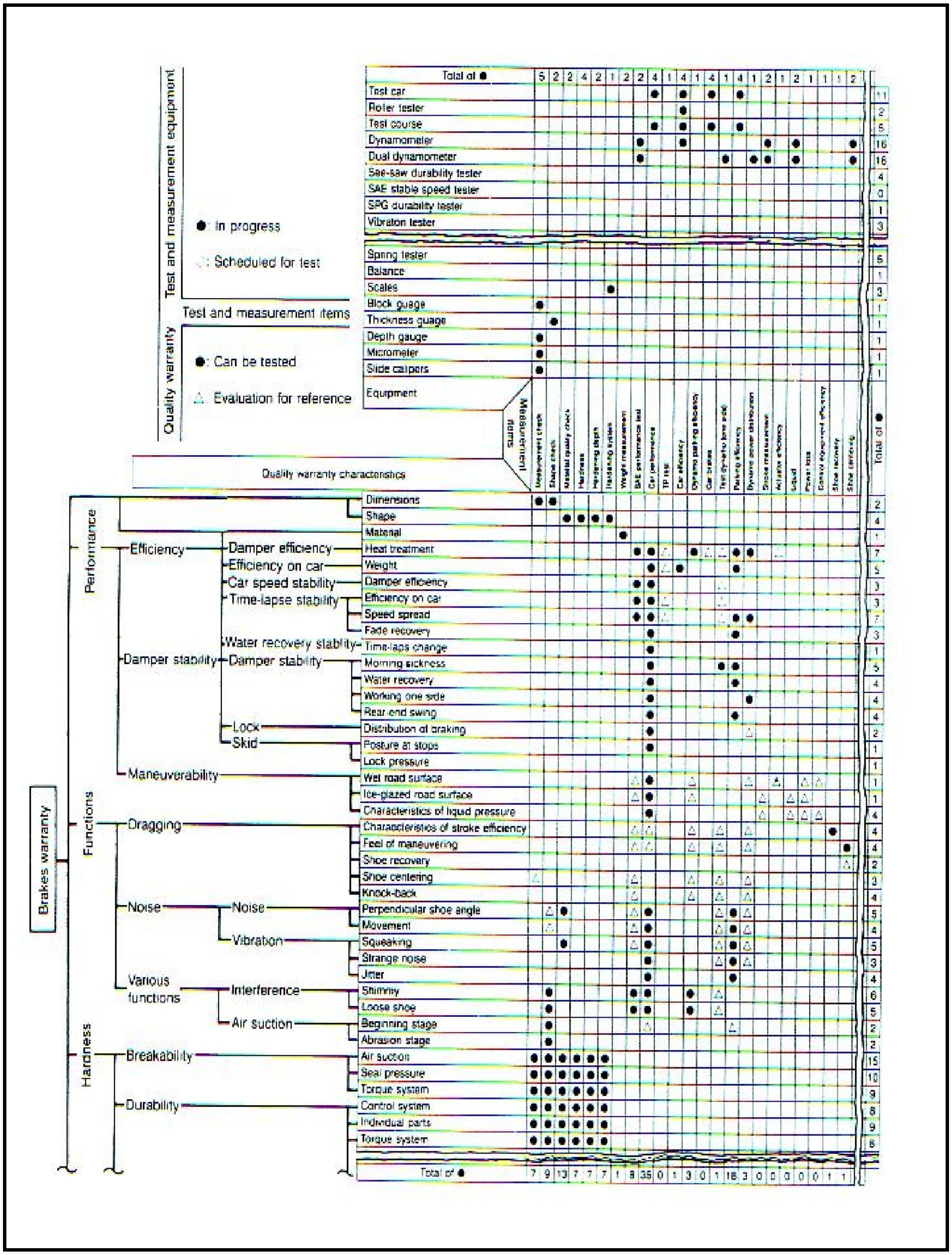


Figure 2.9: Relations diagram (Mizuno, 1988)

In this technique vertical column represent procedure or instructions and each horizontal line represents a function within the organization. The input of a function to a given procedure is shown by a symbol at the intersection of the line and column. The development and use of this type of form can be helpful in ensuring that each and every input to a procedure, instruction, etc is addressed during the planning stage of an audit. It is particularly helpful in deciding whether to use a function or location oriented quality audit. The technique's major disadvantage is the lack of visibility it provides as to where the various documents involved fit into a particular product flow (Mills A. Charles, 1989).

2.2.15 Failure modes and effect analysis (FMEA)

An FMEA is a systematic method of identifying and preventing product and process problems before they occur. FMEA is focused on preventing defects, enhancing safety, and increasing customer satisfaction. Used in both the design and manufacturing process, it can substantially reduce costs by identifying product and process improvements early in the development process when relatively easy and inexpensive changes can be made. The result is a more robust process and the reduction or elimination of the need for after-the fact corrective action and late change crises. The true essence of using FMEA is in its ability to clearly prioritize projects based on certain set of criteria. It also provides a systematic technique to analyze a system and determine the points of failure and assists in getting down to the root cause of the failure. It can be seen from Figure 2.10 that of all the quality control tools described in the previous sections FMEA is a good match to fulfill the requirements of the problem statement as outlined in the first chapter. A simple of example of an FMEA is illustrated in Figure 2.11.

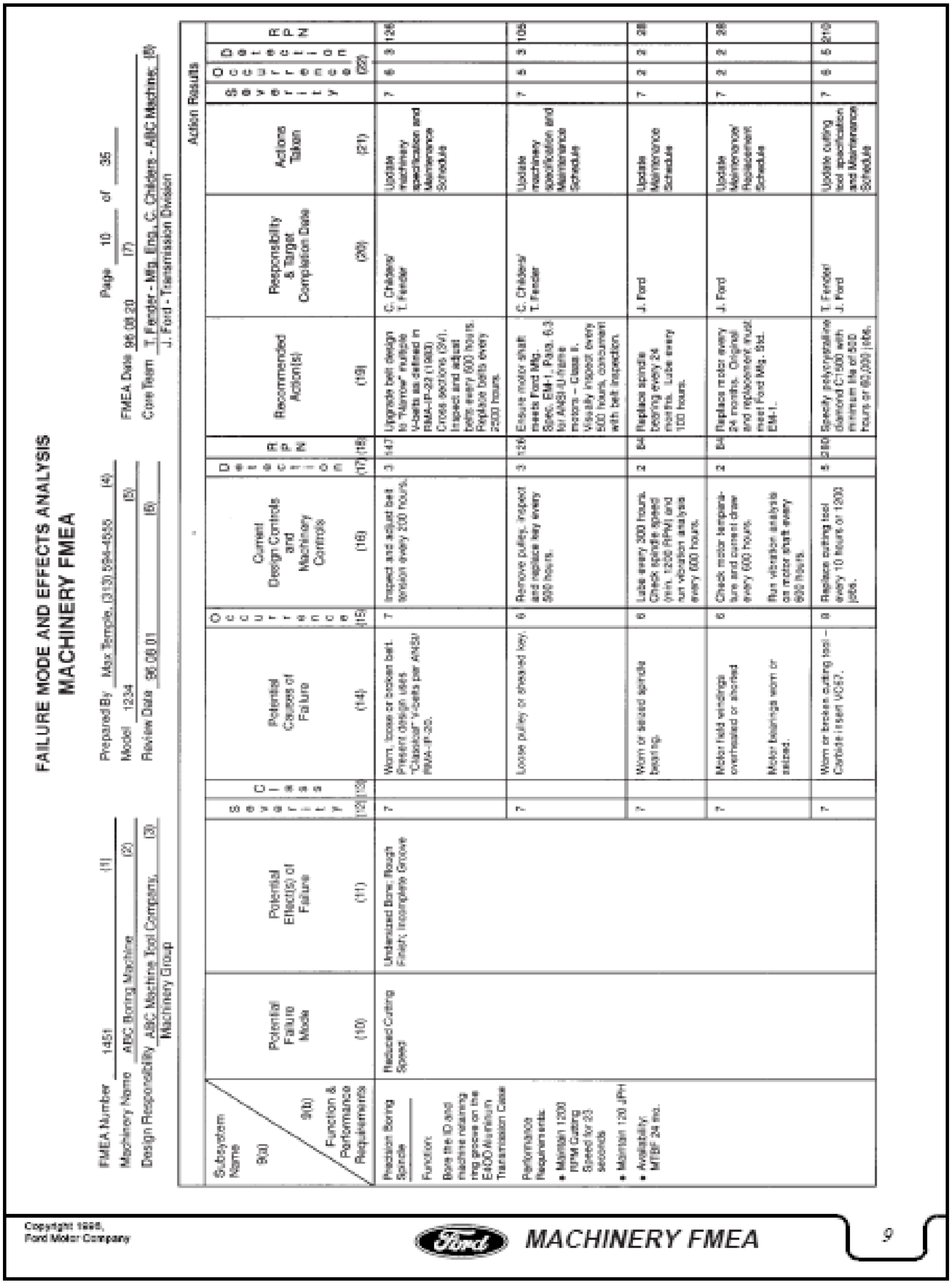
2.3 Applications of FMEA in the industry

2.3.1 Design FMEA

Price and Taylor (2001) have demonstrated the application of the concept of FMEA to design electrical circuits and analyze an electrical system for

	REQUIREMENTS						
	Prioritize / Rank the NCs	Identification of cause of NC	Record the probability of occurrence	Identification of source of NC	Gauge the severity of the NC	Monitor the control action	Tracking impact of control action
Decision Flow Chart				✓			
Critical Path Network				✓			
Process Decision Program Chart		✓		✓		✓	✓
Fault Tree Analysis		✓	✓	✓			
Functional Tree		✓		✓			
Functional Tables		✓		✓		✓	
Quality Audit Check Sheets		✓					
Pareto Charts	✓		✓				✓
Scatter Plot		✓			✓		
Cause and Effect Diagram		✓		✓		✓	
Relations Diagram Method		✓		✓		✓	✓
Systematic Diagram		✓				✓	✓
Matrix Diagram Method		✓		✓	✓		
Matrix Responsibility Table		✓		✓		✓	✓
Failure Modes and Effect Analysis	✓	✓	✓	✓	✓	✓	✓

Figure 2.10 : Comparison of quality control tools



FAILURE MODE AND EFFECTS ANALYSIS
MACHINERY FMEA

FMEA Number 1451 (1)
Machinery Name ABC Boring Machine (2)
Design Responsibility ABC Machine Tool Company, Machinery Group (3)
Prepared By Max Temple, (313) 594-4555 (4)
Model 1234 (5)
Review Date 96 08 01 (6)
Page 10 of 35
FMEA Date 96 08 20 (7)
Core Team T. Fender - Mfg. Eng., C. Childers - ABC Machine; J. Ford - Transmission Division (8)

Subsystem Name 9(a) / Function & Performance Requirements 9(b)	Potential Failure Mode (10)	Potential Effect(s) of Failure (11)	Severity (12)	Class (13)	Potential Causes of Failure (14)	Occurrence (15)	Current Design Controls and Machinery Controls (16)	Detection (17)	RPN (18)	Recommended Action(s) (19)	Responsibility & Target Completion Date (20)	Action Results: Actions Taken (21)	Severity	Occurrence	Detection (22)	RPN
Precision Boring Spindle Function: Bore the ID and machine retaining ring groove on the E4OD Aluminum Transmission Case Performance Requirements: • Maintain 1200 RPM Cutting Speed for 23 seconds • Maintain 120 JPH • Availability: MTBF 24 mo.	Reduced Cutting Speed	Undersized Bore; Rough Finish; Incomplete Groove	7		Worn, loose or broken belt. Present design uses "Classical" V-belts per ANSI/RMA-IP-20.	7	Inspect and adjust belt tension every 200 hours.	3	147	Upgrade belt design to "Narrow" multiple V-belts as defined in RMA-IP-22 (1983) Cross sections (3V). Inspect and adjust belts every 600 hours. Replace belts every 2500 hours.	C. Childers/ T. Fender	Update machinery specification and Maintenance Schedule	7	6	3	126
			7		Loose pulley or sheared key.	6	Remove pulley, inspect and replace key every 500 hours.	3	126	Ensure motor shaft meets Ford Mfg. Spec. EM-1, Para. 6.3 for ANSI-U-frame motors – Class II. Visually inspect every 500 hours, concurrent with belt inspection.	C. Childers/ T. Fender	Update machinery specification and Maintenance Schedule	7	5	3	105
			7		Worn or seized spindle bearing.	6	Lube every 300 hours. Check spindle speed (min. 1200 RPM) and run vibration analysis every 600 hours.	2	84	Replace spindle bearing every 24 months. Lube every 100 hours.	J. Ford	Update Maintenance Schedule	7	2	2	28
			7		Motor field windings overheated or shorted Motor bearings worn or seized.	6	Check motor temperature and current draw every 600 hours. Run vibration analysis on motor shaft every 600 hours.	2	84	Replace motor every 24 months. Original and replacement must meet Ford Mfg. Std. EM-1.	J. Ford	Update Maintenance/ Replacement Schedule	7	2	2	28
			7		Worn or broken cutting tool – Carbide insert VC67.	8	Replace cutting tool every 10 hours or 1200 jobs.	5	280	Specify polycrystalline diamond C1500 with minimum life of 500 hours or 60,000 jobs.	T. Fender/ J. Ford	Update cutting tool specification and Maintenance Schedule	7	6	5	210

Figure 2.11 : Example of Failure mode and effects analysis (Ford FMEA manual, 1996)

failure condition. Design FMEAs are based on product design and are used to evaluate the initial design of the product for manufacturability, assembly, service and functional requirements etc. Design FMEA does not rely on process controls to overcome potential design weaknesses but takes into consideration technical and physical limitations of manufacturing and assembly processes. Design FMEA should be initiated before or at the design concept finalization stage and can be continuously updated as changes occur or additional information is obtained throughout the phases of product development.

2.3.2 Process FMEA

Teoh and Case (2004) have used the concept of process FMEA to evaluate the failure modes associated with manufacturing and assembly process deficiencies. A process FMEA starts with a process flow chart that shows each of the manufacturing steps of a product. The potential failure modes and potential causes for each of the process steps are identified, the current controls are determined, followed by the effects of failures on the manufacturing line operators and product end users. This will assist in identifying the process variables that will impact the reduction of manufacturing or process failure conditions. Process FMEA also develops a ranked list of potential failure modes, thus establishing a priority system for preventive or corrective action considerations.

2.3.3 Machinery FMEA

Researches (Xu *et al.*, 2001) have illustrated the utilization of the concept of FMEA to get to the root cause of failures of turbo charging systems in diesel engines. Machinery FMEA supports the design process in reducing the risk of failure by aiding in the objective evaluation of equipment functions. This ensures that the potential failure modes and their effects on the machinery are taken into account right from the design and development stage. Machinery FMEA also provides additional information to aid in the planning of through and efficient design, validation and development programs. It also assists in developing a ranked list of potential failure modes, thus establishing a priority system for design improvements, development and validation testing analysis. Machinery FMEA is initiated during design concept development and should be continuously updated as changes occur or additional information is obtained throughout the phases of machinery development.

2.3.4 Functional FMEA

Price (1998) has employed the concept of FMEA to carry out functional and behavioral simulation to analyze sneak electrical system for identification and elimination of unexpected interaction of subsystems. Functional FMEA focuses on functions that a product, group of products or process performs rather than on characteristics of specific implementation. Functional FMEA is initiated at the end of the conceptual or preliminary design phase. Functional FMEA is performed on the conceptual design to support the architectural definition and verify necessary design compensations and failure recovery requirements derived from functional requirement analysis. Functional FMEA is generally performed on control systems, software and complex devices whose functionality is more readily understood than the details of their operation.

2.3.5 Interface FMEA

An interface FMEA focuses on the interconnections between various elements of the system so that the characteristics of failures between them can be determined and compliance to requirements can be verified. This type of FMEA is initiated during the detailed design phase. Beginning an interface FMEA as soon as the system interconnections are defined ensures that proper protocols are used and that all interconnections are compliant with design requirements.

2.3.6 Detailed FMEA

This type of analysis is initiated during the detailed design phase. Detailed FMEA is performed to verify that the design complies with the requirements for failures that can cause loss of end item functions, single point failures, fault detection and fault isolation. In hardware detailed FMEA, the components comprise the physical system design. In software detailed FMEA, the components are from the source code. The characteristics of the failure of each and every component is determined and documented in this process. The detailed FMEA is initiated as the design of each element matures and the detailed design schematics, part lists, and detailed software design documents and source code become available.

2.3.7 Service FMEA

Service FMEA focuses on field service after sales – for example, serviceability, spare parts availability and service manpower availability. The objective of this kind of FMEA is to define, demonstrate and maximize solutions in response to quality, reliability, maintainability, cost and productivity as defined by the design specifications and the customer. These goals are achieved through the active participation of personnel in the department of customer service, product development, research, quality assurance, marketing and operations. Thus, the focus of service FMEA is to minimize failure effects on the service and to maximize customer satisfaction.

2.4 Conclusion

It can be concluded from this literature review that of the many quality control tools that are currently in practice FMEA is best suited to be considered as the backbone on which the supplier development information system could be developed.

The literature review also indicates that the concept of FMEA has been used in the past in various facets of the industry to analyze failure conditions in systems. However, there is no evidence of using this concept to develop an information system to identify the source of non-conformities and eliminate it from the system, which illustrates the uniqueness of this thesis.

CHAPTER 3

Developing the supplier development information system

3.1 Introduction

This chapter outlines the systematic procedure behind the development of this supplier development information system. It also provides a detailed description as to how the proposed model intends to meet the objectives of this thesis as outlined in the introductory chapter. Much of this is embodied in what is called the systems development life cycle (SDLC). The SDLC is a phased approach that is followed by analysts (Kendall and Kendall, 1999) for the analysis and design of information systems. The SDLC is divided into seven phases. Although each phase is presented discretely over here, it is never accomplished as a separate step. Instead several activities occur simultaneously during the development of an information system to accomplish the objective within the specified timeframe.

3.2. Identifying problems, opportunities and objectives

The first phase of the system development life cycle consists of identifying the problems, opportunities and objectives of an information system that will allow the manufacturing firm to gain a competitive edge in the market. The primary problem in our case is the inability of the manufacturing firm and the suppliers to cohesively work together to achieve the goal of zero defects. Hence, the objective here is to develop an information system that would enable the manufacturing firm and the suppliers to easily communicate with each other in order to achieve the common goal of zero-defects. The information system should provide a means for the manufacturing firm to keep track of the control actions taken at the supplier's end, so as to prevent the non-conforming parts from reaching the manufacturing firm. From the supplier's perspective the information system should provide them with a list of action items based on the priorities of the manufacturing firm so that the suppliers will be able to immediately align and react to the quality standards of the manufacturing firm. All in all the information system should able to integrate the manufacturing firm with its suppliers.

3.3 Determining the requirements of the information system

During the second phase of SDLC, the users, their data requirements and the procedures that should be in place for the users to perform their tasks in the information system are determined. This helps us to gain a clear understanding how the business works and obtain complete information on the people, goals, data, and procedures involved.

3.3.1 Project requirements

A detailed description of the project requirements is provided in Table 3.1. Project requirements give an outline of what the information system intends to do and the sequence in which it will be done. A detailed description of each project requirement is explained in the requirement description tables.

Table 3.1 Project requirements

Requirement ID	Project Requirement
10	The manufacturing firm identifies and records all the details of the NC's in the database.
2.0	The IS prioritizes the NC's based on the requirements of the manufacturing firm
3.0	The supplier gets a list of action items and immediately takes control action against it.
4.0	Manufacturing firm monitor's the control action taken by the supplier.

3.3.2 Requirement description

A requirement description as shown in Table 3.2 gives a clear picture of how each project requirement will be fulfilled and as to who will perform the task. It also provides a brief description of how the task is performed in the present system and what is the benefit of performing the task in the new system.

