THE REDUCTION OF THE SHUTDOWN MAINTENANCE COST, FREQUENCY AND THE LOSS IN PRODUCTION BY THE PROPER ASSESSMENT OF THE SCOPE OF SHUTDOWN MAINTENANCE WORK

By

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This Thesis is Dedicated With Love to

My Mother

With Prayers for God to Bless Her.

My Father

Who pass away before Witnessing This Achievement May God

Has Mercy on Him.

And

My Brother Abdulrahman and My Two Sisters

For their Encouragement, Goodwill and Understanding.

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ABSTRACT

The reduction of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that occurs as a result of performing shutdown maintenance whilst maintaining shutdown maintenance purpose and without creating any operational, safety, or economic problems during normal operation represents one of the most important issue that supports the overall strategy in the continuous process industries. The importance of this issue stimulated the work in research to find ways and methods to reduce the cost and frequency of shutdown maintenance, in addition to, the loss in production without increasing the number of the unplanned shutdowns or creating interruptions to the production line.

The result of this stimulation was different works in this area of research. Some of these works concentrated on reducing the shutdown maintenance frequency without increasing the unplanned shutdowns by developing methods that search for the optimum frequency. Whereas, the other some of these works concentrated on either reducing shutdown maintenance cost without increasing the loss in production that is caused by shutdown maintenance by the use of reliability, availability and maintainability principles or reducing the shutdown maintenance cost and the loss in production that occurs as a result of performing shutdown maintenance by reducing the shutdown maintenance duration.

The work in this thesis was a contribution to this area of research. Its aim was to develop a model that reduces the shutdown maintenance cost and frequency, in addition to, the loss in production that is caused by shutdown maintenance without creating any operational, safety and economic problems by the reduction of the scope of work of shutdown maintenance (number of shutdown maintenance activities).

The approach that has been used in the research of this thesis in order to achieve this aim was divided into three stages. The first stage was the studying and the understanding of the relationships of interest between the number of shutdown maintenance activities and each one of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production. The purpose of this stage was to investigate the importance of the number of shutdown maintenance activities as a major variable that affects the above mentioned variables of interest. This studying process included a creation of a theoretical framework that describes these

relationships and the variables that constitute them by investigating the relevant literature and by conducting several interviews. In addition, it included an evaluation of these relationships by analysing the data that has been collected by mail questionnaire survey.

Following the first stage, the second stage was the development process of the model structure. This stage included different modelling issues such as the modelling method that was used to develop the proposed model, the description of the model structure and the general and specific characteristics of the model.

The third and last stage of this thesis approach was the testing and validation process of the developed model. The purpose of this process was to ensure that the model performs as expected. This process included the test plan, the way that was used for carrying out this process and the findings from the test.

The result of all of these stages and the thesis approach in general was a verified and refined model that is useful for assessing the scope of work of shutdown maintenance which in turn helps to reduce the shutdown maintenance cost and frequency and the loss in production that occurs as a result of performing shutdown maintenance.

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INTRODUCTION

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1.1 BACKGROUND:

In the industrial world, one of the biggest challenging issues that faces continuous process industries is the reduction of shutdown maintenance cost and frequency and the loss in production that occurs as a result of performing shutdown maintenance activities without creating any operational, economic or safety problems. In other words, the challenge is to contribute to the increase of the profit through the reduction of the total cost of the shutdown maintenance programme, which is represented, by the reduction of the shutdown maintenance cost, shutdown maintenance frequency and the loss in the production.

In continuous process industries, shutdown maintenance is used as the best way to perform preventive maintenance activities since the nature of the relation between manufacturing processes in these industries is a serial relation represented by a single production line. This means that performing planned maintenance activities on the machines and equipment, which do not have redundancies in this production line, requires a total stoppage of the entire line.

Shutdown maintenance, however, is very expensive compared with other types of preventive maintenance. It causes losses in production and sales because it requires total stoppage of the production system. In addition, its direct and overhead costs are high since it needs a huge amount of maintenance and non-maintenance resources to perform its activities.