3.3.3 Process description

The quality control department of the manufacturing firm identifies the non-conforming parts that are delivered by the suppliers. It then enters all the details of the non-conforming part into the database of the information system. The back end of the information system uses an algorithm based on Grey theory to rank the non-conformities based on the information entered into the database by the quality control department. The suppliers are able to immediately log on to the system and view all the non-conformities that were

Table 3.2 : Requirement description

REQUIREMENT ID	1.0
Definition	The manufacturing firm identifies and records all the details of the NC's in the database.
Type	Manual
As in present system	Done through the NCR database system
Task to be done	All the details related to a non-conforming part are recorded in the database.
Benefits	The manufacturing firm will be in a position to track all the non-conformities and hence be in better position to charge the supplier for delivering the non-conforming part and costs associated with it.
Importance	Medium
Stakeholder	Manufacturing firm
REQUIREMENT ID	2.0
Definition	The IS prioritizes the NC's based on the requirements of the manufacturing firm.
Type	Online
As in present system	Does not exist
Task to be done	Rank the non-conformities based on severity, occurrence, detection and DOPP using Grey theory algorithm.
Benefits	The manufacturing firm will be in a position to identify those non-conformities that will impact it the most. It can then ask the suppliers to immediately take control action to prevent the reoccurrence of the non-conformity.
Importance	High
Stakeholder	Manufacturing firm
REQUIREMENT ID	3.0
Definition	The supplier gets a list of action items and immediately takes control action against it.
Type	Online
As in present system	Does not exist
Task to be done	The supplier is provided with a list of non-conformities that are identified in the parts that we delivered by the supplier. These non-conformities are ranked based on the priorities of the manufacturing firm. Supplier then addresses these non-conformities in the same sequence as they are ranked by the manufacturing firm and takes

Table 3.2 : Continued

REQUIREMENT ID	3.0
Task to be done	control action to prevent the reoccurrence of non-conformities.
Benefits	The supplier is able to immediately react to the quality standards of the manufacturing firm.
Importance	High
Stakeholder	Supplier
REQUIREMENT ID	4.0
Definition	Manufacturing firm monitor's the control action taken by the supplier.
Type	Manual
As in present system	Does not exist
Task to be done	The manufacturing firm assigns a new ranking for detection based on the control action taken by the supplier.
Benefits	The effectiveness of the control action taken by the supplier is monitored.
Importance	Medium
Stakeholder	Manufacturing firm

identified in the parts delivered by them.

The information system ranks these non-conformities for the supplier, in decreasing order of impact to the manufacturing firm. Hence the supplier is able to immediately understand the priorities of the manufacturing firm and align to the requirements of the manufacturing firm. The supplier then records the details of the control action taken into the database of the information system. The quality control department monitors the control action taken and assigns a new ranking for detection thereby gauging the effectiveness of the control action taken by the supplier. The Table 3.3 summarizes the various

Table 3.3: Event, trigger and response

Event Description	Trigger (Inputs)	Responses (Outputs)
Inspection of the parts delivered by the suppliers by the quality control personnel.	Delivery of the parts from suppliers.	Identification of non-conforming parts.
Creation of a NCR for the non-conforming part in the database of the IS.	Identification of a non-conformity	All the details of the non-conformity and the associated costs are recorded in the database
Ranking the NC's based on the priorities of the manufacturing firm	Occurrence / Identification of a large number of non-conformities	A prioritized list of action items for the supplier
Supplier takes a control action to prevent the reoccurrence of the NC.	List of action items from the manufacturing firm	Control action recorded in the database of the IS by the supplier
Monitoring the effectiveness of the control action taken	Details of the control action taken by the supplier	New ranking for detection.

processes within the information system and the events that initiate these processes.

3.4 Analyzing system needs

This phase of SDLC comprises of analyzing the system needs with the help of special tools and techniques such as dataflow diagrams, data dictionaries and business rules. Data flow diagrams provide a graphical form of input, process, and output of business's functions. A data dictionary on the other hand is list of the detailed specification of data items used in the system. The business rules outline the relationship between various data items in the system and the actions/rules which govern the operation of the information system.

3.4.1 Data flow diagrams

Data flow diagrams are a means of representing an information system at any level of detail with a graphic network of symbols showing data flows, data stores, data processes, and data sources/destinations. A data flow diagram of the proposed information system is shown in Figure 3.1.

3.4.2 Proposed system data models

The manufacturing firm needs to identify and record details of the non-conforming part that is originating from the suppliers. Non-conformities are identified by a NC Record (entity). The NC record consists of a NCR number which is a unique identifier of the NC record. An NC record contains details regarding the non-conforming part using attributes such as *UnitNumber* which indicates the type of product line to which the part was supposed to be delivered, *PartNumber* which indicates the type of non-conforming part, *DefectiveQty* which indicates the number of non-conforming parts, *LotSize* which represents the lot size of the parts delivered by the supplier from which the non-conforming parts were identified, *KRCode* provides description regarding category of fault associated with the non-conformities, *FailureModeDescription* which gives a detailed description of

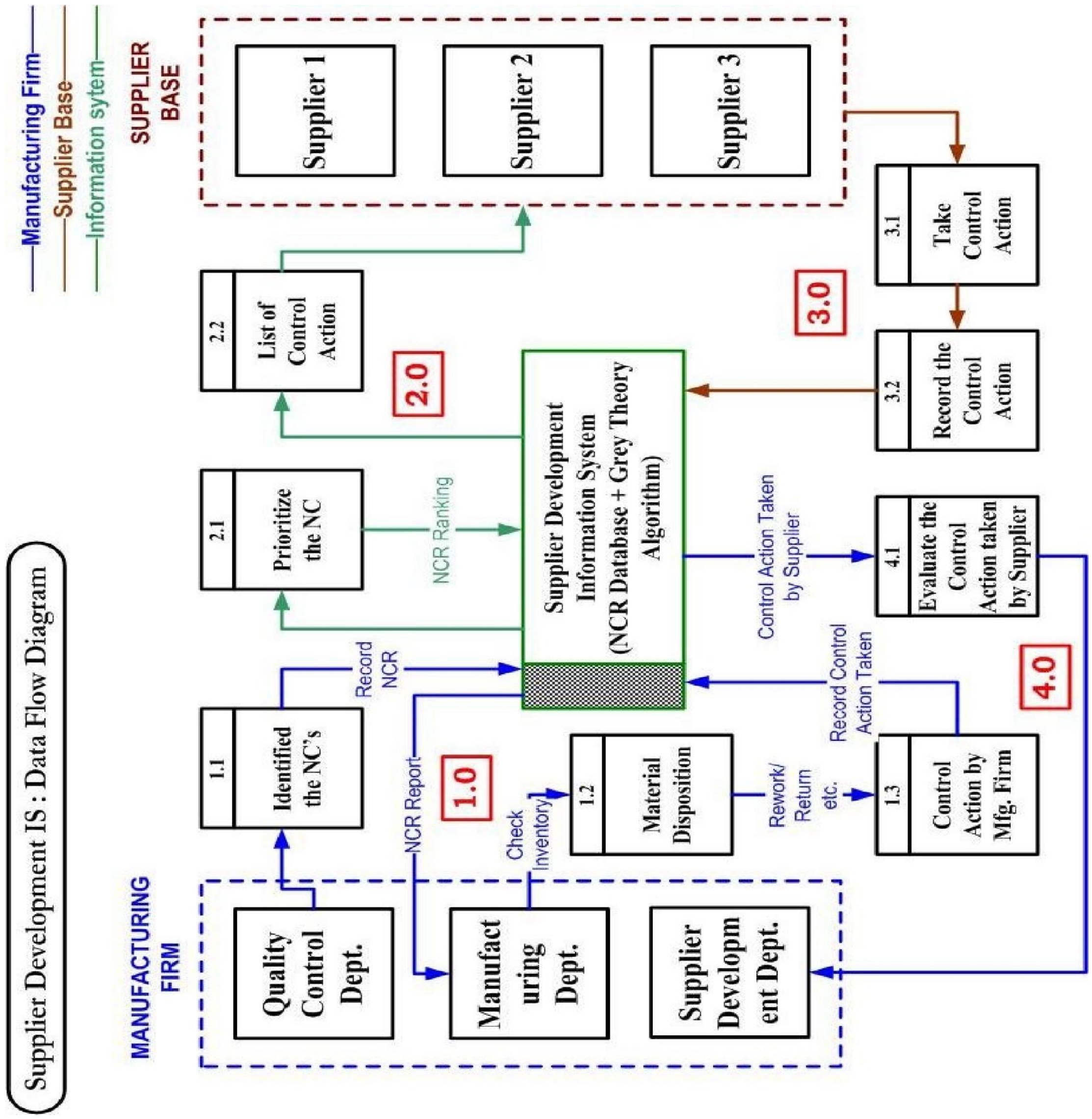


Figure 3.1: Data flow diagram for supplier development information system

the fault associated with a non-conforming part, *Date* provides information regarding when the non-conformity was identified by the quality control department of the manufacturing firm, *DateOfDisposition* indicates the date when the problem associated with the non-conformity was solved at the site of the manufacturing firm, *Effect* denotes the impact of the non-conformity, *Cost* is amount of money that is charged on to the supplier by the manufacturing firm, *Severity* and *Detection* are the two rankings given by the manufacturing firm depending on the magnitude of the non-conformity. The algorithm at the back end of the information system uses all this information to rank the non-conformities based on the priorities of the manufacturing firm.

The supplier on the other hand receives a prioritized list of non-conformities in form of action items and has to immediately have control action in place at its site in order to prevent the reoccurrence of the non-conformity in the parts that are delivered to the manufacturing firm. The supplier records the specifics of the control action taken, in the database under the attribute *ControlActionSupplier*.

The manufacturing firm then reviews the control action taken by the supplier and assigns a rank to detection which is stored in the attribute *NewDetection*. A difference in the ranking of detection will be a measure of effectiveness of the control action taken by the supplier.

3.4.3 Entities involved and description

1) Entity: Vendor

   Definition: Delivery the parts to the manufacturing firm.

   Type: Fundamental

   Attributes:

   a) VendorID (Identifier)
   b) VendorName
   c) Country

2) Entity: Part

   Definition: It is delivered to the manufacturing firm by the suppliers.

   Type: Fundamental

   Attributes:

   a) PartNumber (Identifier)
   b) PartDescription
   c) OpportunityOfDefects
   d) VendorID

3) Entity: NC Record

   Definition: Entity which transfers all the necessary information between the manufacturing firm and the suppliers.

   Type: Fundamental

Attributes:

a) NCRNumber (Identifier)
b) UnitNumber
c) PartNumber
d) DefectiveQty
e) LotSize
f) KRCode
g) FailureModeDescription
h) Date
i) DateOfDisposition
j) Effect
k) Cost
l) Severity
m) ControlAction
n) Detection
o) NCRClosed
p) ControlActionSupplier
q) NewDetection
r) DateSupplierControlAction

3.4.4 Entity relationship diagram

Entity relationship diagrams are used to depict data in terms of the entities and relationships described by the data. It is a tool used to model the logical view of the data and is quite helpful to develop the relationship between the entities and attributes of the entities described in the previous section. Entity relation diagram for the proposed information system is as shown in Figure 3.2.

3.4.5 Data dictionaries

Data dictionaries are used to give detailed description of the data characteristics associated with each attribute of an entity. This information is very critical for building the relationships between the entities and also for writing queries to filter information from the database, which would be fed into the algorithm. Table 3.4, Table 3.5, and Table 3.6 provide detailed description of the data characteristics associated with each attribute of an entity vendor, part, and NC record respectively.

3.4.6 Business rules

Business rules govern the smooth operation of the information system and hence are very critical for the success of an information system. Following is a list of business rules that need to be followed while using this information system.

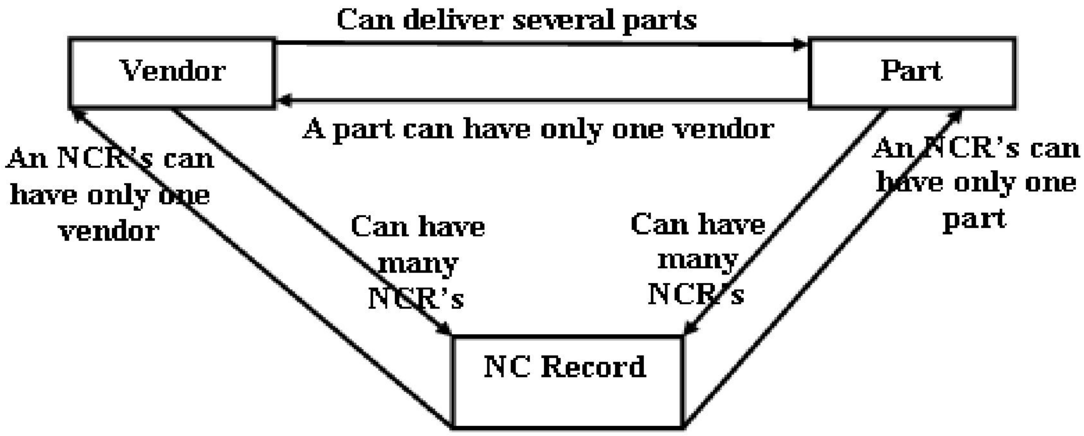


Figure 3.2: Entity relationship diagram

Table 3.4: Data dictionaries for vendor (Entity)

Attributes	Field	Data	Domain			
	Name	Description	Data Type	Length (Max)	Required	Indexed
Vendor ID	VendorID	Vendor who delivered the part	Number	Long Integer	Yes	Yes (No Duplicates)
Vendor Name	VendorName	Name of Vendor	Text	50	Yes	No
Country	Country	Name of Country	Text	20	No	No

Table 3.5: Data dictionaries for part (Entity)

Attributes	Field	Data	Domain			
	Name	Description	Data Type	Length (Max)	Required	Indexed
Part Number	PartNumber	Part that is delivered	Text	20	Yes	Yes (No Duplicates)
Part Description	PartDescriptions	Part Description	Text	50	Yes	No
Defective Opportunity per Part	DOPP	No. defective opportunity per part	Number	Long Integer	Yes	No
Vendor ID	VendorID	Vendor ID of vendor who supplied the part	Number	Long Integer	Yes	Yes (Duplicates OK)

Table 3.6: Data dictionaries for NC record (Entity)

Attributes	Field Name	Data Description	Domain			
			Data Type	Length (Max)	Required	Indexed
NCR Number	NCRNumber	NCR Number	Text	255	Yes	Yes (No Duplicates)
Unit Number	UnitNumber	Type of Product line	Text	255	Yes	No
Part Number	PartNumber	Part Number	Text	255	Yes	Yes (Duplicates OK)
Quantity Defective	DefectiveQty	No. of NC Parts	Number	Double	Yes	No
Lot Size	LotSize	Lot size of parts delivered	Number	Long Integer	Yes	No
KR Code	KRCode	Defect Code	Number	Long Integer	Yes	Yes (Duplicates OK)
Date	Date	Date NCR was created	Date	Shot Date	Yes	No
Date of Disposition	DateOf Disposition	Date control action taken by mfg. firm	Date	Short Date	Yes	No
Effect	Effect	Impact of NC	Text	255	Yes	No
Cost	Cost	Cost of NC	Currency	Currency	Yes	No
Severity	Severity	Severity Ranking	Number	Long Integer	Yes	No
Control Action	ControlAction	Control Action taken by mfg. firm	Text	255	Yes	No
Detection	Detection	Rank for Detection	Number	Long Integer	Yes	No
NCR Closed	NCRClosed	NCR Closed	Yes/ No	Yes/No	Yes	No
Control Action Supplier	ControlAction Supplier	Control action taken by supplier	Text	250	Yes	No
New Detection	NewDetection	New rank for Detection	Number	Long Integer	Yes	No
Date Supplier Control Action	DateSupplier ControlAction	Date Supplier took control action	Date	Short Date	Yes	No

1) As soon as non-conformity is identified a NCR is created.

2) Each non-conforming record is identified with a unique NCR number.

3) The quality control department has to update all the details regarding the identified non-conformity, such as unit number, part number, quantity defective, lot size, KR code, detection, severity, effect, control action taken by the manufacturing firm, etc. in the database of the information.

4) The algorithm of the information system should immediately rank the non-conformities as soon as it has all the details to do so.

5) The suppliers have to logon to the system on a regular basis to check for non-conforming reports from the quality control department of the manufacturing firm.

6) The suppliers have to immediately take necessary control action at their site in the same order as the non-conformities are ranked by the information system.

7) The suppliers have to record all the details of the control action taken in the database of the information system.

8) The manufacturing firm has to review the control action taken by the supplier and assess the effectiveness of the same.

3.4.7 Relationship diagram

A relationship diagram in Figure 3.3 provides a pictorial representation of the relationship of records in the various tables in the database. It also shows the different fields that constitute a table.

Following are a few relationship rules that were followed while creating the tables in the database:

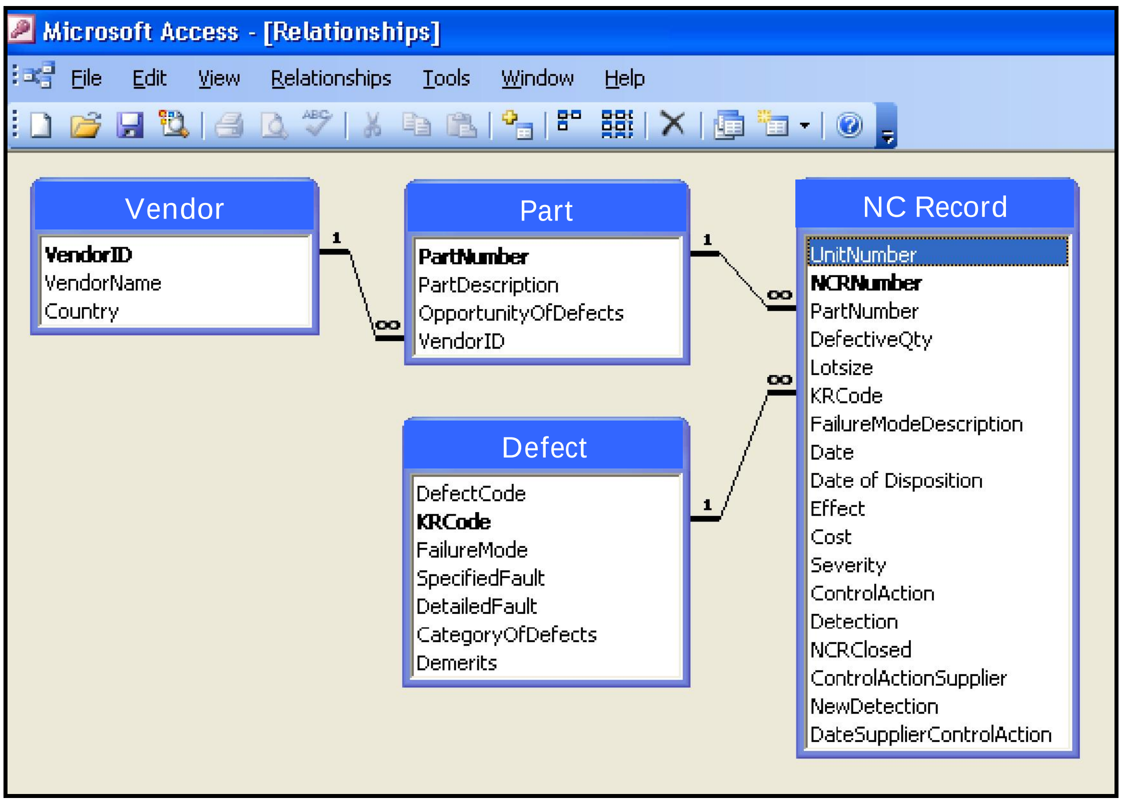


Figure 3.3: Relationship between tables in the database

1) A single vendor can be the supplier of different parts to the manufacturing firm but the manufacturing firm can have only one supplier for a part.
2) A part can have several types of defects but each defect type and part can have only one NC record in the database.
3) There can be many NC records from a supplier in the database, but each NC record is associated with only one supplier.

3.4.8 Application architecture

From the entity description and relationship diagram we can derive the logical model for the information system as shown in Figure 3.4. *VendorID* is the primary key for the Vendor table and is used to identify each record in the Vendor Table. The *PartNumber* is the primary key for the Part Table. The Part Table has a secondary key called *VendorID* which is used to link the records of the Part Table with that of Vendor Table. The primary key of the NCR Table is the *NCRNumber*. There are two secondary keys in the NCR Table, *PartNumber* and the *KRCode*. The *PartNumber* is used to link the records of the NCR table with that of Part Table while *KRCode* is used to link the records of the NCR Table with that if the Defect Table. *KRCode* is the primary key in the Defect Table and is used to identify records in the Defect Table.