On the other hand, leaving machines and equipment in this type of industries without maintenance exposes them to breakdowns and the whole production system to unplanned emergency shutdowns. Emergency shutdowns are much more expensive than shutdown maintenance because they force production systems to have unexpected stoppages. These unplanned stoppages cause huge losses in production and in sales. At the same time, emergency shutdowns are dangerous since they may cause injuries and death to some of the employees and harm to the outside environment. In addition, the cost of resources needed to restore the production system after the occurrence of these emergency shutdowns is very high. Therefore, emergency shutdowns are not accepted.

Specialised industrial people and experts in continuous process industries realised the high cost of shutdown maintenance and the loss in production and sales that occurs as a result of performing its activities. In addition, they realised the importance of this type of maintenance in protecting the production system from emergency shutdowns. Knowles and Andreef (1992) from Ontario Hydro Company, for example, claimed that their company appreciated the importance of shutdown maintenance. However, the cost of the work performed during shutdown maintenance in the company's nuclear power stations represents a significant part of the operating and maintenance cost. Gupta and Paisie senior reliability engineers with Sun Oil Company at Toledo refinery (1997) also stated that recently, their refinery could not support the traditional way of handling shutdown maintenance because it is extensive and expensive and they suggested that the company should seek new cheaper ways to do shutdown maintenance. In addition, through my work with SABIC which owns several petrochemical industries in Saudi Arabia, it has been realised that the company gives a great deal of attention to its shutdown maintenance programme. At the same time, the company searches for a solution to the losses in the production and sales, which are caused by shutdown maintenance.

All of these issues and more stimulated the work in research to find ways or methods to reduce the cost and the frequency of shutdown maintenance and the loss in production that occurs as a result of performing its activities whilst avoiding the creation of any operational, economic or safety problems. This thesis is an effort to contribute to this area of research. Its approach is to reduce the shutdown maintenance cost and frequency, in addition to, the loss in production through the reduction of the scope of work of shutdown maintenance without creating any operational, economic or safety problems. In other words, this thesis is an effort to increase the profit by reducing shutdown maintenance cost, shutdown maintenance frequency and the loss in production.

1.2 DEFINITIONS:

In this section, the definition of shutdown maintenance cost and other very important terminology will be clarified in order to illustrate their meaning that will be used in the context of this thesis.

1.2.1 Scope of Work of Shutdown Maintenance:

In the Oxford English Reference Dictionary (1996) the word scope is defined as:

> the range of matters being dealt with, studied.

In the context of this thesis, scope of work of shutdown maintenance is defined as the range or a set of maintenance and engineering activities to be completed in the shutdown maintenance programme and which constitute the total work of shutdown maintenance.

1.2.2 Shutdown Maintenance Cost:

Cost is defined as (Oxford English Reference Dictionary, 1996):

> a loss or sacrifice/expenditure of time, effort / price paid for a thing.

Also, cost in the business field is defined as a sacrifice of resources in order to produce goods and services (Deakin and Maher, 1991; Drury, 1996; Horngren and Sundem, 1990; Smith, Keith and Stephens, 1988). In addition, maintenance cost is defined in the maintenance field as (British Standard Glossary of terms (3811:1993)):

> The total cost of retaining an item in, or restoring it to, a state in which it can perform its required function.

Shutdown maintenance cost or the cost of shutdown maintenance in the context of this thesis is the sacrifice of resources in order to retain or restore a set of items (machines and equipment) to their required state of functioning by performing shutdown maintenance activities. This cost is a combination of two major types of costs. The first type is the **direct cost of shutdown maintenance** which is the sum of all costs that can be traced directly to shutdown maintenance activities and it includes the direct cost of labour, experts, spare parts, materials, equipment and tools that are used to perform shutdown maintenance activities. The second type is the **overhead cost** which represents the sum of all costs related to shutdown maintenance other than those that constitute the direct cost of shutdown maintenance and it includes the indirect cost of materials, labour, tools, equipment and other expenses that are used for carrying out the whole shutdown maintenance programme.