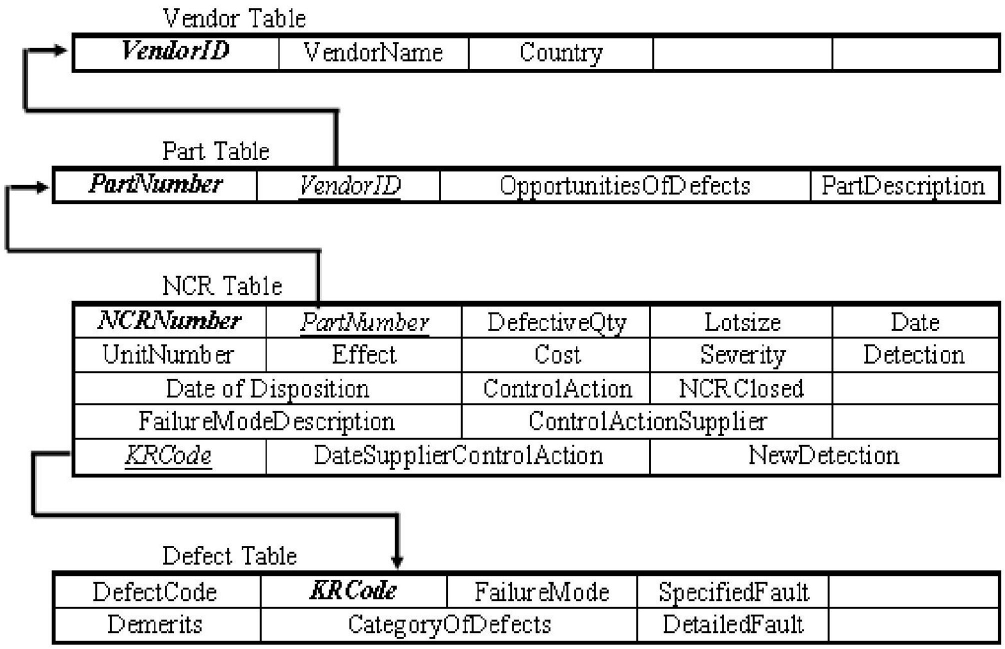


Figure 3.4: Logical model of the information system

3.5 Designing the recommended system

This phase outlines the step by step procedure for the data entry and other logical functions to be performed by the information system so that the desired objective is achieved. The following list provides a detailed step by step instruction describing the operation of the information system:

1) First, the quality control department of the manufacturing firm identifies the non-conformity and records the details (NCR No., part No., unit No., vendor ID, KR code, quantity defective, lot size etc.) regarding the non-conforming part into the database of the Information System (IS).
2) The IS then calculates the probability of occurrence (Occurrence = No. of nonconforming parts / Lot size) associated with this non-conforming part.

3) The engineering division makes decision regarding the material disposition and records the effect of the identified non-conformity in the database of the information system, in other words the decision regarding return, rework, scrap or void is recorded.
4) A rank is assigned based on severity of the non-conformity to the manufacturing firm.
5) If the part is to be reworked, then the rework operator reports the details of the control action taken, into the database of the information system.
6) The information system then assigns a rank to the control action based on the ability to detect the non-conforming part in the final product that is delivered to the customer. All this information entered in the database is used by the FMEA based approach to calculate the RPN number. The approach uses an algorithm which works on the concept of Grey theory to calculate the RPN number and rank the non-conformities. The mathematics of Grey theory in association with this model is explained the next section.
7) The supplier development manager utilizes the results of the RPN ranking from the model, to find out the top 10 non-conformities to the manufacturing firm. The model also enables the manager to trace the suppliers who are resulting in these non-conformities.
8) From the suppliers point of view, the IS provides the supplier a prioritized list of action items based on the priorities of the manufacturing firm that the

supplier needs to immediately work upon them in order to reduce the reoccurrence of non-conforming part.

9) A remedial control action taken at supplier's end to ensure that the non-conformity does not reoccur and the specifics of the control action is recorded in the database of the information system.

10) The supplier development manager monitors the effectiveness of the control action and assigns a new rank of detection for the non-conforming record. The IS then calculates the new RPN and again ranks the non-conformity

3.5.1 Grey theory model

From the previous section it can be clearly concluded that the key for success of this information system lies in its ability to articulate the priorities of the manufacturing firm to the suppliers. This is achieved by ranking the non-conformities based on the priorities of the manufacturing firm and providing this information to the suppliers in the form of a list of action items.

Grey theory was proposed by Julong Deng in 1982, deals with decisions characterized by incomplete information, and explores system behavior using relational analysis. It provides a measure to analyze the relationship between discrete quantitative and qualitative series, and all components in the series shall conform to the following characteristics: existent; countable; extensible and independent. Since factors of this information system fit very well into the framework of an FMEA and since all the components of a traditional FMEA have all these properties, therefore, FMEA is suitable for application of Grey theory. The step by step procedure that was used to develop the algorithm to calculate the RPN using Grey theory, in this information system, is outlined in the following sections. CGL Manufacturing is used as a case study to illustrate the calculations associated with each step.

3.5.2 Establish comparative series

The first step towards the computation of the RPN number using Grey theory is the formulation of a comparative series. The comparative series is derived from an information series with n components or decision factors, which in our case would be probability of occurrence, detection, severity of failure and DOPP. This information series is expressed as, $X_i' = (X'_i(1), X'_i(2), ...X'_i(K)) \in X$, where $x_i(k)$ denoted the k^th^ factors of x_i. If all the information series are comparable, then the n information series in the FMEA model can be represented in the form of the following matrix (Deng, 1989).

$$X = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ .. \\ .. \\ .. \\ X_n \end{bmatrix} = \begin{bmatrix} X_1(1) & X_1(2) & X_1(3) & ..... & X_1(k) \\ X_2(1) & X_2(2) & X_2(3) & ..... & X_2(k) \\ X_3(1) & X_3(2) & X_3(3) & ..... & X_3(k) \\ .. \\ .. \\ .. \\ X_n(1) & X_n(2) & X_n(3) & ..... & X_n(k) \end{bmatrix}$$

Hence, in the case of CGL manufacturing we have

$$X = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \\ X_6 \\ X_7 \\ X_8 \\ X_9 \\ X_{10} \end{bmatrix} = \begin{bmatrix} 0.01 & 2 & 8 & 3 \\ 0.01 & 7 & 7 & 6 \\ 0.03 & 3 & 2 & 8 \\ 0.14 & 2 & 5 & 15 \\ 0.02 & 1 & 8 & 8 \\ 0.01 & 4 & 2 & 8 \\ 0.01 & 5 & 2 & 4 \\ 0.01 & 4 & 9 & 7 \\ 0.01 & 1 & 3 & 7 \\ 0.01 & 7 & 6 & 7 \end{bmatrix}$$

Where $X_k(1)$ represents probability of occurrence , $X_k(2)$ severity ranking, $X_k(3)$ detection and $X_k(4)$ represents DOPP.

3.5.3 Establish the standard series

The degree of relation denotes the relationship between the non-conformities originating from different suppliers and the optimal value of the decision factors. The optimal value of the factors is stored in the form of a series called the standard series which is expressed as $X_0 = (X_0(1), X_0(2), ...X_0(k))$. When conducting an FMEA, the smaller the score, the less the risk of non-conformance; therefore the standard series will consist of the lowest level of all four factors. The lowest score for occurrence, severity (Refer figure A-1), detection (Refer figure A-2), and DOPP is 0,1,1,0 respectively. Hence the standard series will be $X_0 = (X_0(1), X_0(2), X_0(3), X_0(4)) = (0,1,1,0)$

3.5.4 Obtain the difference between the comparative and standard series

To discover the grey relationship, the difference between the scores of decision factors and the norm of standard series is determined and expressed in the form of a matrix as shown below (Chang, 1996)

$$D_0 = \begin{bmatrix} \Delta_{01}(1) & \Delta_{01}(2) & \Delta_{01}(3) & \ldots & \Delta_{01}(k) \\ \Delta_{02}(1) & \Delta_{02}(2) & \Delta_{02}(3) & \ldots & \Delta_{02}(k) \\ \Delta_{03}(1) & \Delta_{03}(2) & \Delta_{03}(3) & \ldots & \Delta_{03}(k) \\ \ldots & & & & \\ \ldots & & & & \\ \ldots & & & & \Delta_{0j}(k) \\ \Delta_{0m}(1) & \Delta_{0m}(2) & \Delta_{0m}(3) & \ldots & \Delta_{0m}(k) \end{bmatrix}$$

Where $\Delta_{0j}(k) = \| X_0(k) - X_j(k) \|$

Therefore, D_o in the case of CGL Manufacturing is calculated as follows:

$$D_0 = \begin{bmatrix} \Delta_{01}(1) & \Delta_{01}(2) & \Delta_{01}(3) & \Delta_{01}(4) \\ \Delta_{02}(1) & \Delta_{02}(2) & \Delta_{02}(3) & \Delta_{02}(4) \\ \Delta_{03}(1) & \Delta_{03}(2) & \Delta_{03}(3) & \Delta_{03}(4) \\ \Delta_{04}(1) & \Delta_{04}(2) & \Delta_{04}(3) & \Delta_{04}(4) \\ \Delta_{05}(1) & \Delta_{05}(2) & \Delta_{05}(3) & \Delta_{05}(4) \\ \Delta_{06}(1) & \Delta_{06}(2) & \Delta_{06}(3) & \Delta_{06}(4) \\ \Delta_{07}(1) & \Delta_{07}(2) & \Delta_{07}(3) & \Delta_{07}(4) \\ \Delta_{08}(1) & \Delta_{08}(2) & \Delta_{08}(3) & \Delta_{08}(4) \\ \Delta_{09}(1) & \Delta_{09}(2) & \Delta_{09}(3) & \Delta_{09}(4) \\ \Delta_{10}(1) & \Delta_{10}(2) & \Delta_{10}(3) & \Delta_{10}(4) \end{bmatrix} = \begin{bmatrix} 0.01 & 1 & 7 & 3 \\ 0.01 & 6 & 6 & 6 \\ 0.03 & 2 & 1 & 8 \\ 0.14 & 1 & 4 & 15 \\ 0.02 & 0 & 7 & 8 \\ 0.01 & 3 & 1 & 8 \\ 0.01 & 4 & 1 & 4 \\ 0.01 & 3 & 8 & 7 \\ 0.01 & 0 & 2 & 7 \\ 0.01 & 6 & 5 & 7 \end{bmatrix}$$

3.5.5 Compute the grey relational coefficient

The decision factors of the failure model are compared with the standard series and the grey relational coefficient is calculated using the following expression: $\gamma(X_0(k), X_i(k)) = \dfrac{\Delta_{min} + \zeta\ \Delta_{max}}{\Delta_{0j}(k) + \zeta\ \Delta_{max}}$

Where, j = 1, 2 …m and k = 1, 2 …n

x_0(k) is the standard series and x_i(k) is the comparative series.

$$\Delta_{0j}(k) = \left\| X_0(k) - X_j(k) \right\|$$

$$\Delta \min = \min_{\forall j \in i} \ \min_{\forall k} \left\| X_0(k) - X_j(k) \right\| = 0$$

$$\Delta \max = \max_{\forall j \in i} \ \max_{\forall k} \left\| X_0(k) - X_j(k) \right\| = 15$$

ζ is an identifier, $\zeta \in (0,1)$, only affecting the relative value of risk without changing the priority. Generally, ζ is taken to be 0.5 (Deng, 1989). Therefore the Grey relation coefficient matrix is calculated as follows:

$$\gamma(X) = \begin{bmatrix} \gamma_{01}(1) & \gamma_{01}(2) & \gamma_{01}(3) & \gamma_{01}(4) \\ \gamma_{02}(1) & \gamma_{02}(2) & \gamma_{02}(3) & \gamma_{02}(4) \\ \gamma_{03}(1) & \gamma_{03}(2) & \gamma_{03}(3) & \gamma_{03}(4) \\ \gamma_{04}(1) & \gamma_{04}(2) & \gamma_{04}(3) & \gamma_{04}(4) \\ \gamma_{05}(1) & \gamma_{05}(2) & \gamma_{05}(3) & \gamma_{05}(4) \\ \gamma_{06}(1) & \gamma_{06}(2) & \gamma_{06}(3) & \gamma_{06}(4) \\ \gamma_{07}(1) & \gamma_{07}(2) & \gamma_{07}(3) & \gamma_{07}(4) \\ \gamma_{08}(1) & \gamma_{08}(2) & \gamma_{08}(3) & \gamma_{08}(4) \\ \gamma_{09}(1) & \gamma_{09}(2) & \gamma_{09}(3) & \gamma_{09}(4) \\ \gamma_{10}(1) & \gamma_{10}(2) & \gamma_{10}(3) & \gamma_{10}(4) \end{bmatrix} = \begin{bmatrix} 0.99778 & 0.81818 & 0.39130 & 0.69231 \\ 0.99778 & 0.42857 & 0.42857 & 0.47368 \\ 0.99338 & 0.69231 & 0.81818 & 0.39130 \\ 0.96983 & 0.81818 & 0.52941 & 0.24324 \\ 0.99558 & 1.00000 & 0.39130 & 0.39130 \\ 0.99778 & 0.60000 & 0.81818 & 0.39130 \\ 0.99778 & 0.52941 & 0.81818 & 0.60000 \\ 0.99778 & 0.60000 & 0.36000 & 0.42857 \\ 0.99778 & 1.00000 & 0.69231 & 0.42857 \\ 0.99778 & 0.42857 & 0.47368 & 0.42857 \end{bmatrix}$$

3.5.6 Determine the degree of grey relation

To find the degree of grey relation, the weighting coefficient of the decision factors must be first decided in order to be used in the following formulation:

$$\Gamma(X_i, X_j) = \sum_{k=1}^{n} \beta_k \gamma\,(X_i(k), X_j(k))$$

β_k is the weighting coefficient of factors. Since, all the four factors were equally important therefore $\sum_{k=1}^{n} \beta_k = 1$. The above formulation can be modified as: $\Gamma(x_i, x_j) = \frac{1}{n}\sum_{k=1}^{n} \gamma\,(x_i(k), x_j(k))$

where, n is the number of decision factors. This equation is used to calculate the degree of grey relation:

$$\Gamma(X) = \begin{bmatrix} \Gamma_{01} \\ \Gamma_{02} \\ \Gamma_{03} \\ \Gamma_{04} \\ \Gamma_{05} \\ \Gamma_{06} \\ \Gamma_{07} \\ \Gamma_{08} \\ \Gamma_{09} \\ \Gamma_{10} \end{bmatrix} = \begin{bmatrix} 0.724894141 \\ 0.582152443 \\ 0.723792835 \\ 0.640166103 \\ 0.694545979 \\ 0.701817218 \\ 0.736344072 \\ 0.596588533 \\ 0.779665456 \\ 0.582164443 \end{bmatrix}$$

3.5.7 Obtain the risk priority

In FMEA the degree of grey relation denotes the relationship between scores of potential causes and optimal values of the decision factors. The greater the degree of grey relation, the smaller the effect of the cause. Therefore, the increasing order of degree of relation represents the risk of potential causes to be improved, which in our case will the non-conformities originating from different suppliers.

$$\Gamma_{02} \leq \Gamma_{10} \leq \Gamma_{08} \leq \Gamma_{04} \leq \Gamma_{05} \leq \Gamma_{06} \leq \Gamma_{03} \leq \Gamma_{01} \leq \Gamma_{07} \leq \Gamma_{09}$$

The rank of the non-conformities when calculated using Grey theory and DOPP approach is summarized in Table 3.7.

In the traditional approach RPN number is calculated as a product severity, occurrence, detection and DOPP. RPN calculation for the same set of non-conformities by the traditional approach is shown in Table 3.8.

3.6 Developing the software

MS Access is used as the Database Management System Software for developing this information system. This database is developed and

Table 3.7: Ranking of NC based on Grey theory and DOPP approach

Ranking	NCR Number	RPN(Grey relation coefficient)
1	48049	0.582152443
2	60685	0.582164443
3	50325	0.596588533
4	61020	0.640166103
5	61035	0.694545979
6	60692	0.701817218
7	50430	0.723792835
8	60774	0.724894141
9	50324	0.736344072
10	48068	0.779665456

Table 3.8: RPN calculation and ranking (Traditional Approach)

Ranking	NCR Number	Occurrence	Severity	Detection	RPN
1	61020	0.14	2	5	1.4
2	48049	0.01	7	7	0.49
3	60685	0.01	7	6	0.42
4	50325	0.01	4	9	0.36
5	50430	0.03	3	2	0.18
6	60774	0.01	2	8	0.16
7	61035	0.02	1	8	0.16
8	50324	0.01	5	2	0.1
9	60692	0.01	4	2	0.08
10	48068	0.01	1	3	0.03

maintained by the supplier development and quality control department of the manufacturing firm. A Visual Basic 6.0 front end was developed to enhance the ease of data entry as well as to add security features to the information system. Visual Basic also provides the flexibility to integrate the mathematical algorithm, as proposed in the previous sections, with this information system. The following software is required for the smooth operation of the information system:

1) Windows NT/XP operating system.
2) MS Access DBMS system.
3) MS Visual Basic 6.0
4) Internet Explorer or Mozilla internet browser

Table 3.9 gives a brief description of the Work Breakdown Structure (WBS) number followed by a design phase and schedule chart (Figure3.5) that was followed for developing this supplier development information system:

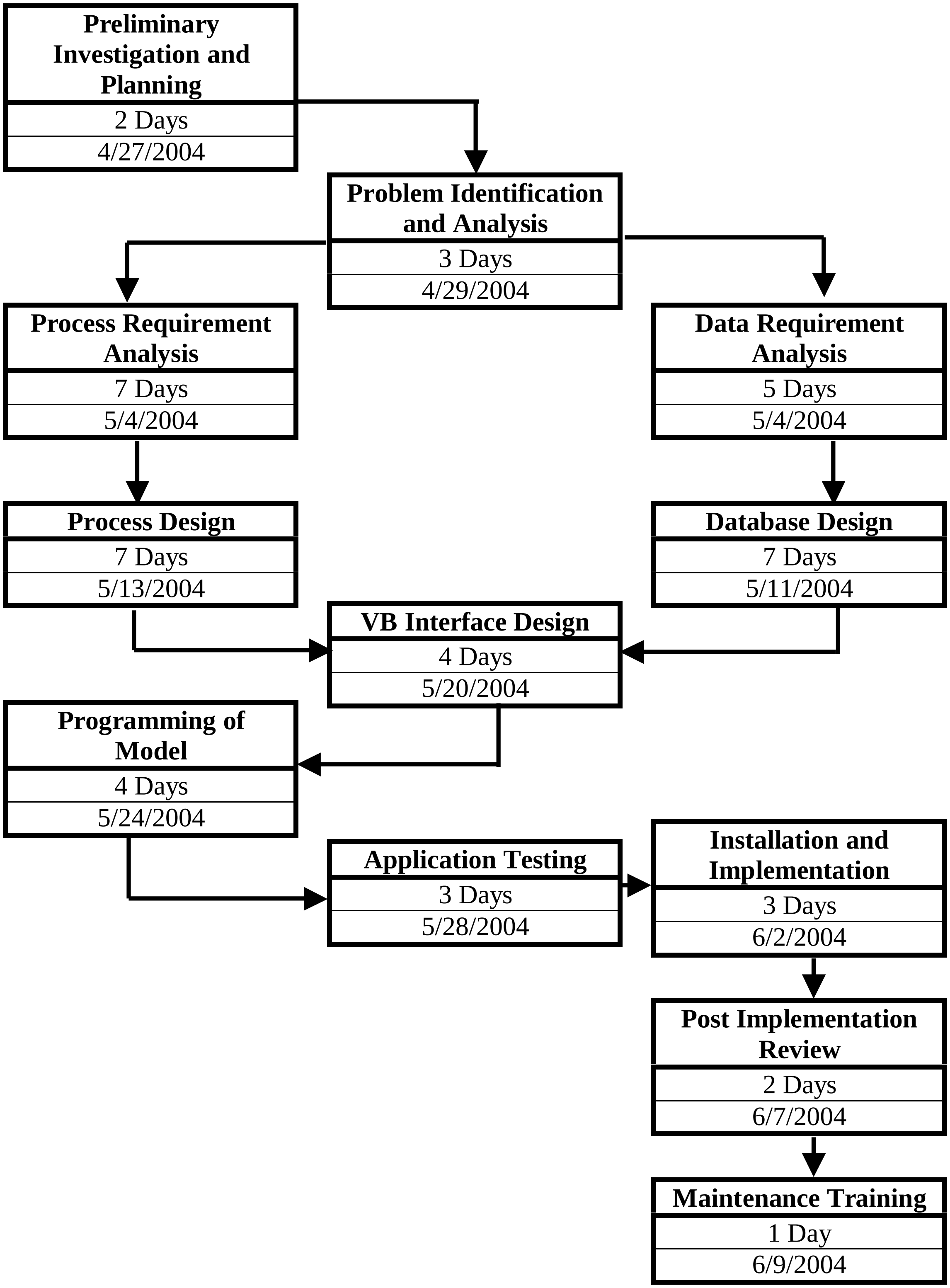


Figure 3.5: Schedule Chart

Table 3.9: Work breakdown structure

WBS Number	Task Description
1.0	Project Initiation
1.1	Draft Project Plan
2.0	Analysis Phase
2.1	Plan User Interviews
2.2	Schedule user interviews
3.0	Examination and test
4.0	Design
5.0	Test
6.0	Implementation
7.0	Post Implementation Review

3.7 Testing and maintaining the system

Before the information system can be used, it must be tested. It is always less costly to catch problems before the system is delivered over to users or before the implementation of the project. Some of the testing is completed by the programmers alone, some of it by the system analyst or the end users (which in our case was the quality control dept and supplier development manager) in conjunction with the programmers.

In support of the strategic goal for information system to achieve Level III on the Software Engineering Institute's Capability Maturity Model, this information system has be developed in accordance with the SDLC methodology and is supposed to follow the following guidelines for maintenance:

1) The project team which in our case will be spearheaded by the supplier development manager and will hold weekly status meetings, chaired by the

project manager. All project status meetings minutes and reports will be shared with the IT department.

2) The clients, which in our case would be the suppliers, will utilize electronic mail, dialogue, and written completion criteria on a regular basis as vehicles for project communication after the implementation.

3) The following directory folder shall be used to store charter and all subsequent documentation related to any modifications or guidelines for changes to the information system:

   H:\Information Technology Projects\Supplier Development IS\

3.8 Implementing and evaluating the system

The last phase of the system development life cycle comprises installing the information system at the different supplier locations. It also involves linking the field of the information system with that of the existent system to ensure smooth transfer of information. Regular meetings are conducted to create and awareness about the new system among the end users. Clear guidelines for using and maintaining this information system are formulated and documented as described in the previous section.

CHAPTER 4

Case study and results

4.1 Introduction

This chapter begins with a comparison of results of RPN numbers from the model that is developed as described in Chapter 3. Further, it also draws a comparison of the RPN rankings from the two approaches for the same non-conforming record. However, hypothesis testing is used to prove that there is significant difference in the manner in which the two approaches rank the non-conformities. Following which a cost analysis is performed to determine which of the two approaches will be a better system to rank the non-conformities.

4.2 Results of RPN numbers and RPN ranking

The table A-22 provided a detailed illustration of how the RPN numbers were calculated for each non-conforming record using the traditional approach. Table A-23 summarizes the calculations associated with calculating the RPN number (Grey relation coefficient) using the new approach. Table 4.1 summarizes the results of the RPN numbers from the two approaches and ranks assigned the same non-conforming record using the two approaches. The question that arises is that is whether the new approach of ranking the non-conformities significantly different than the traditional approach of ranking the non-conformities. If yes, then it is beneficial to replace the traditional approach of ranking the non-conformities with the new approach as proposed in this thesis.

Table 4.1: Results of the RPN number and ranking of the non-conformities

NCR Number	RPN Traditional Method	Ranking Traditional Method	RPN using DOPP & Grey Theory	Ranking DOPP & Grey Theory
47567	0.32	143	0.66731	145
47568	0.45	149	0.64488	115
47569	0.30	68	0.67146	146
47570	0.32	129	0.66513	90
47571	0.18	162	0.72186	148
47577	0.48	44	0.63894	170
47578	0.01	200	0.92252	200
47597	1.92	36	0.56241	57
47598	0.72	41	0.60386	142
48017	0.90	61	0.58943	118
48031	0.40	145	0.65270	76
48035	0.06	191	0.79094	187
48038	0.56	62	0.62749	39
48041	0.32	97	0.66457	144
48049	0.49	108	0.63822	52
48054	1.96	27	0.56180	32
48057	0.98	23	0.58508	107
48058	0.24	150	0.68668	117
48059	0.36	121	0.65575	83
48060	0.03	194	0.86446	194
48062	0.36	151	0.66202	89
48064	0.60	120	0.62749	88
48068	0.05	197	0.79580	189
48070	1.60	96	0.57284	48
48074	0.16	182	0.72379	151
48075	0.54	136	0.63574	135
48076	1.12	95	0.58463	37
48077	0.24	82	0.68513	116
48081	0.24	139	0.69039	162
48082	0.56	93	0.62966	86
48084	0.30	101	0.66736	98
48085	0.42	161	0.65022	75
48093	0.02	199	0.90854	199
48095	0.20	141	0.70465	165
48099	9.12	10	0.52241	47
49365	0.84	135	0.59335	125
49366	0.80	99	0.59805	70
49367	0.18	154	0.72076	169

Table 4.1: Continued

NCR Number	RPN Traditional Method	Ranking Traditional Method	RPN using DOPP & Grey Theory	Ranking DOPP & Grey Theory
49368	0.10	176	0.74384	185
49369	0.60	159	0.62584	100
49377	1.12	48	0.58355	161
49379	0.84	83	0.59510	59
49380	2.40	16	0.55224	42
49382	0.24	89	0.69468	184
49383	0.45	80	0.64589	63
49385	0.64	88	0.61035	132
49386	3.24	19	0.54120	9
49389	0.27	157	0.68034	111
49395	3.60	17	0.53861	64
49397	1.80	34	0.56785	38
49399	0.30	71	0.67274	175
49400	0.70	54	0.60519	77
50219	0.36	138	0.66142	168
50220	14.40	5	0.50700	10
50221	0.48	123	0.63877	106
50224	2.88	56	0.54292	81
50228	0.96	39	0.58727	154
50301	0.08	165	0.75234	178
50303	0.60	57	0.62306	85
50304	2.80	53	0.54438	3
50308	1.44	14	0.57745	141
50309	0.72	24	0.60441	174
50310	0.72	66	0.60225	94
50312	0.90	130	0.58809	14
50317	1.12	78	0.58215	5
50318	0.54	160	0.63336	56
50319	0.21	156	0.70182	126
50321	6.30	12	0.52259	2
50322	0.70	100	0.60681	78
50323	0.81	63	0.59545	16
50324	0.07	181	0.75604	179
50325	0.42	128	0.64964	72
50326	0.64	77	0.61809	27
50327	0.06	188	0.76787	190
50329	0.60	49	0.62606	87
50330	0.49	92	0.63711	54

Table 4.1: Continued

NCR Number	RPN Traditional Method	Ranking Traditional Method	RPN using DOPP & Grey Theory	Ranking DOPP & Grey Theory
50427	0.36	140	0.66131	140
50430	0.28	168	0.67967	172
50431	0.12	180	0.73634	183
50434	0.60	142	0.62476	92
50435	1.98	33	0.56156	103
50438	0.24	166	0.68660	112
50440	0.90	110	0.58992	11
50460	1.20	76	0.58215	65
50480	2.52	22	0.54850	17
50482	0.60	133	0.62251	121
50483	1.20	59	0.58215	58
50485	0.72	105	0.60386	152
50487	0.28	106	0.67956	196
50491	2.80	29	0.54441	15
50492	0.28	113	0.67967	156
50496	0.50	131	0.63626	101
50497	33.60	2	0.49952	8
50499	1.12	74	0.58411	35
50500	0.30	146	0.67900	155
60151	0.21	144	0.69778	123
60152	0.06	186	0.75636	176
60154	0.64	79	0.61911	28
60160	2.24	21	0.55404	46
60161	0.80	148	0.59659	29
60162	0.63	124	0.62180	153
60168	0.70	118	0.60471	108
60169	2.10	25	0.55666	102
60174	0.96	26	0.58622	96
60175	0.60	107	0.62391	33
60176	2.16	18	0.55659	49
60179	0.05	169	0.83834	192
60180	0.49	125	0.63658	44
60184	0.30	163	0.66816	99
60185	0.64	81	0.61967	31
60186	3.24	31	0.53955	6
60191	0.84	69	0.59444	12
60193	0.24	86	0.69094	122
60194	0.45	60	0.64447	109
60197	3.78	13	0.53846	129

Table 4.1: Continued

NCR Number	RPN Traditional Method	Ranking Traditional Method	RPN using DOPP & Grey Theory	Ranking DOPP & Grey Theory
60206	2.00	9	0.55991	97
60212	5.40	8	0.52827	45
60213	1.40	37	0.57951	143
60225	1.44	20	0.57580	150
60227	0.40	73	0.65270	171
60234	0.06	190	0.77911	177
60235	0.16	178	0.72216	149
60236	0.36	132	0.65468	80
60237	0.40	126	0.65164	73
60242	0.24	177	0.69659	124
60243	0.36	147	0.65270	79
60652	4.48	30	0.53659	4
60653	0.40	65	0.65113	120
60655	1.40	50	0.57771	95
60656	1.40	64	0.58070	61
60657	3.20	11	0.54277	133
60658	1.26	72	0.58144	30
60661	0.18	137	0.70488	136
60662	1.80	47	0.56714	113
60668	1.60	98	0.57355	104
60669	9.45	3	0.51140	62
60670	2.10	52	0.55834	66
60671	2.40	38	0.55373	50
60672	1.60	40	0.57355	74
60673	0.84	43	0.59183	139
60674	0.42	152	0.64748	69
60677	0.06	195	0.77967	180
60682	0.06	196	0.79094	195
60683	0.90	116	0.59022	130
60685	0.48	119	0.63877	53
60686	1.68	42	0.56923	43
60687	1.26	55	0.58138	23
60688	0.42	134	0.64890	71
60689	0.36	155	0.65543	84
60691	0.48	75	0.64392	60
60692	0.14	184	0.73629	163
60695	0.72	91	0.60368	21
60697	19.98	7	0.50174	36
60699	0.15	187	0.73040	166

Table 4.1: Continued

NCR Number	RPN Traditional Method	Ranking Traditional Method	RPN using DOPP & Grey Theory	Ranking DOPP & Grey Theory
60774	0.10	171	0.74672	173
60781	0.27	167	0.68061	110
60789	0.30	103	0.67274	193
60791	0.35	164	0.66360	91
60792	0.08	189	0.74967	188
60793	0.21	94	0.69889	131
60795	0.20	158	0.70432	127
60796	0.24	112	0.68286	181
60801	2.16	35	0.55569	26
60812	0.54	104	0.63361	134
60814	0.96	51	0.58617	119
60836	0.48	114	0.64017	105
60838	0.80	102	0.60222	20
61003	0.15	179	0.72489	157
61004	0.64	109	0.61318	25
61005	0.01	201	0.92252	201
61006	1.62	32	0.57278	159
61007	0.56	153	0.63300	51
61010	1.40	45	0.57942	67
61012	0.36	127	0.65731	137
61015	4.50	15	0.53387	13
61017	2.24	58	0.55569	22
61018	5.20	4	0.53112	138
61019	0.12	185	0.73634	160
61020	2.52	46	0.54441	114
61021	0.02	193	0.88180	198
61022	10.80	6	0.50985	7
61023	0.10	173	0.73894	167
61024	0.20	175	0.70182	128
61025	0.36	174	0.66069	93
61027	0.15	85	0.73470	182
61028	0.16	122	0.72270	147
61029	0.48	115	0.63959	55
61032	0.64	70	0.62180	34
61033	0.14	183	0.73629	164
61034	2.40	28	0.55169	41
61035	0.24	172	0.69455	158
61037	0.64	67	0.61911	82
61038	0.70	84	0.60736	24

Table 4.1: Continued

NCR Number	RPN Traditional Method	Ranking Traditional Method	RPN using DOPP & Grey Theory	Ranking DOPP & Grey Theory
61041	0.06	170	0.79039	186
61043	0.81	117	0.59604	19
61044	0.56	111	0.63039	40
61045	0.80	87	0.59659	18
61047	42.72	1	0.49755	1

4.3 Hypothesis testing for testing the difference in results of RPN number

Many problems in engineering require that one makes a decision whether to accept or reject a statement about a parameter. The statement is called hypothesis, and the decision making procedure about the hypothesis is called hypothesis testing (Montgomery C. Douglas *et al.*, 2001). The parameter in this case would be the RPN number that is calculated by the traditional approach and the new approach using the concept of Grey theory and DOPP.

Statistical hypothesis testing can also be used during the data analysis stage to build a comparative experiment and draw conclusions from the experimental design for further analysis (Montgomery C. Douglas *et al.*, 2001). Hence, this concept of hypothesis testing is applied to test whether the new approach proposed in this thesis results in a different RPN number as compared to the RPN number calculated by the traditional approach, for a same non-conformity. If proved true, this would provide the foundation to carry out an economic analysis and hence authenticate the benefit the new approach will have over the traditional one. A systematic procedure of hypothesis testing as outlined by Montgomery is followed to execute this comparative experiment and test the hypothesis.

4.3.1. Identify the parameter of interest

The first step in hypothesis testing is to identify the parameter of interest. As stated above the objective is to carry out a comparative experiment to test if there is any difference in the RPN number as calculated by the traditional approach versus that of the new approach as proposed in this thesis. In other words, we want to test for the variation between the two samples and not within the two samples. Hence, the parameters of interest will be μ_1 and μ_2, the mean of the RPN numbers of traditional approach and the new approach, respectively.

4.3.2. State the null hypothesis, H_o

The null hypothesis is the hypothesis that we wish to test. In this case we intend to test if there is no difference in the means of the RPN numbers from the two different approaches i.e. μ_1 and μ_2. Hence, the null hypothesis is stated as follows:

There is no difference in means of the RPN numbers as calculated by the two approaches. In other words, both the approaches result in the same RPN numbers for a given non-conformity. Hence,

$$H_o: \mu_1 - \mu_2 = 0 \quad \text{or} \quad H_o: \mu_1 = \mu_2$$

4.3.3. Specify the alternative hypothesis, H_a

The rejection of the null hypothesis always leads to acceptance of the alternative hypothesis. Hence, the alternative hypothesis in this case will be stated as follows:

There exists a significant difference in means of the RPN numbers as calculated by the two different approaches. In other words, both the approaches result in different RPN numbers for a given non-conformity. Hence,

$$\boldsymbol{H_a}\textbf{:}\ \mu_1 - \mu_2 \neq \mathbf{0} \quad \textbf{or} \quad \boldsymbol{H_a}\textbf{:}\ \mu_1 \neq \mu_2$$

4.3.4. Choose a significance level, α

The probability of rejecting the null hypothesis H_o in favor of the alternative H_a when, in fact, H_o is really true (Type I error) is denoted by the Greek letter α. Since rejecting the null hypothesis is a strong conclusion; hence the probability of wrongly rejecting the H_o (α) is always set by the analyst (Montgomery C. Douglas et al., 2001). A close look at the RPN numbers from the two approaches reveal that a 95% confidence level is adequate to be able to confidently reject the null the hypothesis. Hence, the significant level α is set to 0.05 in this experiment.

4.3.5. Test for normality

One of the underlying assumptions while performing a hypothesis test is that if the sample size is greater than 30 (in this case n = 91), then the sample data under test should follow a normal distribution. Hence, it is essential that we test the sample size for normality before we proceed with the hypothesis testing. Both the samples (RPN numbers from the two approaches) were tested for normality using Minitab.

It can be seen from the Figure 4.1 that the p-value from the Anderson - Darling normality test is 0.102. This is greater than the α value of 0.05 that was initially set for conducting this hypothesis test. This proves the normality of the sample data of RPN numbers obtained from the traditional approach.

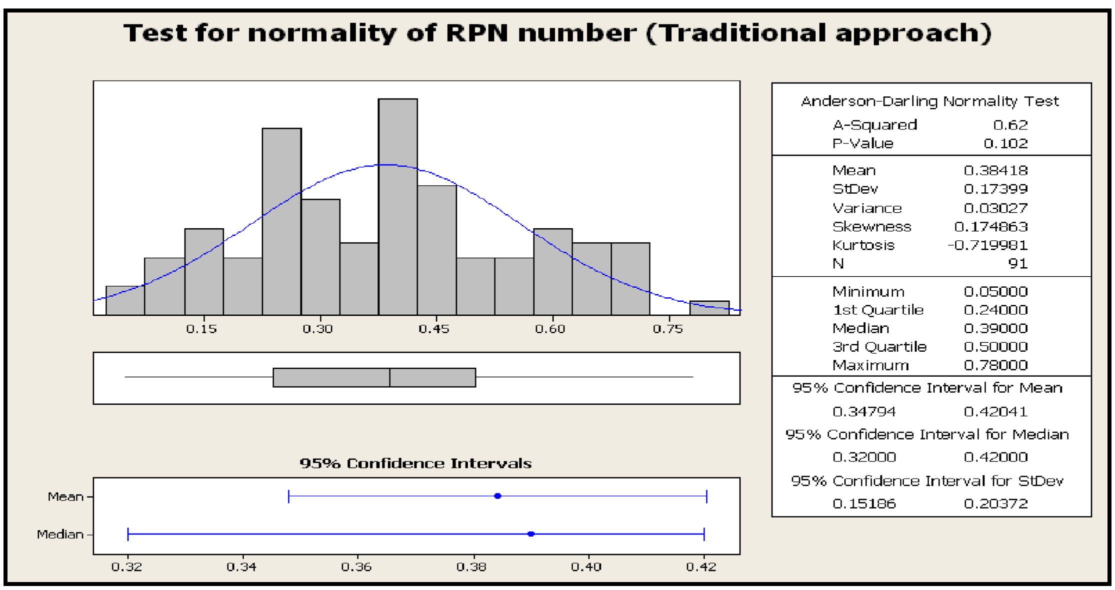


Figure 4.1: Test for normality of RPN number (Traditional approach)

Figure 4.2 indicates that the p-value from the Anderson - Darling normality test is 0.070. This again is greater than the α value of 0.05, hence proving the normality of the sample data of RPN number obtained from the new approach.

4.3.6. Calculate the sample size

Suppose that the null hypothesis H_o: $\mu_1 - \mu_2 = \delta_o$ (where, in this case $\delta_o = 0$) is false and that the true difference in means is $\mu_1 - \mu_2 = \delta$, where $\delta > \delta_o$. Then, we need to find the sample size that is required to be able to significantly differentiate a difference in means (δ) of 2.5 ($\sigma^2 = \sigma_1^2 + \sigma_1^2 = 0.4212$ and $6\sigma = 2.5$) between the two samples with a probability of at

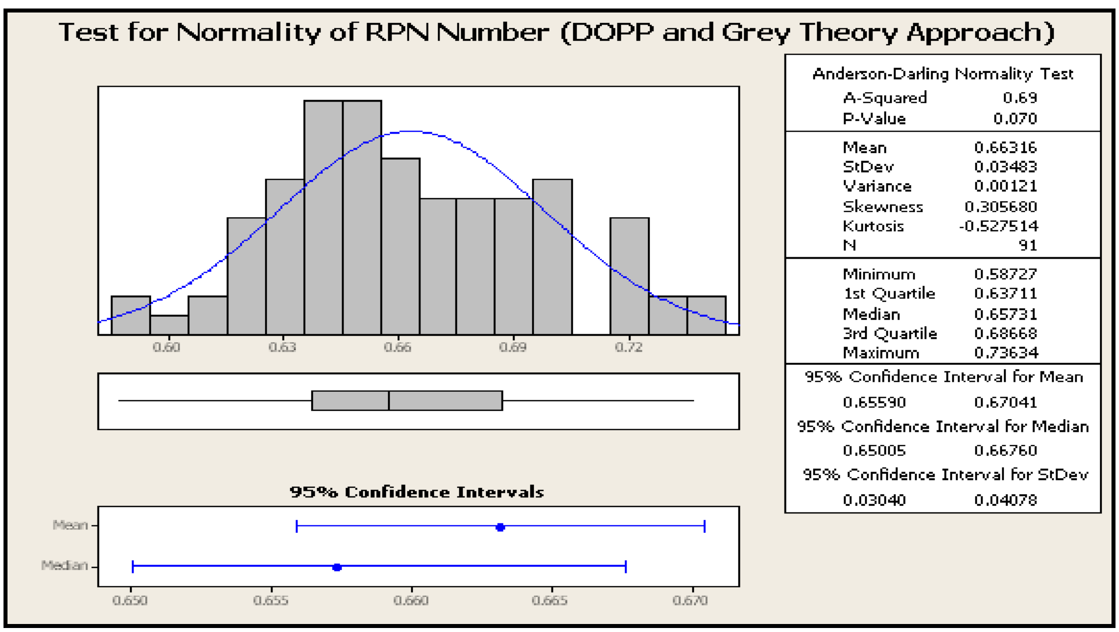


Figure 4.2: Test for normality of RPN number (DOPP and grey theory approach)

least 0.95 (β) and a significance level of 0.05. Minitab is used to calculate the desired sample size for the experiment. A snapshot of the results from Minitab is shown in Figure 4.3. It is found that a sample size of at least 80 samples is required to be able to state that there is at least a difference of 2.5 in the means of the RPN numbers from the two approaches, with a confidence level of 0.95. RPN numbers from the two approaches for 91 non-conformities were taken into consideration while designing this comparative experiment which is well above the required sample size to confidently reject the null hypothesis if it is false (Type II error).