Shutdown maintenance cost can also be known in the context of this thesis as the **off-line maintenance cost**, since it represents the total cost of performing maintenance activities on machines when the plant is in a planned shutdown situation. Another very important term that is associated with this term in the context of this thesis is the **on-line maintenance cost** which is the cost of maintenance labour, spare parts, materials, tools, equipment and other expenses that are needed to perform any other types of maintenance programmes that do not require a total stoppage of the production line. This term is so called because it represents the total cost of performing maintenance activities on machines while the plant is running.

1.2.3 The Loss in Production as a Result of Performing Shutdown Maintenance Activities:

The loss in production as a result of performing shutdown maintenance activities in the context of this thesis is the loss of the opportunity to produce plant products as a result of preferring to perform shutdown maintenance programme. In other words, it is the profit sacrificed as a result of preferring to perform shutdown maintenance.

1.2.4 Critical Maintenance Activities:

The word critical is defined in Oxford English Reference Dictionary (1996) as:

> decisive or crucial/ decisive or crucial thing.

Critical maintenance activities in the context of this thesis are those activities that will cause operational or economic problems to the plant or safety problems to the plant and the outside environment if they are performed while the production line (plant) is running. These activities require a total shutdown of the plant (total stoppage of the production line) when they are performed and they are of the following three kinds:

1. Operationally critical maintenance activities: These activities are the ones that will cause unaccepted partial or unplanned full shutdown to the plant (unaccepted partial or unplanned total stoppage to the production line) if they are performed while the production line (plant) is running. They are associated with those machines or equipment that are very important to the plant operations and which either do not have redundancy or standby to take over or their partial operation is not enough to run the whole plant (production line).
2. Safety critical maintenance activities: These activities are the ones that will cause harm and danger for the environment, the workplace or both if they are performed while the production line (plant) is running. They are associated with those machines and equipment, which need special safety precautions that are only available, when the plant is in total shutdown satiation.
3. Costly (economically) critical maintenance activities: These activities are the ones which their cost when they are performed during the running of the plant (production line) are higher than their cost when they are performed during the planned shutdown of the plant. In other words, the on-line maintenance cost of performing these activities is higher than their off-line maintenance cost.

1.3 THESIS AIM AND OBJECTIVES:

The aim of this thesis is to investigate the creation of a new model, which has the ability to reduce the shutdown maintenance cost and frequency and the loss in production that occurs as a result of performing shutdown maintenance activities through the reduction of the scope of work of shutdown maintenance (number of shutdown maintenance activities) and without creating any operational, economic or safety problems. This aim could be broken down into the following objectives:

1. To investigate the need to reduce the shutdown maintenance cost and the frequency and the loss in production that is caused by shutdown maintenance.

2. To study and investigate current methods for reducing the cost and the frequency of shutdown maintenance, in addition to, the loss in production that occurs as a result of performing shutdown maintenance activities.
3. To investigate the importance of the scope of work of shutdown maintenance (number of shutdown maintenance activities) as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that occurs as a result of performing shutdown maintenance by studying and understanding the following relationships:
   A. The relationship between the shutdown maintenance cost and the scope of work of shutdown maintenance (number of shutdown maintenance activities).
   B. The relationship between the shutdown maintenance frequency and the scope of work of shutdown maintenance (number of shutdown maintenance activities).
   C. The relationship between the loss in production as a result of performing shutdown maintenance activities and the scope of work of shutdown maintenance (number of shutdown maintenance activities).
4. To investigate whether it is possible to develop a model to reduce the scope of work of shutdown maintenance (number of shutdown maintenance activities) which in turn reduces the cost and the frequency of shutdown maintenance, in addition to, the loss in production that is caused by shutdown maintenance.
5. To validate and verify the proposed model.

1.4 A GUIDE TO THE THESIS:

This thesis is organised into nine chapters as follows:

- The first chapter discusses the background of the thesis problem and illustrates the meaning of very important terms that have been used in the context of the thesis. Also, it specifies the aim and objectives of the thesis and provides a guide to the research.