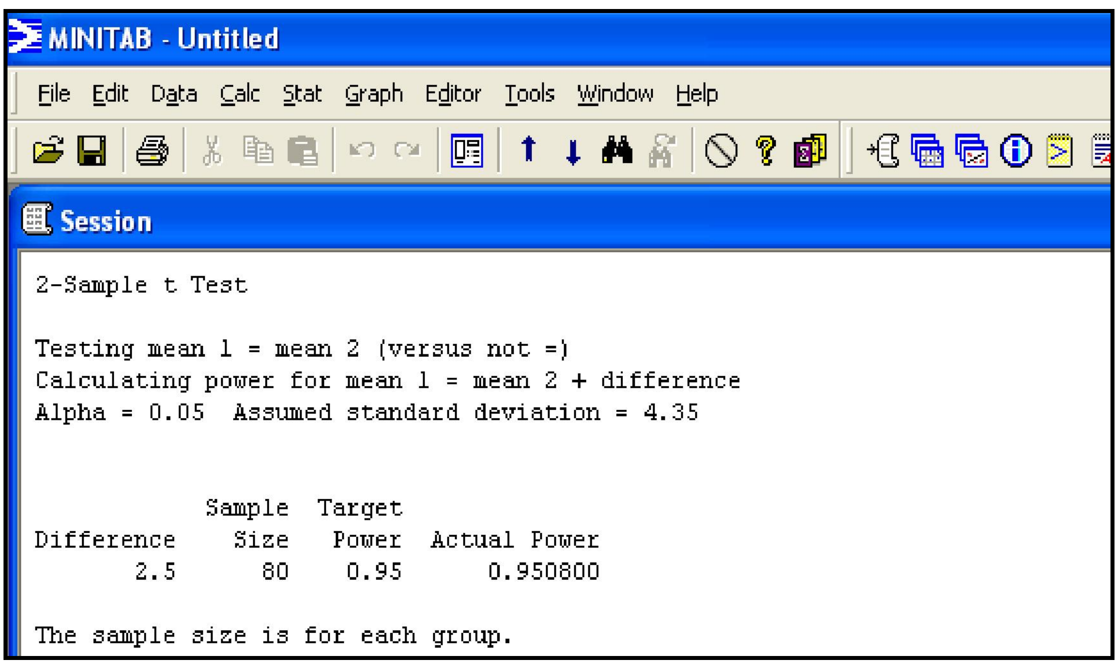


Figure 4.3: Test for sample size

4.3.7. Paired t test

A paired t test is appropriate for computing a hypothesis test of the mean difference between paired observations when the paired differences follow a normal distribution. A paired t-test matches responses that are dependent or related in a pair wise manner. In this case the two RPN numbers are from the same non-conforming record and we are testing for the differences between the RPN numbers from the two approaches for the same non-conformity. Also both the samples of RPN numbers follow a normal distribution. Hence, a paired t test is best suited to perform this type of hypothesis test. Minitab is used to carry out the paired t test and the results of the paired t test are shown in the Figure 4.4.

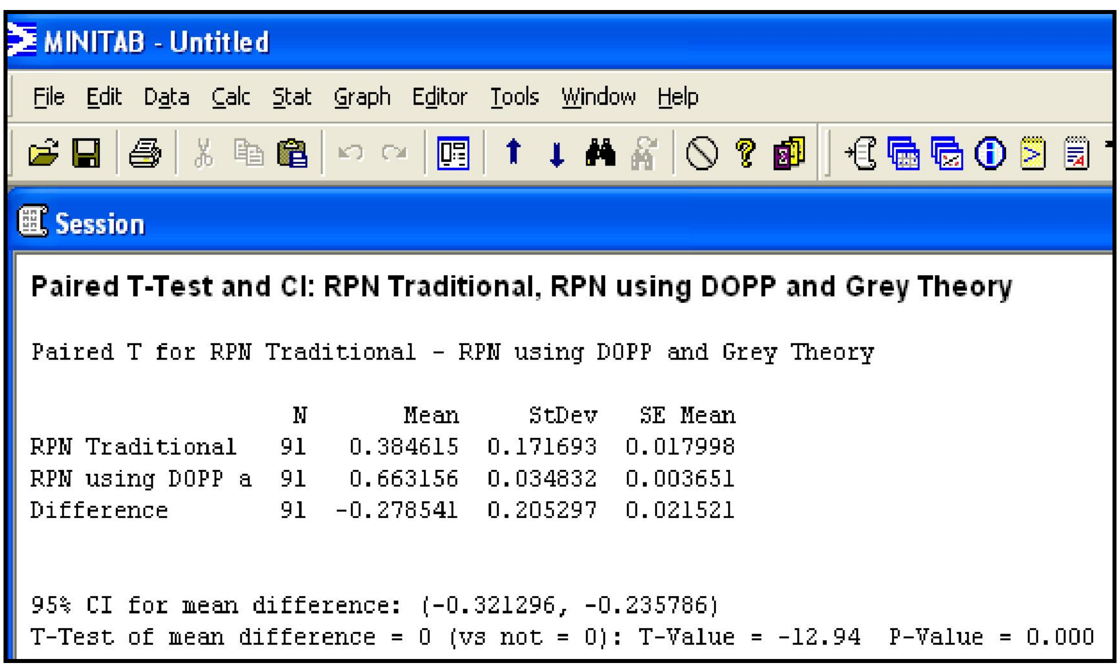


Figure 4.4: Result of paired t test

4.3.8. State the rejection or acceptance region

The snapshot of the Minitab results (Figure 4.4) indicate that the 95% confidence interval for difference in means of RPN numbers from the two approaches lie in the range of (-0.321296, -0.235786). It is to be noted that this confidence interval does not include zero which indicates that the means of the RPN numbers from the two samples are not equal to each other.

4.3.9. Accept or reject the null hypothesis

It is also to be noted from the snap shot of the Minitab results (Figure 4.4) that we do not have sufficient evidence to accept the null hypothesis. In other words, we have to reject the null hypothesis and accept the alternative hypothesis. This proves the fact the RPN number obtained by the new approach is significantly different than the RPN calculated by the traditional approach for the same non-conforming record. Since the RPN number is the basis for ranking the non-conformities, we can conclude that the two approaches will result in two significantly different rankings for the same set of non-conformities.

The supplier development information system uses RPN number as a basis for prioritizing the non-conformities for the suppliers and manufacturing firm. The results from hypothesis testing proves that there exist a significant difference in RPN numbers calculated using the two approaches. Hence it can be concluded that the two approaches would result in different rankings for the same set of non-conformities. The question still arises; "which of the two approaches would better rank or prioritize the non-conformities?"

4.4 Economic analysis

Economic analyses serve as a means to facilitate easier project comparison and selection. It quantifies the difference between alternatives by reducing the alternatives to a common base. We could use economic analysis to compare the prioritization of the non-conformities by the two approaches and hence decide as to which of the two approaches would better prioritize or rank the non-conformities for the suppliers so that it will result in a greater cost savings to the supplier.

The term future worth in an economic analysis means an amount at some ending or termination time that is equivalent to a particular schedule of receipts or disbursements under consideration. If only disbursements are considered (as in this case), the term can be best expressed as future worth cost or future cost (Canada R. John *et al.*, 1996). The two ranking systems provide a supplier with two different sequences in which the non-conformities are supposed to be addressed. Hence, in order to compare the two ranking systems we need to perform a future cost analysis of disbursements occurring to a supplier because of the sequence in which the non-conformities are addressed by each of the ranking systems. The new ranking system would benefit the suppliers most if it will result in a lower future cost of expenditure (sum of rework, return or scrap costs etc.) than the traditional ranking system.

The cost savings or the difference between the future costs of expenditure from the two approaches depends on two factors. The first would be the difference in sequence of disbursements between two approaches (which depends on the ranking of the non-conformities by the two approaches) and second would be the cost components of the disbursements that are accounted by this model. There will be a significant difference in the combinations of sequence by which the same set of non-conformities can be ranked for a supplier using the two approaches if there is more number of non-conformities originating from that supplier. Hence, only those suppliers (from this database) who resulted in more than 8 non-conformities were considered for the future worth cost comparison of the two approaches.

4.4.1. Future worth cost analysis for Brute Manufacturing Ltd.

Brute Manufacturing Ltd accounted for all together 27 non-conforming records in this database. The details of costs and time associated with these non-conformities are shown in Table A-1. The non-conformities are then prioritized or in other words ranked using the traditional approach of calculating the RPN number. Based on this ranking, a future worth economic analysis of disbursements associated with each non-conforming record is carried out. (See Table A-2) The same set of non-conformities is then ranked using the new approach based on Grey theory and DOPP. The results of the

future worth economic analysis by following the new approach of ranking the non-conformities is shown in Table A-3

The results of the economic analysis indicate that the net future worth of expenditure of all the non-conformities when addressed in the sequence given by the traditional approach of ranking the non-conformities would amount to $37,782.968. Similarly, the net future worth of expenditure for the same set of non-conformities when addressed in the sequence given by the new approach of ranking the non-conformities using Grey theory and DOPP would amount to $37,164.779. Hence it can be concluded that Brute Manufacturing Ltd. will save $618.188 if they follow the new approach of ranking the non-conformities.

4.4.2. Future worth cost analysis for Sun Source

Sun Source accounted for all together 16 non-conforming records in this database. The details of costs and time associated with these non-conformities are shown in Table A-4. The non-conformities are then prioritized or in other words ranked using the traditional approach of calculating the RPN number. Based on this ranking, a future worth economic analysis of disbursements associated with each non-conforming record is carried out. (See Table A-5) The same set of non-conformities is then ranked using the new approach based on Grey theory and DOPP. The results of the

future worth economic analysis by following the new approach of ranking the non-conformities is shown in Table A-6

The results of the economic analysis indicate that the net future worth of expenditure of all the non-conformities when addressed in the sequence given by the traditional approach of ranking the non-conformities would amount to $31,129.552. Similarly, the net future worth of expenditure for the same set of non-conformities when addressed in the sequence given by the new approach of ranking the non-conformities using Grey theory and DOPP would amount to $30,931.849. Hence it can be concluded that Sun Source will save $197.703 if they follow the new approach of ranking the non-conformities.

4.4.3. Future worth cost analysis for MTO Metal Products

MTO Metal Products accounted for all together 13 non-conforming records in this database. The details of costs and time associated with these non-conformities are shown in Table A-7. The non-conformities are then prioritized or in other words ranked using the traditional approach of calculating the RPN number. Based on this ranking, a future worth economic analysis of disbursements associated with each non-conforming record is carried out. (Table A-8) The same set of non-conformities is then ranked using the new approach based on Grey theory and DOPP. The results of the

future worth economic analysis by following the new approach of ranking the non-conformities is shown in Table A-9

The results of the economic analysis indicate that the net future worth of expenditure of all the non-conformities when addressed in the sequence given by the traditional approach of ranking the non-conformities would amount to $6,461.436. Similarly, the net future worth of expenditure for the same set of non-conformities when addressed in the sequence given by the new approach of ranking the non-conformities using Grey theory and DOPP would amount to $6,404.840. Hence it can be concluded that MTO Metal Products will save $56.595 if they follow the new approach of ranking the non-conformities.

4.4.4. Future worth cost analysis for Recreation & Ind. Products

Recreation & Ind. Products accounted for all together 11 non-conforming records in this database. The details of costs and time associated with these non-conformities are shown in Table A-10. The non-conformities are then prioritized or in other words ranked using the traditional approach of calculating the RPN number. Based on this ranking, a future worth economic analysis of disbursements associated with each non-conforming record is carried out. (Table A-11) The same set of non-conformities is then ranked using the new approach based on Grey theory and DOPP. The results of the

future worth economic analysis by following the new approach of ranking the non-conformities is shown in Table A-12

The results of the economic analysis indicate that the net future worth of expenditure of all the non-conformities when addressed in the sequence given by the traditional approach of ranking the non-conformities would amount to $10,388.698. Similarly, the net future worth of expenditure for the same set of non-conformities when addressed in the sequence given by the new approach of ranking the non-conformities using Grey theory and DOPP would amount to $10,352.902. Hence it can be concluded that Recreation & Ind. Products will save $35.796 if they follow the new approach of ranking the non-conformities.

4.4.5. Future worth cost analysis for Quality Components Inc

Quality Components Inc accounted for all together 10 non-conforming records in this database. The details of costs and time associated with these non-conformities are shown in Table A-13. The non-conformities are then prioritized or in other words ranked using the traditional approach of calculating the RPN number. Based on this ranking, a future worth economic analysis of disbursements associated with each non-conforming record is carried out. (See Table A-14) The same set of non-conformities is then ranked using the new approach based on Grey theory and DOPP. The results of the

future worth economic analysis by following the new approach of ranking the non-conformities is shown in Table A-15

The results of the economic analysis indicate that the net future worth of expenditure of all the non-conformities when addressed in the sequence given by the traditional approach of ranking the non-conformities would amount to $35,129.944. Similarly, the net future worth of expenditure for the same set of non-conformities when addressed in the sequence given by the new approach of ranking the non-conformities using Grey theory and DOPP would amount to $35,008.012. Hence it can be concluded that Quality Components Inc will save $121.933 if they follow the new approach of ranking the non-conformities.

4.4.6. Future worth cost analysis for CGL Manufacturing Ltd.

CGL Manufacturing Ltd accounted for all together 10 non-conforming records in this database. The details of costs and time associated with these non-conformities are shown in Table A-16. The non-conformities are then prioritized or in other words ranked using the traditional approach of calculating the RPN number. Based on this ranking, a future worth economic analysis of disbursements associated with each non-conforming record is carried out. (See able A-17) The same set of non-conformities is then ranked using the new approach based on Grey theory and DOPP. The results of the

future worth economic analysis by following the new approach of ranking the non-conformities is shown in Table A-18

The results of the economic analysis indicate that the net future worth of expenditure of all the non-conformities when addressed in the sequence given by the traditional approach of ranking the non-conformities would amount to $22,217.694. Similarly, the net future worth of expenditure for the same set of non-conformities when addressed in the sequence given by the new approach of ranking the non-conformities using Grey theory and DOPP would amount to $22,166.308. Hence it can be concluded that CGL Manufacturing Ltd. will save $51.386 if they follow the new approach of ranking the non-conformities.

4.4.7. Future worth cost analysis for D&G Panel Hardness

D&G Panel Hardness accounted for all together 9 non-conforming records in this database. The details of costs and time associated with these non-conformities are shown in Table A-19. The non-conformities are then prioritized or in other words ranked using the traditional approach of calculating the RPN number. Based on this ranking, a future worth economic analysis of disbursements associated with each non-conforming record is carried out. (See Table A-20) The same set of non-conformities is then ranked using the new approach based on Grey theory and DOPP. The results of the

future worth economic analysis by following the new approach of ranking the non-conformities is shown in Table A-21

The results of the economic analysis indicate that the net future worth of expenditure of all the non-conformities when addressed in the sequence given by the traditional approach of ranking the non-conformities would amount to $8,249.458. Similarly, the net future worth of expenditure for the same set of non-conformities when addressed in the sequence given by the new approach of ranking the non-conformities using Grey theory and DOPP would amount to $8,187.992. Hence it can be concluded that D&G Panel Hardness will save $61.467 if they follow the new approach of ranking the non-conformities.

4.4.8. Conclusions from economic analyses

The results from the economic analyses are summarized in the Table 4.2. It is clearly evident that the new approach of ranking the non-conformities will result in cost savings to the supplier.

Hence, we can conclude that the new method of ranking the non-conformities is better than the traditional method of ranking the non-conformities. The question then arises is that how do you quantify this improvement? It can be seen that on an average a supplier will be able to save around $163.295 if the new ranking system is followed. The supplier base of the manufacturing firm consists of about 417 different suppliers. Hence, the

Table 4.2: Summary of results of future worth economic analysis

Name of Vendor	No. of NC Records	Future Cost (Traditional Method)	Future Cost (New Method)	Cost Savings
Brute Manufacturing Ltd.	27	$37,782.968	$37,164.779	$618.188
Sun Source	16	$31,129.552	$30,931.849	$197.703
MTO Metal Products	13	$6,461.436	$6,404.840	$56.595
Recreation & Ind. Product	11	$10,388.698	$10,352.902	$35.796
Quality Components, Inc	10	$35,129.944	$35,008.012	$121.933
CGL Manufacturing Ltd	10	$22,217.694	$22,166.308	$51.386
D&G Panel and Hardness	9	$8,249.458	$8,187.992	$61.467
	96	Average Savings / Vendor =		$163.295

net average savings to the supplier base by using this supplier development information will be around $68,094.175. However, average savings/supplier/non-conformity is around $1.70. Since, there are around 60 suppliers and all together around 201 non-conformities in this database the average saving due to this model alone will be around $20,513.98.

The second factor that will contribute towards a significant difference in future costs between the two approaches is the cost components of non-conformity disbursements. If the disbursements accounts for the all the categories of costs associated with that particular non-conformity then the difference between the future costs from the two approaches would also be significant. However, this model accounts for only the following costs:

1) Direct labor cost: Those labor costs that are conveniently and directly charged on to the supplier who resulted in the non-conformity.

2) Replacement cost: The cost of completely replacing a non-conforming part.

There are certain costs which are not be captured by the manufacturing firm and hence are not accounted by this model. These costs consist of:

1) Overhead costs which includes the indirect labor and material costs.
2) The transportation costs associated with the replacement of a non-conforming part.
3) The opportunity cost due loss in sales because of the non-conformity.

4.5 Conclusion

It can be concluded from the results of the hypothesis testing and the economic analysis that the new approach proposed in this thesis is not only different as compared to the traditional approach but also will result in more cost savings to the supplier. These cost savings will grow into a large number as the number of non-conforming parts from a supplier grows.

CHAPTER 5

Conclusion

5.1 Introduction

This Chapter throws some light on milestones achieved by the research carried out in this thesis, thereby, summarizing all the major conclusions that can be drawn out of it. It also identifies avenues for further research and the improvements that could be made to the current model to enhance its decision and data analysis capability.

5.2 Summary of research

There are several conclusions that can be drawn out of the research carried out in this thesis. One of the first conclusions can be drawn from the results of the economic analysis in Chapter 4, which indicates that the new approach of using Grey theory and DOPP to rank the non-conformities will result in more cost savings to the supplier as compared to the traditional FMEA based approach of ranking the non-conformities.

The proposed information system also provides a method by which the manufacturing firm can easily communicate with its suppliers to ensure that the suppliers can immediately align themselves and react to the quality requirements of the manufacturing firm. This also ensures that the suppliers have a clear understanding of the priorities of the manufacturing firm and the order in which the non-conformities need to be addressed. This fulfills all the requirements of the problem statement as outlined in Chapter 1.

The research also demonstrates how the manufacturing firm can easily integrate different suppliers located at remote sites to reduce the number of defects and the downtime on the lines, with little or no cost to the supplier thereby assisting the suppliers to remain competitive in the market. The use of Visual Basic as a front end in this model ensures that different users who will be accessing the system need not undergo any specific training or have additional expertise to use the algorithm of the model to solve a production or quality issue associated with the manufacturing of a product. This would otherwise be an additional expense for the suppliers while trying to implement this supplier development information system at their site.

Further, the successful implementation of this model will demonstrate how quality control tools could be used in conjunction with an information system to develop business solutions with better decision analysis capabilities to solve problems associated to quality and production. Hence this application of quality control tools to information system could be considered as a first step to the development of several other business office systems or intelligent systems.

5.3 Future work and recommendation

Further research could be carried out to develop an intelligent system that would assist the supplier in narrowing down the choice of a quality control tool that could be used to resolve the problem associated with the reoccurrence of a non-conforming part. The addition of this feature to the information system would ensure that the supplier knows exactly what needs to be done to eliminate the reoccurrence of the non-conforming part from the production system.

Integration of a cost accounting model to capture all the indirect and opportunity costs associated with a non-conformity will definitely add more value to the decision making capabilities of this information system. It will also provide the manufacturing firm with an altogether new dimension to evaluate and quantify the impact of the non-conformity.

The information system could also be linked with the inventory control system of the manufacturing firm so that with the identification of a non-conformity will automatically initiate a request for expedited replenishment of the non-conforming part. As a consequence there will be not only be considerable reduction in the downtime on the lines but it will also assist the material handling and inventory control department to have insight regarding the fluctuations in the demand of the non-conforming part.

Further, this information system could also open avenues for development of a more robust system that will link the supplier evaluation module (SEM) with this information system. Hence the model could not only be used for achieving the objective of zero-defects but also to monitor the performance of suppliers in the supplier base, over a period of time.