- The second chapter is a literature review of current relevant literature regarding shutdown maintenance and the methods that are used to reduce its cost and its frequency and the loss in production that occurs as a result of performing its activities.

- The third chapter reviews the current practice of shutdown maintenance and the limitation of the current models and methods that are discussed in the second chapter. Also, it proposes the idea for a new model to reduce the cost and the frequency of shutdown maintenance, in addition to, the loss in production that is caused by the shutdown maintenance and discusses the research methodology of the thesis that has been used to satisfy thesis aim which is represented by the development of the newly proposed model.

- The fourth chapter discusses the first part of the first stage of the thesis research methodology. In particular, it discusses the first part of the investigation process of the importance of number of shutdown maintenance activities (the scope of work of shutdown maintenance) as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production. This part is the development of a theoretical framework that describes the following relationships of interest:
  1. The relationship between the scope of work of shutdown maintenance (number of shutdown maintenance activities) and the shutdown maintenance cost.
  2. The relationship between the scope of work of shutdown maintenance (number of shutdown maintenance activities) and the shutdown maintenance frequency.
  3. The relationship between the scope of work of shutdown maintenance (number of shutdown maintenance activities) and the loss in production that occurs as a result of performing shutdown maintenance activities.

  The discussion in this chapter includes important subjects such as the way that has been used to develop this theoretical framework and the description of this theoretical framework structure which includes the description of the above mentioned relationships and all the related variables that constitute them.

- The fifth chapter discusses the survey design that has been used to satisfy the purpose of the investigation process and the development of the selected data-collection method (questionnaire) that has been used to collect data for the investigation process. In addition, it discusses the way of performing the pre-testing and the pilot study of the questionnaire that has been developed and the implementation of the main survey.

- The sixth chapter discusses the data analysis process that facilitates the analysis objectives of the first stage of the thesis research methodology (the investigation process of the importance of number of shutdown maintenance activities as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production). In addition, it discusses the results of this process and compares them with findings from the literature review and the interviews.

- The seventh chapter discusses the second stage of the thesis research methodology, which is based on the results of the first stage. In particular, it discusses the development of the proposed model that reduces the cost and the frequency of shutdown maintenance and the loss in production that is caused by shutdown maintenance through the proper assessment of the scope of work of shutdown maintenance. This discussion includes important subjects such as the selection of the modelling method that has been used to develop the proposed model and the description of the developed model structure that is based on the results of analysing the relationships of interest in the first stage of the thesis research methodology.

- The eighth chapter represents the third stage of the thesis research methodology in which it describes the testing process of the developed model that has been carried out by implementing the model on two of the continuous process plants in Saudi Arabia.

- The ninth chapter outlines the main conclusions drawn from the research and suggests further wok that could take place in the research area of this thesis.

Figure 1.1 shows the organisation of these chapters.