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APPENDIX

Table A-1: Details of all the non-conformities (Brute Manufacturing Ltd)

Details of all the non-conformities from Brute Manufacturing Ltd.
Vendor ID: 84979

Sl. No	NCR Number	Unit No.	Part Number	No. of Non-Conforming Parts	Effect	Time to rectify the Non-Conformities (In days)	Cost of the NC to Supplier
1	47597	540	54073	5	Return	3	$1,037.710
2	47598	540	54074	5	Return	4	$2,345.830
3	48017	600	210262	5	Scrap	3	$1,937.710
4	48041	8421	11415441	2	Rework	3	$94.010
5	48054	8411	207296	4	Rework	3	$1,806.860
6	49365	6620	209191	4	Void	4	$2,345.830
7	49366	6620	209458	2	Void	4	$482.380
8	49367	6620	202552	2	Void	9	$592.570
9	49397	600	210262	4	Void	4	$2,345.830
10	50219	540	54077	4	Void	4	$49.380
11	50220	540	206983	20	Void	5	$571.470
12	50221	540	207587	2	Void	7	$900.750
13	50319	8411	207571	1	Scrap	9	$236.720
14	50480	540	54080	4	Void	3	$1,937.710
15	50482	8421	207315	3	Rework	6	$226.270
16	50483	8411	207314	3	Rework	3	$53.240
17	50499	6620	209184	2	Rework	3	$998.710
18	60151	8411	11415604	1	Void	3	$495.070
19	60161	6620	207594	1	Rework	4	$4,852.380
20	60212	600	60029	18	Return	3	$8,865.780
21	60225	540	202552	14	Rework	6	$39.370
22	60668	8411	208766	6	Rework	4	$2,345.830
23	60670	8411	207324	6	Rework	8	$1,983.500
24	60688	540	54072	1	Rework	4	$48.380
25	60689	8411	11416032	1	Rework	3	$72.600
26	61019	6620	207751	1	Rework	3	$18.710
27	61032	6620	208808	1	Rework	4	$452.380

Table A-2: Traditional approach of ranking non-conformities and economic analysis (Brute Manufacturing Ltd)

Traditional approach of ranking non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
5	50220	5.00	$571.470	0.01404	0.00000	0.33427	$586.362
8	60212	3.00	$8,865.780	0.00843	0.01404	0.32022	$9,086.990
20	60225	6.00	$39.370	0.01685	0.02247	0.31180	$40.326
22	50480	3.00	$1,937.710	0.00843	0.03933	0.29494	$1,982.197
27	48054	3.00	$1,806.860	0.00843	0.04775	0.28652	$1,847.145
34	49397	4.00	$2,345.830	0.01124	0.05618	0.27809	$2,396.577
36	47597	3.00	$1,037.710	0.00843	0.06742	0.26685	$1,059.242
41	47598	4.00	$2,345.830	0.01124	0.07584	0.25843	$2,392.953
52	60670	8.00	$1,983.500	0.02247	0.08708	0.24719	$2,021.595
59	50483	3.00	$53.240	0.00843	0.10955	0.22472	$54.169
61	48017	3.00	$1,937.710	0.00843	0.11798	0.21629	$1,970.235
70	61032	4.00	$452.380	0.01124	0.12640	0.20787	$459.675
74	50499	3.00	$998.710	0.00843	0.13764	0.19663	$1,013.938
97	48041	3.00	$94.010	0.00843	0.14607	0.18820	$95.382
98	60668	4.00	$2,345.830	0.01124	0.15449	0.17978	$2,378.512
99	49366	4.00	$482.380	0.01124	0.16573	0.16854	$488.678
123	50221	7.00	$900.750	0.01966	0.17697	0.15730	$911.721
133	50482	6.00	$226.270	0.01685	0.19663	0.13764	$228.680
134	60688	4.00	$48.380	0.01124	0.21348	0.12079	$48.832
135	49365	4.00	$2,345.830	0.01124	0.22472	0.10955	$2,365.692
138	50219	4.00	$49.380	0.01124	0.23596	0.09831	$49.755
144	60151	3.00	$495.070	0.00843	0.24719	0.08708	$498.399
148	60161	4.00	$4,852.380	0.01124	0.25562	0.07865	$4,881.841
154	49367	9.00	$592.570	0.02528	0.26685	0.06742	$595.652
155	60689	3.00	$72.600	0.00843	0.29213	0.04213	$72.836
156	50319	9.00	$236.720	0.02528	0.32584	0.00843	$236.874
185	61019	3.00	$18.710	0.00843	0.33427	0.00000	$18.710
					0.33427		**$37,782.968**

Table A-3: Grey theory and DOPP based approach of ranking of non-conformities and economic analysis (Brute Manufacturing Ltd.)

Grey theory & DOPP based ranking of non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
10	50319	9.00	$236.720	0.02528	0.00000	0.33427	$242.889
17	61019	3.00	$18.710	0.00843	0.02528	0.30899	$19.160
29	49366	4.00	$482.380	0.01124	0.03371	0.30056	$493.668
32	60225	6.00	$39.370	0.01685	0.04494	0.28933	$40.256
34	60212	3.00	$8,865.780	0.00843	0.06180	0.27247	$9,053.656
35	50499	3.00	$998.710	0.00843	0.07022	0.26404	$1,019.213
38	50482	6.00	$226.270	0.01685	0.07865	0.25562	$230.765
45	48017	3.00	$1,937.710	0.00843	0.09551	0.23876	$1,973.646
57	48041	3.00	$94.010	0.00843	0.10393	0.23034	$95.691
58	61032	4.00	$4.000	0.01124	0.11236	0.22191	$4.069
66	47597	3.00	$1,037.710	0.00843	0.12360	0.21067	$1,054.672
70	48054	3.00	$1,806.860	0.00843	0.13202	0.20225	$1,835.204
71	47598	4.00	$2,345.830	0.01124	0.14045	0.19382	$2,381.084
84	50219	4.00	$49.380	0.01124	0.15169	0.18258	$50.079
104	60688	4.00	$48.380	0.01124	0.16292	0.17135	$49.022
106	50221	7.00	$900.750	0.01966	0.17416	0.16011	$911.918
118	60689	3.00	$72.600	0.00843	0.19382	0.14045	$73.389
121	60668	4.00	$2,345.830	0.01124	0.20225	0.13202	$2,369.787
123	49365	4.00	$2,345.830	0.01124	0.21348	0.12079	$2,367.738
125	50220	5.00	$571.470	0.01404	0.22472	0.10955	$576.309
126	60161	4.00	$4,852.380	0.01124	0.23876	0.09551	$4,888.177
142	60151	3.00	$495.070	0.00843	0.25000	0.08427	$498.291
144	49367	9.00	$592.570	0.02528	0.25843	0.07584	$596.039
150	49397	4.00	$2,345.830	0.01124	0.28371	0.05056	$2,354.976
160	50480	3.00	$1,937.710	0.00843	0.29494	0.03933	$1,943.583
168	60670	8.00	$1,983.500	0.02247	0.30337	0.03090	$1,988.222
169	50483	3.00	$53.240	0.00843	0.32584	0.00843	$53.275
					0.33427		**$37,164.779**

Table A-4: Details of all the non-conformities (Sun source)

Details of all the non-conformities from Sun Source
Vendor ID: 84801

Sl. No	NCR Number	Unit No.	Part Number	No. of Non-Conforming Parts	Effect	Time to rectify the Non-Conformities (In days)	Cost of the NC to Supplier
1	50309	8411	11415383	12	Void	3.00	$3,394.010
2	50308	8421	11415384	12	Void	3.00	$4,795.070
3	60186	540	11415852	3	Rework	3.00	$72.600
4	49389	6620	11415926	1	Return	9.00	$1,592.570
5	61045	540	13	1	Void	6.00	$39.370
6	60174	6620	203073	4	Return	5.00	$2,681.470
7	48058	6620	203075	1	Return	3.00	$1,806.860
8	61029	6620	203084	1	Scrap	3.00	$53.240
9	61025	6620	204219	1	Void	12.00	$226.270
10	60769	8421	206283	1	Return	12.00	$1,983.500
11	50330	6620	208108	1	Return	14.00	$1,996.720
12	50496	8411	208217	2	Return	14.00	$2,601.750
13	50317	8411	208769	1	Return	4.00	$4,852.380
14	47571	8421	209394	1	Rework	3.00	$1,937.710
15	60683	540	537	5	Return	4.00	$2,345.830
16	60237	6620	84712	1	Return	3.00	$283.550

Table A-5: Traditional approach of ranking non-conformities and economic analysis (Sun Source)

Traditional approach of ranking non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
14	50308	3.00	$4,795.070	0.00843	0.00000	0.28371	$4,900.919
24	50309	3.00	$3,394.010	0.00843	0.00843	0.27528	$3,466.682
26	60174	5.00	$2,681.470	0.01404	0.01685	0.26685	$2,737.110
31	60186	3.00	$72.600	0.00843	0.03090	0.25281	$74.026
78	50317	4.00	$4,852.380	0.01124	0.03933	0.24438	$4,944.507
87	61045	6.00	$39.370	0.01685	0.05056	0.23315	$40.083
90	60769	12.00	$1,983.500	0.03371	0.06742	0.21629	$2,016.794
92	50330	14.00	$1,996.720	0.03933	0.10112	0.18258	$2,024.976
115	61029	3.00	$53.240	0.00843	0.14045	0.14326	$53.830
116	60683	4.00	$2,345.830	0.01124	0.14888	0.13483	$2,370.299
126	60237	3.00	$283.550	0.00843	0.16011	0.12360	$286.260
131	50496	14.00	$2,601.750	0.03933	0.16854	0.11517	$2,624.913
150	48058	3.00	$1,806.860	0.00843	0.20787	0.07584	$1,817.437
157	49389	9.00	$1,592.570	0.02528	0.21629	0.06742	$1,600.854
162	47571	3.00	$1,937.710	0.00843	0.24157	0.04213	$1,944.004
174	61025	12.00	$226.270	0.03371	0.25000	0.03371	$226.858
					0.28371		**$31,129.552**

Table A-6: Grey theory and DOPP based ranking of non-conformities and economic analysis (Sun Source)

Grey theory & DOPP based ranking of non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
5	50317	4.00	$4,852.380	0.01124	0.00000	0.28371	$4,959.494
6	60186	3.00	$72.600	0.00843	0.01124	0.27247	$74.138
18	61045	6.00	$39.370	0.01685	0.01966	0.26404	$40.178
54	50330	14.00	$1,996.720	0.03933	0.03652	0.24719	$2,035.069
55	61029	3.00	$53.240	0.00843	0.07584	0.20787	$54.099
68	60769	12.00	$1,983.500	0.03371	0.08427	0.19944	$2,014.180
73	60237	3.00	$283.550	0.00843	0.11798	0.16573	$287.190
93	61025	12.00	$226.270	0.03371	0.12640	0.15730	$229.026
96	60174	5.00	$2,681.470	0.01404	0.16011	0.12360	$2,707.098
101	50496	14.00	$2,601.750	0.03933	0.17416	0.10955	$2,623.778
111	49389	9.00	$1,592.570	0.02528	0.21348	0.07022	$1,601.200
117	48058	3.00	$1,806.860	0.00843	0.23876	0.04494	$1,813.121
130	60683	4.00	$2,345.830	0.01124	0.24719	0.03652	$2,352.432
141	50308	3.00	$4,795.070	0.00843	0.25843	0.02528	$4,804.409
148	47571	3.00	$1,937.710	0.00843	0.26685	0.01685	$1,940.225
174	50309	3.00	$3,394.010	0.00843	0.27528	0.00843	$3,396.212
					0.28371		**$30,931.849**

Table A-7: Details of all the non-conformities (MTO Metal Products)

Details of all the non-conformities from MTO Metal Product
Vendor ID: 84801

Sl. No	NCR Number	Unit No.	Part Number	No. of Non-Conforming Parts	Effect	Time to rectify the Non-Conformities (In days)	Cost of the NC to Supplier
1	47567	8411	54313	2	Rework	3	$33.180
2	48035	6620	205061	1	Void	4	$30.740
3	48081	540	54312	2	Rework	5	$33.180
4	48082	540	54313	2	Rework	5	$33.180
5	49379	8421	11415426	2	Void	28	$51.500
6	49399	540	2147	4	Scrap	14	$2,988.670
7	50323	6620	11415021	1	Scrap	2	$143.560
8	50460	540	873	3	Rework	7	$443.550
9	50491	8421	206035	4	Rework	6	$57.200
10	60695	8411	11415426	1	Rework	5	$58.500
11	61010	600	208864	4	Return	4	$2,384.390
12	61022	8411	206035	15	Rework	5	$94.930
13	61047	6620	204216	89	Void	7	$10.620

Table A-8: Traditional approach of ranking non-conformities and economic analysis (MTO Metal Products)

Traditional approach of ranking non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
1	61047	7.00	$10.620	0.01966	0.00000	0.26685	$10.840
6	61022	5.00	$94.930	0.01404	0.01966	0.24719	$96.753
29	50491	6.00	$57.200	0.01685	0.03371	0.23315	$58.236
45	61010	4.00	$2,384.390	0.01124	0.05056	0.21629	$2,424.413
63	50323	2.00	$143.560	0.00562	0.06180	0.20506	$145.844
71	49399	14.00	$2,988.670	0.03933	0.06742	0.19944	$3,034.897
76	50460	7.00	$443.550	0.01966	0.10674	0.16011	$449.049
83	49379	28.00	$51.500	0.07865	0.12640	0.14045	$52.060
91	60695	5.00	$58.500	0.01404	0.20506	0.06180	$58.779
93	48082	5.00	$33.180	0.01404	0.21910	0.04775	$33.302
139	48081	5.00	$33.180	0.01404	0.23315	0.03371	$33.266
143	47567	3.00	$33.180	0.00843	0.24719	0.01966	$33.230
191	48035	4.00	$30.740	0.01124	0.25562	0.01124	$30.767
					0.26685		**$6,461.436**

Table A-9: Grey theory and DOPP based ranking of non-conformities and economic analysis (MTO Metal Products)

Grey theory & DOPP based ranking of non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
1	61047	7.00	$10.620	0.01966	0.00000	0.26685	$10.840
7	61022	5.00	$94.930	0.01404	0.01966	0.24719	$96.753
15	50491	6.00	$57.200	0.01685	0.03371	0.23315	$58.236
16	50323	2.00	$143.560	0.00562	0.05056	0.21629	$145.970
21	60695	5.00	$58.500	0.01404	0.05618	0.21067	$59.456
59	49379	28.00	$51.500	0.07865	0.07022	0.19663	$52.285
65	50460	7.00	$443.550	0.01966	0.14888	0.11798	$447.596
67	61010	4.00	$2,384.390	0.01124	0.16854	0.09831	$2,402.500
86	48082	5.00	$33.180	0.01404	0.17978	0.08708	$33.403
145	47567	3.00	$33.180	0.00843	0.19382	0.07303	$33.367
162	48081	5.00	$33.180	0.01404	0.20225	0.06461	$33.345
175	49399	14.00	$2,988.670	0.03933	0.21629	0.05056	$3,000.322
187	48035	4.00	$30.740	0.01124	0.25562	0.01124	$30.767
					0.26685		**$6,404.840**

Table A-10: Details of all the non-conformities (Recreation & Ind. Product)

Details of all the non-conformities from Recreation & Ind. Product
Vendor ID: 84801

Sl. No	NCR Number	Unit No.	Part Number	No. of Non-Conforming Parts	Effect	Time to rectify the Non-Conformities (In days)	Cost of the NC to Supplier
1	60176	540	2676	6	Rework	13	$68.760
2	60197	6620	207266	27	Scrap	4	$3,423.650
3	60655	6620	204067	6	Rework	3	$26.820
4	60661	6620	207899	1	Rework	4	$26.970
5	60671	6620	208736	6	Rework	7	$195.180
6	60672	6620	208735	5	Rework	6	$95.180
7	60673	600	2008	6	Rework	5	$2,162.860
8	60789	540	2596	9	Rework	15	$2,230.970
9	61012	8411	208567	2	Rework	4	$20.920
10	61015	6620	204209	6	Rework	3	$42.230
11	61027	6620	210467	2	Rework	8	$1,993.620

Table A-11: Traditional approach of ranking non-conformities and economic analysis (Recreation & Ind. Product)

Traditional approach of ranking non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
13	60197	4.00	$3,423.650	0.01124	0.00000	0.20225	$3,477.357
15	61015	3.00	$42.230	0.00843	0.01124	0.19101	$42.855
18	60176	13.00	$68.760	0.03652	0.01966	0.18258	$69.733
38	60671	7.00	$195.180	0.01966	0.05618	0.14607	$197.386
40	60672	6.00	$95.180	0.01685	0.07584	0.12640	$96.110
43	60673	5.00	$2,162.860	0.01404	0.09270	0.10955	$2,181.172
50	60655	3.00	$26.820	0.00843	0.10674	0.09551	$27.018
85	61027	8.00	$1,993.620	0.02247	0.11517	0.08708	$2,007.025
103	60789	15.00	$2,230.970	0.04213	0.13764	0.06461	$2,242.090
127	61012	4.00	$20.920	0.01124	0.17978	0.02247	$20.956
137	60661	4.00	$26.970	0.01124	0.19101	0.01124	$26.993
					0.20225		**$10,388.698**

Table A-12: Grey theory and DOPP based ranking of non-conformities and economic analysis (Recreation & Ind. Product)

Grey theory & DOPP based ranking of non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
13	61015	3.00	$42.230	0.00843	0.00000	0.20225	$42.892
49	60176	13.00	$68.760	0.03652	0.00843	0.19382	$69.793
50	60671	7.00	$195.180	0.01966	0.04494	0.15730	$197.557
74	60672	6.00	$95.180	0.01685	0.06461	0.13764	$96.194
95	60655	3.00	$26.820	0.00843	0.08146	0.12079	$27.070
129	60197	4.00	$3,423.650	0.01124	0.08989	0.11236	$3,453.384
136	60661	4.00	$26.970	0.01124	0.10112	0.10112	$27.181
137	61012	4.00	$20.920	0.01124	0.11236	0.08989	$21.065
139	60673	5.00	$2,162.860	0.01404	0.12360	0.07865	$2,175.992
182	61027	8.00	$1,993.620	0.02247	0.13764	0.06461	$2,003.557
193	60789	15.00	$2,230.970	0.04213	0.16011	0.04213	$2,238.216
					0.20225		**$10,352.902**

Table A-13: Details of all the non-conformities (Quality Components, Inc)

Details of all the non-conformity from Quality Components, Inc
Vendor ID: 85303

Sl. No	NCR Number	Unit No.	Part Number	No. of Non-Conforming Parts	Effect	Time to rectify the Non-Conformities (In days)	Cost of the NC to Supplier
1	48038	8411	211633	1	Return	3	$19,117.820
2	48070	8421	210908	3	Rework	7	$1,274.920
3	48093	540	210142	1	Return	4	$4,909.420
4	49368	540	835	2	Void	26	$450.000
5	49385	8411	11415591	4	Void	6	$2,022.640
6	50440	8411	210907	1	Return	20	$75.540
7	50485	540	209101	6	Rework	8	$1,421.070
8	60193	6620	204918	1	Rework	4	$3,070.760
9	60686	6620	206449	4	Rework	3	$432.840
10	60691	6620	208716	1	Rework	4	$1,847.710

Table A-14: Traditional approach of ranking non-conformities and economic analysis (Quality Components, Inc)

Traditional approach of ranking non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
42	60686	3.00	$432.840	0.00843	0.00000	0.23876	$440.867
62	48038	3.00	$19,117.820	0.00843	0.00843	0.23034	$19,459.743
75	60691	4.00	$1,847.710	0.01124	0.01685	0.22191	$1,879.537
86	60193	4.00	$3,070.760	0.01124	0.02809	0.21067	$3,120.954
88	49385	6.00	$2,022.640	0.01685	0.03933	0.19944	$2,053.925
96	48070	7.00	$1,274.920	0.01966	0.05618	0.18258	$1,292.961
105	50485	8.00	$1,421.070	0.02247	0.07584	0.16292	$1,439.000
110	50440	20.00	$75.540	0.05618	0.09831	0.14045	$76.361
176	49368	26.00	$450.000	0.07303	0.15449	0.08427	$452.928
199	48093	4.00	$4,909.420	0.01124	0.22753	0.01124	$4,913.667
					0.23876		**$35,129.944**

Table A-15: Grey theory and DOPP based ranking of non-conformities and economic analysis (Quality Components, Inc)

Grey theory & DOPP based ranking of non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
11	50440	20.00	$75.540	0.05618	0.00000	0.23876	$76.941
39	48038	3.00	$19,117.820	0.00843	0.05618	0.18258	$19,388.358
43	60686	3.00	$432.840	0.00843	0.06461	0.17416	$438.681
48	48070	7.00	$1,274.920	0.01966	0.07303	0.16573	$1,291.285
60	60691	4.00	$1,847.710	0.01124	0.09270	0.14607	$1,868.598
122	60193	4.00	$3,070.760	0.01124	0.10393	0.13483	$3,102.790
132	49385	6.00	$2,022.640	0.01685	0.11517	0.12360	$2,041.971
152	50485	8.00	$1,421.070	0.02247	0.13202	0.10674	$1,432.792
185	49368	26.00	$450.000	0.07303	0.15449	0.08427	$452.928
199	48093	4.00	$4,909.420	0.01124	0.22753	0.01124	$4,913.667
					0.23876		**$35,008.012**

Table A-16: Details of all the non-conformities (CGL Manufacturing Ltd)

Details of all the non-conformity from CGL Manufacturing Ltd
Vendor ID: 84997

Sl. No	NCR Number	Unit No.	Part Number	No. of Non-Conforming Parts	Effect	Time to rectify the Non-Conformities (In days)	Cost of the NC to Supplier
1	48049	8411	11415633	1	Rework	20	$76.340
2	48068	8421	211121	1	Rework	3	$2,943.190
3	50324	6620	210139	1	Scrap	4	$3,117.390
4	50325	6620	210140	1	Scrap	4	$105.010
5	50430	8421	11415634	3	Rework	9	$5,050.650
6	60685	8411	8417	1	Rework	3	$75.860
7	60692	6620	208865	1	Rework	7	$475.850
8	60774	8411	11415596	1	Rework	3	$3,639.270
9	61020	6620	11415894	14	Rework	13	$4,223.590
10	61035	8411	205635	2	Rework	9	$2,355.890

Table A-17: Traditional approach of ranking non-conformities and economic analysis (CGL Manufacturing Ltd)