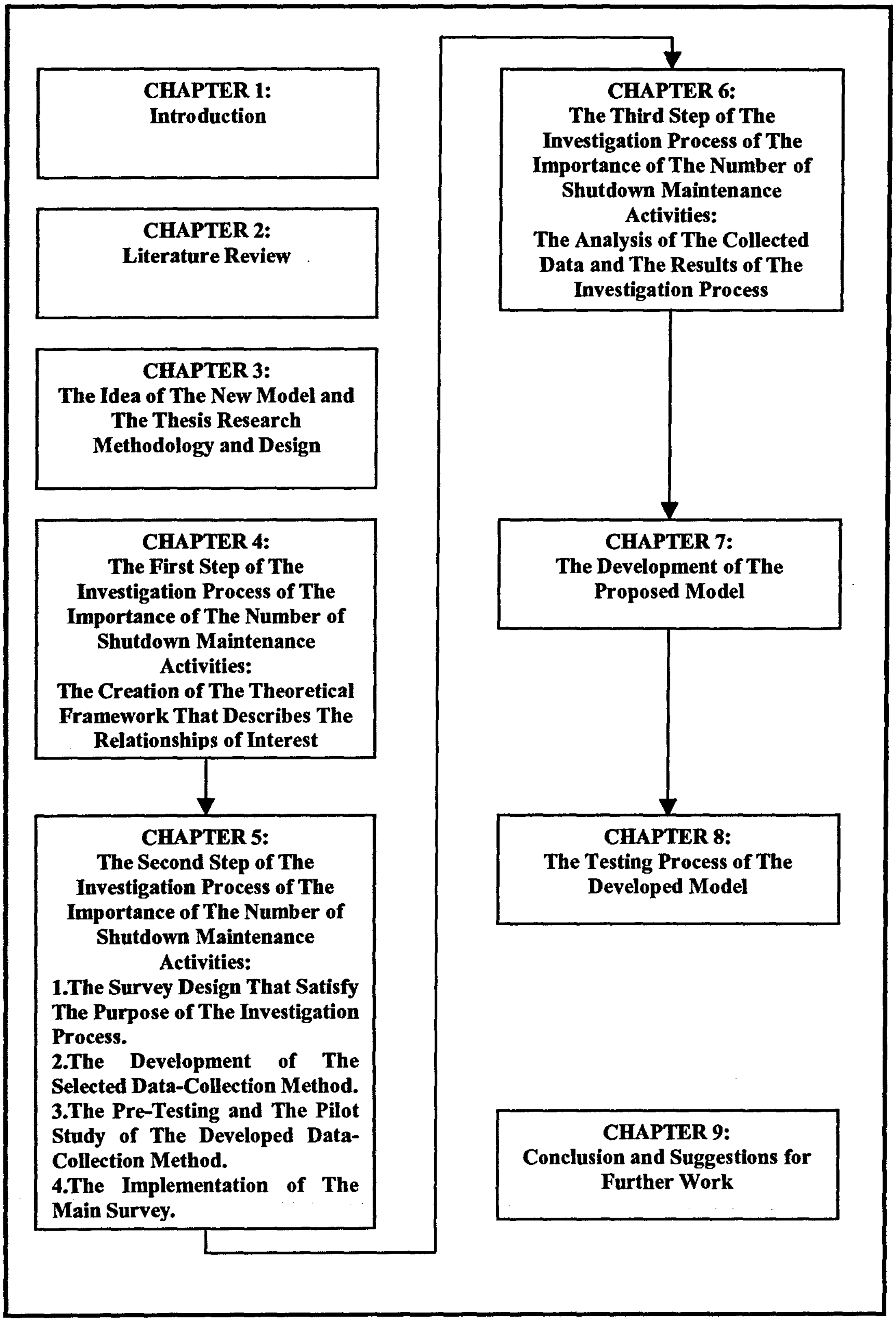

Figure 1.1 The Organisation of The Thesis Chapters

CHAPTER 2

LITERATURE REVIEW

2

2.1 INTRODUCTION:

A significant amount of literature has been written about shutdown maintenance in which the aim was to contribute to the increase of the profit through making shutdown maintenance less expensive and less frequent. In other words, the aim of the literature was to find methods and ways for reducing the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by shutdown maintenance.

According to the approaches that have been used to achieve this aim, the literature in this research area could be classified into three categories. In the first category, the work of the literature was based on reducing shutdown maintenance frequency without affecting the availability of machines and facilities and the level of performance. The literature in this category concentrated on searching for the optimum frequency that satisfies predetermined constraints. In the second category, the approach in the literature was based on reducing shutdown maintenance cost and the loss in production that is caused by shutdown maintenance through the reduction of shutdown maintenance duration. In this category, the work of the literature was concentrated on the following:

1. Improving the way of handling information within each phase and between phases of shutdown maintenance.
2. Improving the way of utilising shutdown maintenance resources (materials, labour, etc.).

In addition to these two categories, the third and the final category is represented by a research, which was conducted by Gupta and Paisie (1997) in which they claimed that a reduction in the shutdown maintenance cost could be achieved through the use of reliability, availability, and maintainability (RAM) principles. Figure 2.1 illustrates the efforts that have been done and discussed in the literature to achieve the above-mentioned aim.