Traditional approach of ranking non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
46	61020	13.00	$4,223.590	0.03652	0.00000	0.21067	$4,292.628
108	48049	20.00	$76.340	0.05618	0.03652	0.17416	$77.370
119	60685	3.00	$75.860	0.00843	0.09270	0.11798	$76.552
128	50325	4.00	$105.010	0.01124	0.10112	0.10955	$105.899
168	50430	9.00	$5,050.650	0.02528	0.11236	0.09831	$5,089.010
171	60774	3.00	$3,639.270	0.00843	0.13764	0.07303	$3,659.783
172	61035	9.00	$2,355.890	0.02528	0.14607	0.06461	$2,367.633
181	50324	4.00	$3,117.390	0.01124	0.17135	0.03933	$3,126.839
184	60692	7.00	$475.850	0.01966	0.18258	0.02809	$476.880
197	48068	3.00	$2,943.190	0.00843	0.20225	0.00843	$2,945.099
					0.21067		**$22,217.694**

Table A-18: Grey theory and DOPP based ranking of non-conformities and economic analysis (CGL Manufacturing Ltd)

Grey theory & DOPP based ranking of non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
52	48049	20.00	$76.340	0.05618	0.00000	0.21067	$77.588
53	60685	3.00	$75.860	0.00843	0.05618	0.15449	$76.767
72	50325	4.00	$105.010	0.01124	0.06461	0.14607	$106.197
114	61020	13.00	$4,223.590	0.03652	0.07584	0.13483	$4,267.645
158	61035	9.00	$2,355.890	0.02528	0.11236	0.09831	$2,373.783
163	60692	7.00	$475.850	0.01966	0.13764	0.07303	$478.532
172	50430	9.00	$5,050.650	0.02528	0.15730	0.05337	$5,071.438
173	60774	3.00	$3,639.270	0.00843	0.18258	0.02809	$3,647.146
179	50324	4.00	$3,117.390	0.01124	0.19101	0.01966	$3,122.111
189	48068	3.00	$2,943.190	0.00843	0.20225	0.00843	$2,945.099
					0.21067		**$22,166.308**

Table A-19: Details of all the non-conformities (D&G Panel Hardness)

Details of all the non-conformity from D&G Panel Hardness
Vendor ID: 23501

Sl. No	NCR Number	Unit No.	Part Number	No. of Non-Conforming Parts	Effect	Time to rectify the Non-Conformities (In days)	Cost of the NC to Supplier
1	47577	8411	11415555	6	Return	4	$3,394.010
2	48062	8421	11415059	1	Return	12	$72.600
3	48064	8411	11415108	2	Return	8	$681.470
4	48074	8421	210575	1	Scrap	4	$183.500
5	50224	8411	11415546	8	Rework	8	$53.240
6	50301	8421	11415555	1	Rework	11	$483.550
7	50427	6620	11415743	2	Use As Is	20	$2,475.850
8	60199	8411	207443	1	Rework	8	$119.730
9	60795	8411	206161	1	Return	18	$654.370

Table A-20: Traditional approach of ranking non-conformities and economic analysis (D&G Panel Hardness)

Traditional approach of ranking non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
44	47577	4.00	$3,394.010	0.01124	0.00000	0.26124	$3,462.937
56	50224	8.00	$53.240	0.02247	0.01124	0.25000	$54.274
120	48064	8.00	$681.470	0.02247	0.03371	0.22753	$693.508
140	50427	20.00	$2,475.850	0.05618	0.05618	0.20506	$2,515.232
151	48062	12.00	$72.600	0.03371	0.11236	0.14888	$73.437
158	60795	18.00	$654.370	0.05056	0.14607	0.11517	$660.196
165	50301	11.00	$483.550	0.03090	0.19663	0.06461	$485.960
182	48074	4.00	$183.500	0.01124	0.22753	0.03371	$183.977
192	60199	8.00	$119.730	0.02247	0.23876	0.02247	$119.937
					0.26124		**$8,249.458**

Table A-21: Grey theory and DOPP based ranking of non-conformities and economic analysis (D&G Panel Hardness)

Grey theory & DOPP based ranking of non-conformities and economic analysis

Rank of the NC	NCR No.	Time to Rectify the Non-Conformities (In days)	Cost of the NC to Supplier	Time to Rectify the Non-Conformities (In Years)	Cumulative Time to Rectify the NC (In years)	N	Future Worth of the Expenditure (F/P, i%, N)
81	50224	8.00	$53.240	0.02247	0.00000	0.26124	$54.321
88	48064	8.00	$681.470	0.02247	0.02247	0.23876	$694.108
89	48062	12.00	$72.600	0.03371	0.04494	0.21629	$73.819
127	60795	18.00	$654.370	0.05056	0.07865	0.18258	$663.630
140	50427	20.00	$2,475.850	0.05618	0.12921	0.13202	$2,501.134
151	48074	4.00	$183.500	0.01124	0.18539	0.07584	$184.574
170	47577	4.00	$3,394.010	0.01124	0.19663	0.06461	$3,410.928
178	50301	11.00	$483.550	0.03090	0.20787	0.05337	$485.540
191	60199	8.00	$119.730	0.02247	0.23876	0.02247	$119.937
					0.26124		**$8,187.992**

Table A- 22: RPN number calculation traditional approach

NCRNumber	Occurence	Severity	Detection	Traditional_RPN	Ranking_TraditionalRPN
61047	0.89	6	8	42.72	1
50497	0.7	6	8	33.6	2
60669	0.37	6	9	19.98	3
61018	0.6	3	8	14.4	4
50220	0.2	9	6	10.8	5
61022	0.15	7	9	9.45	6
60697	0.38	4	6	9.12	7
60212	0.18	7	5	6.3	8
60206	0.1	6	9	5.4	9
48099	0.26	4	5	5.2	10
60657	0.25	3	6	4.5	11
50321	0.07	8	8	4.48	12
60197	0.27	2	7	3.78	13
50308	0.12	5	6	3.6	14
61015	0.06	6	9	3.24	15
49380	0.06	6	9	3.24	16
49395	0.1	4	8	3.2	17
60176	0.06	8	6	2.88	18
49386	0.04	7	10	2.8	19
60225	0.14	2	10	2.8	20
60160	0.06	6	7	2.52	21
50480	0.04	9	7	2.52	22
48057	0.05	8	6	2.4	23
50309	0.12	5	4	2.4	24
60169	0.12	4	5	2.4	25
60174	0.04	7	8	2.24	26
48054	0.04	7	8	2.24	27
61034	0.06	6	6	2.16	28
50491	0.04	6	9	2.16	29
60652	0.03	10	7	2.1	30
60186	0.03	7	10	2.1	31
61006	0.2	5	2	2	32
50435	0.11	3	6	1.98	33
49397	0.04	7	7	1.96	34
60801	0.04	8	6	1.92	35
47597	0.05	4	9	1.8	36
60213	0.1	9	2	1.8	37
60671	0.06	7	4	1.68	38
50228	0.09	3	6	1.62	39

Table A-22: Continued					
NCRNumber	**Occurence**	**Severity**	**Detection**	**Traditional_RPN**	**Ranking_TraditionalRPN**
60672	0.05	8	4	1.6	40
47598	0.05	4	8	1.6	41
60686	0.04	5	8	1.6	42
60673	0.06	4	6	1.44	43
47577	0.06	3	8	1.44	44
61010	0.04	5	7	1.4	45
61020	0.14	2	5	1.4	46
60662	0.1	2	7	1.4	47
49377	0.14	5	2	1.4	48
50329	0.02	9	7	1.26	49
60655	0.06	3	7	1.26	50
60814	0.06	4	5	1.2	51
60670	0.06	4	5	1.2	52
50304	0.02	7	8	1.12	53
49400	0.02	8	7	1.12	54
60687	0.02	8	7	1.12	55
50224	0.08	2	7	1.12	56
50303	0.02	7	7	0.98	57
61017	0.03	4	8	0.96	58
50483	0.03	8	4	0.96	59
60194	0.02	6	8	0.96	60
48017	0.05	3	6	0.9	61
48038	0.01	10	9	0.9	62
50323	0.01	9	10	0.9	63
60656	0.03	10	3	0.9	64
60653	0.02	7	6	0.84	65
50310	0.03	4	7	0.84	66
61037	0.02	7	6	0.84	67
47569	0.02	7	6	0.84	68
60191	0.01	9	9	0.81	69
61032	0.01	9	9	0.81	70
49399	0.04	4	5	0.8	71
60658	0.02	5	8	0.8	72
60227	0.05	8	2	0.8	73
50499	0.02	8	5	0.8	74
60691	0.01	8	9	0.72	75
50460	0.03	3	8	0.72	76
50326	0.01	8	9	0.72	77
50317	0.01	9	8	0.72	78

Table A-22: Continued					
NCRNumber	**Occurence**	**Severity**	**Detection**	**Traditional_RPN**	**Ranking_TraditionalRPN**
60154	0.01	9	8	0.72	79
49383	0.01	10	7	0.7	80
60185	0.01	7	10	0.7	81
48077	0.01	7	10	0.7	82
49379	0.02	7	5	0.7	83
61038	0.01	8	8	0.64	84
61027	0.02	4	8	0.64	85
60193	0.01	8	8	0.64	86
61045	0.01	8	8	0.64	87
49385	0.04	2	8	0.64	88
49382	0.04	4	4	0.64	89
60769	0.01	8	8	0.64	90
60695	0.01	7	9	0.63	91
50330	0.01	10	6	0.6	92
48082	0.02	5	6	0.6	93
60793	0.01	6	10	0.6	94
48076	0.02	6	5	0.6	95
48070	0.03	5	4	0.6	96
48041	0.02	5	6	0.6	97
60668	0.06	5	2	0.6	98
49366	0.02	7	4	0.56	99
50322	0.02	4	7	0.56	100
48084	0.01	8	7	0.56	101
60838	0.01	7	8	0.56	102
60789	0.09	3	2	0.54	103
60812	0.03	9	2	0.54	104
50485	0.06	3	3	0.54	105
50487	0.25	2	1	0.5	106
60175	0.01	7	7	0.49	107
48049	0.01	7	7	0.49	108
61004	0.01	7	7	0.49	109
50440	0.01	8	6	0.48	110
61044	0.01	8	6	0.48	111
60796	0.04	2	6	0.48	112
50492	0.02	4	6	0.48	113
60836	0.02	4	6	0.48	114
61029	0.01	6	8	0.48	115
60683	0.05	1	9	0.45	116
61043	0.01	5	9	0.45	117

Table A-22: Continued					
NCRNumber	**Occurence**	**Severity**	**Detection**	**Traditional_RPN**	**Ranking_TraditionalRPN**
60168	0.03	3	5	0.45	118
60685	0.01	7	6	0.42	119
48064	0.02	7	3	0.42	120
48059	0.01	6	7	0.42	121
61028	0.01	7	6	0.42	122
50221	0.02	3	7	0.42	123
60162	0.05	2	4	0.4	124
60180	0.01	8	5	0.4	125
60237	0.01	5	8	0.4	126
61012	0.02	4	5	0.4	127
50325	0.01	4	9	0.36	128
47570	0.01	4	9	0.36	129
50312	0.01	6	6	0.36	130
50496	0.02	3	6	0.36	131
60236	0.01	6	6	0.36	132
50482	0.03	2	6	0.36	133
60688	0.01	4	9	0.36	134
49365	0.04	3	3	0.36	135
48075	0.03	4	3	0.36	136
60661	0.01	5	7	0.35	137
50219	0.04	4	2	0.32	138
48081	0.02	4	4	0.32	139
50427	0.02	4	4	0.32	140
48095	0.02	3	5	0.3	141
50434	0.02	3	5	0.3	142
47567	0.02	5	3	0.3	143
60151	0.01	6	5	0.3	144
48031	0.01	10	3	0.3	145
50500	0.02	3	5	0.3	146
60243	0.01	4	7	0.28	147
60161	0.01	7	4	0.28	148
47568	0.02	7	2	0.28	149
48058	0.01	9	3	0.27	150
48062	0.01	9	3	0.27	151
60674	0.01	6	4	0.24	152
61007	0.01	4	6	0.24	153
49367	0.02	2	6	0.24	154
60689	0.01	3	8	0.24	155
50319	0.01	3	8	0.24	156

Table A-22: Continued					
NCRNumber	**Occurence**	**Severity**	**Detection**	**Traditional_RPN**	**Ranking_TraditionalRPN**
49389	0.01	8	3	0.24	157
60795	0.01	8	3	0.24	158
49369	0.02	3	4	0.24	159
50318	0.01	3	8	0.24	160
48085	0.01	3	7	0.21	161
47571	0.01	7	3	0.21	162
60184	0.01	3	7	0.21	163
60791	0.01	4	5	0.2	164
50301	0.01	4	5	0.2	165
50438	0.01	5	4	0.2	166
60781	0.01	3	6	0.18	167
50430	0.03	3	2	0.18	168
60179	0.01	6	3	0.18	169
61041	0.01	2	8	0.16	170
60774	0.01	2	8	0.16	171
61035	0.02	1	8	0.16	172
61023	0.01	3	5	0.15	173
61025	0.01	3	5	0.15	174
61024	0.01	5	3	0.15	175
49368	0.02	1	7	0.14	176
60242	0.01	7	2	0.14	177
60235	0.01	3	4	0.12	178
61003	0.01	3	4	0.12	179
50431	0.02	5	1	0.1	180
50324	0.01	5	2	0.1	181
48074	0.01	1	10	0.1	182
61033	0.01	4	2	0.08	183
60692	0.01	4	2	0.08	184
61019	0.01	1	7	0.07	185
60152	0.01	1	6	0.06	186
60699	0.01	2	3	0.06	187
50327	0.02	3	1	0.06	188
60792	0.02	3	1	0.06	189
60234	0.01	1	6	0.06	190
48035	0.01	1	6	0.06	191
60199	0.01	1	6	0.06	192
61021	0.01	5	1	0.05	193
48060	0.01	1	5	0.05	194
60677	0.01	1	5	0.05	195

Table A-22: Continued					
NCRNumber	**Occurence**	**Severity**	**Detection**	**Traditional_RPN**	**Ranking_TraditionalRPN**
60682	0.03	1	1	0.03	196
48068	0.01	1	3	0.03	197
61040	0.02	1	1	0.02	198
48093	0.01	1	2	0.02	199
47578	0.01	1	1	0.01	200
61005	0.01	1	1	0.01	201

Table A- 23 : Calculation of RPN using Grey theory and DOPP

NCR	Comparative Series				Diffrence Series				Relational Series				Degree of
Number	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	Relation
60653	0.02	7	6	3	0.02	6	5	2	0.99558	0.42857	0.47368	0.69231	0.647535
49400	0.02	8	7	4	0.02	7	6	3	0.99558	0.39130	0.42857	0.60000	0.603863
60225	0.14	2	10	4	0.14	1	9	3	0.96983	0.81818	0.33333	0.60000	0.680336
49367	0.02	2	6	4	0.02	1	5	3	0.99558	0.81818	0.47368	0.60000	0.721860
61007	0.01	4	6	14	0.01	3	5	13	0.99778	0.60000	0.47368	0.25714	0.582152
60674	0.01	6	4	11	0.01	5	3	10	0.99778	0.47368	0.60000	0.31034	0.595453
49386	0.04	7	10	9	0.04	6	9	8	0.99119	0.42857	0.33333	0.36000	0.528274
61003	0.01	3	4	6	0.01	2	3	5	0.99778	0.69231	0.60000	0.47368	0.690944
60687	0.02	8	7	8	0.02	7	6	7	0.99558	0.39130	0.42857	0.39130	0.551689
60175	0.01	7	7	8	0.01	6	6	7	0.99778	0.42857	0.42857	0.39130	0.561557
60657	0.25	3	6	5	0.25	2	5	4	0.94737	0.69231	0.47368	0.52941	0.660693
60160	0.06	6	7	7	0.06	5	6	6	0.98684	0.47368	0.42857	0.42857	0.579417
60796	0.04	2	6	3	0.04	1	5	2	0.99119	0.81818	0.47368	0.69231	0.743841
61024	0.01	5	3	8	0.01	4	2	7	0.99778	0.52941	0.69231	0.39130	0.652702
60699	0.01	2	3	11	0.01	1	2	10	0.99778	0.81818	0.69231	0.31034	0.704654
60652	0.03	10	7	13	0.03	9	6	12	0.99338	0.33333	0.42857	0.27273	0.507002
50321	0.07	8	8	16	0.07	7	7	15	0.98468	0.39130	0.39130	0.23077	0.499515
61045	0.01	8	8	8	0.01	7	7	7	0.99778	0.39130	0.39130	0.39130	0.542924
50327	0.02	3	1	6	0.02	2	0	5	0.99558	0.69231	1.00000	0.47368	0.790392
61037	0.02	7	6	5	0.02	6	5	4	0.99558	0.42857	0.47368	0.52941	0.606811
60179	0.01	6	3	1	0.01	5	2	0	0.99778	0.47368	0.69231	1.00000	0.790944
61021	0.01	5	1	1	0.01	4	0	0	0.99778	0.52941	1.00000	1.00000	0.881799
61041	0.01	2	8	2	0.01	1	7	1	0.99778	0.81818	0.39130	0.81818	0.756363
49383	0.01	10	7	4	0.01	9	6	3	0.99778	0.33333	0.42857	0.60000	0.589922
60673	0.06	4	6	4	0.06	3	5	3	0.98684	0.60000	0.47368	0.60000	0.665132
48035	0.01	1	6	4	0.01	0	5	3	0.99778	1.00000	0.47368	0.60000	0.767867
61022	0.15	7	9	10	0.15	6	8	9	0.96774	0.42857	0.36000	0.33333	0.522412
61022	0.15	7	9	10	0.15	6	8	9	0.96774	0.42857	0.36000	0.33333	0.522412
50491	0.04	6	9	10	0.04	5	8	9	0.99119	0.47368	0.36000	0.33333	0.539552
50322	0.02	4	7	8	0.02	3	6	7	0.99558	0.60000	0.42857	0.39130	0.603863
49377	0.14	5	2	6	0.14	4	1	5	0.96983	0.52941	0.81818	0.47368	0.697776
50303	0.02	7	7	4	0.02	6	6	3	0.99558	0.42857	0.42857	0.60000	0.613180
50304	0.02	7	8	20	0.02	6	7	19	0.99558	0.42857	0.39130	0.19149	0.501735
50434	0.02	3	5	13	0.02	2	4	12	0.99558	0.69231	0.52941	0.27273	0.622505
60168	0.03	3	5	10	0.03	2	4	9	0.99338	0.69231	0.52941	0.33333	0.637108
61035	0.02	1	8	8	0.02	0	7	7	0.99558	1.00000	0.39130	0.39130	0.694546
60185	0.01	7	10	6	0.01	6	9	5	0.99778	0.42857	0.33333	0.47368	0.558343
50438	0.01	5	4	7	0.01	4	3	6	0.99778	0.52941	0.60000	0.42857	0.638941
48031	0.01	10	3	8	0.01	9	2	7	0.99778	0.33333	0.69231	0.39130	0.603682
49389	0.01	8	3	6	0.01	7	2	5	0.99778	0.39130	0.69231	0.47368	0.638770
60193	0.01	8	8	2	0.01	7	7	1	0.99778	0.39130	0.39130	0.81818	0.649643
61025	0.01	3	5	13	0.01	2	4	12	0.99778	0.69231	0.52941	0.27273	0.623057
61047	0.89	6	8	12	0.89	5	7	11	0.83488	0.47368	0.39130	0.29032	0.497548
61015	0.06	6	9	10	0.06	5	8	9	0.98684	0.47368	0.36000	0.33333	0.538465

Table A-23: Continued

NCR Number	Comparative Series				Diffrence Series				Relational Series				Degree of Relation
	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	
60655	0.06	3	7	8	0.06	2	6	7	0.98684	0.69231	0.42857	0.39130	0.624756
61029	0.01	6	8	6	0.01	5	7	5	0.99778	0.47368	0.39130	0.47368	0.584114
48058	0.01	9	3	5	0.01	8	2	4	0.99778	0.36000	0.69231	0.52941	0.644876
60174	0.04	7	8	3	0.04	6	7	2	0.99119	0.42857	0.39130	0.69231	0.625843
60791	0.01	4	5	9	0.01	3	4	8	0.99778	0.60000	0.52941	0.36000	0.621799
49380	0.06	6	9	6	0.06	5	8	5	0.98684	0.47368	0.36000	0.47368	0.573553
60180	0.01	8	5	8	0.01	7	4	7	0.99778	0.39130	0.52941	0.39130	0.577451
60836	0.02	4	6	6	0.02	3	5	5	0.99558	0.60000	0.47368	0.47368	0.635736
60689	0.01	3	8	9	0.01	2	7	8	0.99778	0.69231	0.39130	0.36000	0.610349
60838	0.01	7	8	9	0.01	6	7	8	0.99778	0.42857	0.39130	0.36000	0.544415
60792	0.02	3	1	7	0.02	2	0	6	0.99558	0.69231	1.00000	0.42857	0.779114
50308	0.12	5	6	3	0.12	4	5	2	0.97403	0.52941	0.47368	0.69231	0.667357
50309	0.12	5	4	2	0.12	4	3	1	0.97403	0.52941	0.60000	0.81818	0.730405
61017	0.03	4	8	18	0.03	3	7	17	0.99338	0.60000	0.39130	0.20930	0.548496
50312	0.01	6	6	18	0.01	5	5	17	0.99778	0.47368	0.47368	0.20930	0.538613
60793	0.01	6	10	2	0.01	5	9	1	0.99778	0.47368	0.33333	0.81818	0.655746
49369	0.02	3	4	16	0.02	2	3	15	0.99558	0.69231	0.60000	0.23077	0.629663
60697	0.38	4	6	13	0.38	3	5	12	0.92213	0.60000	0.47368	0.27273	0.567136
61038	0.01	8	8	7	0.01	7	7	6	0.99778	0.39130	0.39130	0.42857	0.552241
49379	0.02	7	5	8	0.02	6	4	7	0.99558	0.42857	0.52941	0.39130	0.586216
48057	0.05	8	6	3	0.05	7	5	2	0.98901	0.39130	0.47368	0.69231	0.636577
47569	0.02	7	6	2	0.02	6	5	1	0.99558	0.42857	0.47368	0.81818	0.679003
47568	0.02	7	2	10	0.02	6	1	9	0.99558	0.42857	0.81818	0.33333	0.643915
48064	0.02	7	3	9	0.02	6	2	8	0.99558	0.42857	0.69231	0.36000	0.619114
48077	0.01	7	10	2	0.01	6	9	1	0.99778	0.42857	0.33333	0.81818	0.644467
48062	0.01	9	3	7	0.01	8	2	6	0.99778	0.36000	0.69231	0.42857	0.619665
50323	0.01	9	10	6	0.01	8	9	5	0.99778	0.36000	0.33333	0.47368	0.541200
60658	0.02	5	8	11	0.02	4	7	10	0.99558	0.52941	0.39130	0.31034	0.556659
61006	0.2	5	2	6	0.2	4	1	5	0.95745	0.52941	0.81818	0.47368	0.694681
60213	0.1	9	2	5	0.1	8	1	4	0.97826	0.36000	0.81818	0.52941	0.671464
48075	0.03	4	3	9	0.03	3	2	8	0.99338	0.60000	0.69231	0.36000	0.661421
61004	0.01	7	7	9	0.01	6	6	8	0.99778	0.42857	0.42857	0.36000	0.553731
61020	0.14	2	5	15	0.14	1	4	14	0.96983	0.81818	0.52941	0.24324	0.640166
60186	0.03	7	10	12	0.03	6	9	11	0.99338	0.42857	0.33333	0.29032	0.511401
60242	0.01	7	2	9	0.01	6	1	8	0.99778	0.42857	0.81818	0.36000	0.651134
50427	0.02	4	4	6	0.02	3	3	5	0.99558	0.60000	0.60000	0.47368	0.667315
50329	0.02	9	7	3	0.02	8	6	2	0.99558	0.36000	0.42857	0.69231	0.619114
48076	0.02	6	5	13	0.02	5	4	12	0.99558	0.47368	0.52941	0.27273	0.567850
60656	0.03	10	3	10	0.03	9	2	9	0.99338	0.33333	0.69231	0.33333	0.588088
50430	0.03	3	2	8	0.03	2	1	7	0.99338	0.69231	0.81818	0.39130	0.723793
48049	0.01	7	7	6	0.01	6	6	5	0.99778	0.42857	0.42857	0.47368	0.582152
60151	0.01	6	5	4	0.01	5	4	3	0.99778	0.47368	0.52941	0.60000	0.650220
50492	0.02	4	6	3	0.02	3	5	2	0.99558	0.60000	0.47368	0.69231	0.690392
61034	0.06	6	6	9	0.06	5	5	8	0.98684	0.47368	0.47368	0.36000	0.573553

Table A-23: Continued

NCR	Comparative Series				Diffrence Series				Relational Series				Degree of
Number	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	Relation
60769	0.01	8	8	4	0.01	7	7	3	0.99778	0.39130	0.39130	0.60000	0.595098
49385	0.04	2	8	7	0.04	1	7	6	0.99119	0.81818	0.39130	0.42857	0.657312
60812	0.03	9	2	6	0.03	8	1	5	0.99338	0.36000	0.81818	0.47368	0.661311
60682	0.03	1	1	9	0.03	0	0	8	0.99338	1.00000	1.00000	0.36000	0.838344
60152	0.01	1	6	6	0.01	0	5	5	0.99778	1.00000	0.47368	0.47368	0.736288
50301	0.01	4	5	2	0.01	3	4	1	0.99778	0.60000	0.52941	0.81818	0.736344
47577	0.06	3	8	2	0.06	2	7	1	0.98684	0.69231	0.39130	0.81818	0.722159
50224	0.08	2	7	20	0.08	1	6	19	0.98253	0.81818	0.42857	0.19149	0.605194
50318	0.01	3	8	14	0.01	2	7	13	0.99778	0.69231	0.39130	0.25714	0.584634
48041	0.02	5	6	3	0.02	4	5	2	0.99558	0.52941	0.47368	0.69231	0.672745
60695	0.01	7	9	8	0.01	6	8	7	0.99778	0.42857	0.36000	0.39130	0.544415
60774	0.01	2	8	3	0.01	1	7	2	0.99778	0.81818	0.39130	0.69231	0.724894
49397	0.04	7	7	7	0.04	6	6	6	0.99119	0.42857	0.42857	0.42857	0.569226
61040	0.02	1	1	6	0.02	0	0	5	0.99558	1.00000	1.00000	0.47368	0.867315
61005	0.01	1	1	3	0.01	0	0	2	0.99778	1.00000	1.00000	0.69231	0.922523
48038	0.01	10	9	4	0.01	9	8	3	0.99778	0.33333	0.36000	0.60000	0.572779
48068	0.01	1	3	7	0.01	0	2	6	0.99778	1.00000	0.69231	0.42857	0.779665
50228	0.09	3	6	4	0.09	2	5	3	0.98039	0.69231	0.47368	0.60000	0.686596
60814	0.06	4	5	6	0.06	3	4	5	0.98684	0.60000	0.52941	0.47368	0.647485
48070	0.03	5	4	19	0.03	4	3	18	0.99338	0.52941	0.60000	0.20000	0.580697
50440	0.01	8	6	13	0.01	7	5	12	0.99778	0.39130	0.47368	0.27273	0.533875
48099	0.26	4	5	15	0.26	3	4	14	0.94538	0.60000	0.52941	0.24324	0.579508
48074	0.01	1	10	8	0.01	0	9	7	0.99778	1.00000	0.33333	0.39130	0.680605
60662	0.1	2	7	10	0.1	1	6	9	0.97826	0.81818	0.42857	0.33333	0.639587
61027	0.02	4	8	1	0.02	3	7	0	0.99558	0.60000	0.39130	1.00000	0.746720
60789	0.09	3	2	3	0.09	2	1	2	0.98039	0.69231	0.81818	0.69231	0.795797
48017	0.05	3	6	7	0.05	2	5	6	0.98901	0.69231	0.47368	0.42857	0.645894
48093	0.01	1	2	2	0.01	0	1	1	0.99778	1.00000	0.81818	0.81818	0.908537
50325	0.01	4	9	7	0.01	3	8	6	0.99778	0.60000	0.36000	0.42857	0.596589
50324	0.01	5	2	4	0.01	4	1	3	0.99778	0.52941	0.81818	0.60000	0.736344
50326	0.01	8	9	6	0.01	7	8	5	0.99778	0.39130	0.36000	0.47368	0.555693
60781	0.01	3	6	8	0.01	2	5	7	0.99778	0.69231	0.47368	0.39130	0.638770
49366	0.02	7	4	9	0.02	6	3	8	0.99558	0.42857	0.60000	0.36000	0.596037
60669	0.37	6	9	4	0.37	5	8	3	0.92402	0.47368	0.36000	0.60000	0.589427
60677	0.01	1	5	7	0.01	0	4	6	0.99778	1.00000	0.52941	0.42857	0.738941
61028	0.01	7	6	2	0.01	6	5	1	0.99778	0.42857	0.47368	0.81818	0.679555
50487	0.25	2	1	3	0.25	1	0	2	0.94737	0.81818	1.00000	0.69231	0.864464
48081	0.02	4	4	4	0.02	3	3	3	0.99558	0.60000	0.60000	0.60000	0.698894
50497	0.7	6	8	9	0.7	5	7	8	0.86538	0.47368	0.39130	0.36000	0.522593
50460	0.03	3	8	12	0.03	2	7	11	0.99338	0.69231	0.39130	0.29032	0.591828
60184	0.01	3	7	8	0.01	2	6	7	0.99778	0.69231	0.42857	0.39130	0.627492
60227	0.05	8	2	3	0.05	7	1	2	0.98901	0.39130	0.81818	0.69231	0.722701
61023	0.01	3	5	4	0.01	2	4	3	0.99778	0.69231	0.52941	0.60000	0.704876

Table A-23: Continued

NCR Number	Comparative Series				Diffrence Series				Relational Series				Degree of Relation
	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	
60237	0.01	5	8	6	0.01	4	7	5	0.99778	0.52941	0.39130	0.47368	0.598046
60685	0.01	7	6	7	0.01	6	5	6	0.99778	0.42857	0.47368	0.42857	0.582152
49368	0.02	1	7	4	0.02	0	6	3	0.99558	1.00000	0.42857	0.60000	0.756037
60206	0.1	6	9	3	0.1	5	8	2	0.97826	0.47368	0.36000	0.69231	0.626063
60212	0.18	7	5	8	0.18	6	4	7	0.96154	0.42857	0.52941	0.39130	0.577707
49399	0.04	4	5	2	0.04	3	4	1	0.99119	0.60000	0.52941	0.81818	0.734696
47567	0.02	5	3	6	0.02	4	2	5	0.99558	0.52941	0.69231	0.47368	0.672745
50499	0.02	8	5	10	0.02	7	4	9	0.99558	0.39130	0.52941	0.33333	0.562406
50480	0.04	9	7	8	0.04	8	6	7	0.99119	0.36000	0.42857	0.39130	0.542766
50219	0.04	4	2	6	0.04	3	1	5	0.99119	0.60000	0.81818	0.47368	0.720764
47598	0.05	4	8	3	0.05	3	7	2	0.98901	0.60000	0.39130	0.69231	0.668156
47597	0.05	4	9	8	0.05	3	8	7	0.98901	0.60000	0.36000	0.39130	0.585079
60688	0.01	4	9	7	0.01	3	8	6	0.99778	0.60000	0.36000	0.42857	0.596589
60683	0.05	1	9	13	0.05	0	8	12	0.98901	1.00000	0.36000	0.27273	0.655435
49395	0.1	4	8	8	0.1	3	7	7	0.97826	0.60000	0.39130	0.39130	0.590217
48060	0.01	1	5	3	0.01	0	4	2	0.99778	1.00000	0.52941	0.69231	0.804876
48095	0.02	3	5	4	0.02	2	4	3	0.99558	0.69231	0.52941	0.60000	0.704324
60176	0.06	8	6	6	0.06	7	5	5	0.98684	0.39130	0.47368	0.47368	0.581379
48082	0.02	5	6	6	0.02	4	5	5	0.99558	0.52941	0.47368	0.47368	0.618089
60154	0.01	9	8	6	0.01	8	7	5	0.99778	0.36000	0.39130	0.47368	0.555693
61019	0.01	1	7	9	0.01	0	6	8	0.99778	1.00000	0.42857	0.36000	0.696589
61033	0.01	4	2	8	0.01	3	1	7	0.99778	0.60000	0.81818	0.39130	0.701817
61043	0.01	5	9	12	0.01	4	8	11	0.99778	0.52941	0.36000	0.29032	0.544379
60162	0.05	2	4	10	0.05	1	3	9	0.98901	0.81818	0.60000	0.33333	0.685132
60161	0.01	7	4	19	0.01	6	3	18	0.99778	0.42857	0.60000	0.20000	0.556589
50221	0.02	3	7	7	0.02	2	6	6	0.99558	0.69231	0.42857	0.42857	0.636256
50319	0.01	3	8	5	0.01	2	7	4	0.99778	0.69231	0.39130	0.52941	0.652702
60199	0.01	1	6	3	0.01	0	5	2	0.99778	1.00000	0.47368	0.69231	0.790944
60670	0.06	4	5	14	0.06	3	4	13	0.98684	0.60000	0.52941	0.25714	0.593349
50482	0.03	2	6	11	0.03	1	5	10	0.99338	0.81818	0.47368	0.31034	0.648897
48054	0.04	7	8	7	0.04	6	7	6	0.99119	0.42857	0.39130	0.42857	0.559909
60236	0.01	6	6	6	0.01	5	5	5	0.99778	0.47368	0.47368	0.47368	0.604709
60197	0.27	2	7	7	0.27	1	6	6	0.94340	0.81818	0.42857	0.42857	0.654680
48059	0.01	6	7	5	0.01	5	6	4	0.99778	0.47368	0.42857	0.52941	0.607363
48084	0.01	8	7	3	0.01	7	6	2	0.99778	0.39130	0.42857	0.69231	0.627492
50220	0.2	9	6	10	0.2	8	5	9	0.95745	0.36000	0.47368	0.33333	0.531116
61044	0.01	8	6	7	0.01	7	5	6	0.99778	0.39130	0.47368	0.42857	0.572836
60191	0.01	9	9	7	0.01	8	8	6	0.99778	0.36000	0.36000	0.42857	0.536589
50500	0.02	3	5	5	0.02	2	4	4	0.99558	0.69231	0.52941	0.52941	0.686677
60194	0.02	6	8	3	0.02	5	7	2	0.99558	0.47368	0.39130	0.69231	0.638218
60686	0.04	5	8	8	0.04	4	7	7	0.99119	0.52941	0.39130	0.39130	0.575802
49382	0.04	4	4	2	0.04	3	3	1	0.99119	0.60000	0.60000	0.81818	0.752343
50483	0.03	8	4	9	0.03	7	3	8	0.99338	0.39130	0.60000	0.36000	0.586170

Table A-23: Continued

NCR Number	Comparative Series				Diffrence Series				Relational Series				Degree of Relation
	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	S_o	S_s	S_d	DOPP	
61012	0.02	4	5	5	0.02	3	4	4	0.99558	0.60000	0.52941	0.52941	0.663600
60795	0.01	8	3	5	0.01	7	2	4	0.99778	0.39130	0.69231	0.52941	0.652702
50485	0.06	3	3	9	0.06	2	2	8	0.98684	0.69231	0.69231	0.36000	0.682864
60692	0.01	4	2	8	0.01	3	1	7	0.99778	0.60000	0.81818	0.39130	0.701817
61010	0.04	5	7	7	0.04	4	6	6	0.99119	0.52941	0.42857	0.42857	0.594436
61032	0.01	9	9	5	0.01	8	8	4	0.99778	0.36000	0.36000	0.52941	0.561799
50317	0.01	9	8	12	0.01	8	7	11	0.99778	0.36000	0.39130	0.29032	0.509852
60668	0.06	5	2	19	0.06	4	1	18	0.98684	0.52941	0.81818	0.20000	0.633609
60671	0.06	7	4	11	0.06	6	3	10	0.98684	0.42857	0.60000	0.31034	0.581440
60672	0.05	8	4	7	0.05	7	3	6	0.98901	0.39130	0.60000	0.42857	0.602222
60801	0.04	8	6	9	0.04	7	5	8	0.99119	0.39130	0.47368	0.36000	0.554044
60661	0.01	5	7	3	0.01	4	6	2	0.99778	0.52941	0.42857	0.69231	0.662018
50435	0.11	3	6	8	0.11	2	5	7	0.97614	0.69231	0.47368	0.39130	0.633359
50330	0.01	10	6	5	0.01	9	5	4	0.99778	0.33333	0.47368	0.52941	0.583553
47578	0.01	1	1	3	0.01	0	0	2	0.99778	1.00000	1.00000	0.69231	0.922523
48085	0.01	3	7	12	0.01	2	6	11	0.99778	0.69231	0.42857	0.29032	0.602246
60243	0.01	4	7	8	0.01	3	6	7	0.99778	0.60000	0.42857	0.39130	0.604415
50431	0.02	5	1	6	0.02	4	0	5	0.99558	0.52941	1.00000	0.47368	0.749668
50310	0.03	4	7	6	0.03	3	6	5	0.99338	0.60000	0.42857	0.47368	0.623908
61018	0.6	3	8	3	0.6	2	7	2	0.88235	0.69231	0.39130	0.69231	0.664568
50496	0.02	3	6	9	0.02	2	5	8	0.99558	0.69231	0.47368	0.36000	0.630392
60169	0.12	4	5	7	0.12	3	4	6	0.97403	0.60000	0.52941	0.42857	0.633002
60234	0.01	1	6	6	0.01	0	5	5	0.99778	1.00000	0.47368	0.47368	0.736288
60235	0.01	3	4	7	0.01	2	3	6	0.99778	0.69231	0.60000	0.42857	0.679665
49365	0.04	3	3	16	0.04	2	2	15	0.99119	0.69231	0.69231	0.23077	0.651644
60691	0.01	8	9	4	0.01	7	8	3	0.99778	0.39130	0.36000	0.60000	0.587272

Effect on	Criteria: Severity of Effect	Rating
Hazardous – without warning	Very high severity ranking – Affects operator, plant, or maintenance personnel, safety and/or affects non-compliance with government regulations	10
Hazardous – with warning	High severity ranking – Affects operator, plant, or maintenance personnel, safety and/or affects non-compliance with government regulations	9
Very High Downtime or Defective Parts	Downtime of more than 8 hours or defective parts loss more than 4 hours of production	8
High Downtime or Defective Parts	Downtime of 4 to 7 hours or defective parts loss of 2 to 4 hours of production	7
Moderate Downtime or Defective Parts	Downtime of 1 to 3 hours or defective parts loss of 1 to 2 hours of production	6
Low Downtime or Defective Parts	Downtime of 30 minutes to 1 hour or defective parts loss of up to 1 hour of production	5
Very Low Downtime – No Defective Parts	Downtime up to 30 minutes – no defective parts	4
Minor Effect	Process parameter variability exceeds Upper/Lower Control limits. Adjustment or other process controls need to be taken – no defective parts	3
Very Minor Effect	Process parameter variability within Upper/Lower Control limits. Adjustment or other process controls need to be taken – no defective parts	2
No Effect	Process parameter variability within Upper/Lower Control limits, adjustment or other process controls not needed or can be taken between shifts or at normal maintenance – no defective parts	1

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Figure A-1: Severity evaluation criteria ranking (Ford FMEA Manual, 1996)

Detection	Criteria: Likelihood of Detection by Design or Machinery Controls	Rating
Absolute Uncertainty	Machinery Controls CANNOT detect a potential cause and subsequent failure, or there is no Design or Machinery Control	10
Very Remote	Very remote chance a Design/Machinery Control will detect a potential cause and subsequent failure mode	9
Remote	Remote chance a Design/Machinery Control will detect a potential cause and subsequent failure mode, and Machinery Control will provide indicator of imminent failure	8
Very Low	Very low chance a Design/Machinery Control will detect a potential cause and subsequent failure mode, and Machinery Control will prevent an imminent failure (e.g., stop machine)	7
Low	Low chance a Design/Machinery Control will detect a potential cause and subsequent failure mode, and Machinery Control will prevent an imminent failure (e.g., stop machine)	6
Moderate	Moderate chance a Design/Machinery Control will detect a potential cause and subsequent failure mode, and Machinery Control will prevent an imminent failure (e.g., stop machine) and isolate the cause	5
Moderately High	Moderately high chance a Design/Machinery Control will detect a potential cause and subsequent failure mode, and Machinery Control will prevent an imminent failure (e.g., stop machine) and isolate the cause. Machinery Control MAY be required	4
High	High chance a Design/Machinery Control will detect a potential cause and subsequent failure mode, and Machinery Control will prevent an imminent failure (e.g., stop machine) and isolate the cause. Machinery Control MAY be required	3
Very High	Very high chance a Design Control will detect a potential cause and subsequent failure mode. Machinery Controls NOT required	2
Almost Certain	Design Controls will almost certainly detect a potential cause and subsequent failure mode. Machinery Controls NOT required	1

Figure A- 2: Detection evaluation criteria ranking (Ford FMEA manual, 1996)

VITA

Abhishek Padiyar was born in Mangalore, India on February 9, 1980. He was raised in Kudremukh. He graduated from Kendriya Vidyalaya, Kudremukh in 1997. From there, he went to Manipal Insitute of Technology, Manipal and received a B.S in Mechanical Engineering in 2001. Abhishek is currently pursuing his Masters in Industrial and Information Engineering at the University of Tennessee, Knoxville, TN.