The objective of this chapter is to review this literature in order to define a direction of subsequent research and explore the possibility of developing a model that has the capability of making shutdown maintenance less expensive and less frequent without creating any operational, economic or safety problems.

The way that has been used to review the literature was based on dividing the review process into four stages. Each of which is represented by a section in this chapter. The first stage of this reviewing process which is also the next following section of this chapter reviews the literature about maintenance, which represents the origin of shutdown maintenance. Following this stage is the second stage, which reviews the use of maintenance in manufacturing systems. After that, the third stage of the reviewing process discusses the shutdown maintenance practice in continuous process industries. The final stage which is also the fifth section of this chapter, represents the review of the literature about the ways and the methods that have been developed in order to reduce the shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance.

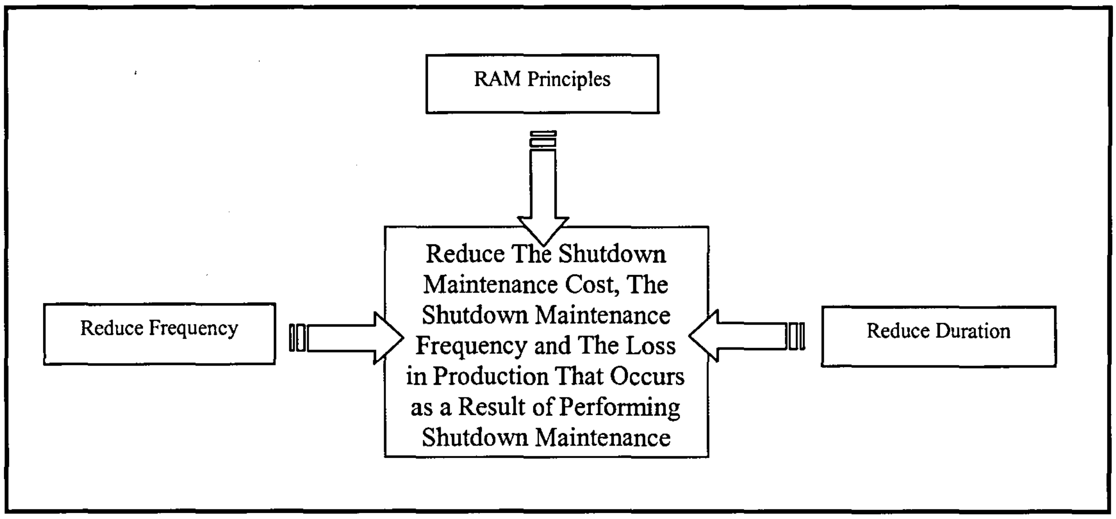

Figure 2.1 The Efforts That Have Been Done in The Literature in Order to Reduce Shutdown Maintenance Cost, Shutdown Maintenance Frequency and The Loss in production That Occurs as a Result of Performing Shutdown Maintenance

2.2 MAINTENANCE:

This section is an introductory section for the discussion about the ways and the methods that have been developed to reduce shutdown maintenance cost and frequency and the loss in production that is caused by performing shutdown maintenance activities. It includes important subjects about maintenance such as maintenance definition, maintenance objectives, types of maintenance, and general information about shutdown maintenance. In addition, it includes a discussion about the history of maintenance, which illustrates the importance of maintenance, and how it is necessary for manufacturing and service industries. In the following subsections this history and the other important subjects about maintenance will be presented.

2.2.1 Maintenance History:

In the period of pre-World War II, people thought of maintenance as an added cost to the plant which did not increase the value of finished product (Longley, 1986). The people of that era tried to ignore this function and its activities (Corder, 1976; Shenoy and Bhadury 1998). However, they found that the ignorance of this function will end up with closing the business or performing more expensive function which was represented by the replacement of every failed component, part or even the whole machine (Corder, 1976; Shenoy and Bhadury 1998). Therefore, the maintenance at that era was restricted to fixing the unit when it breaks because it was the cheapest alternative (Corder, 1976; Longley, 1986; Shenoy and Bhadury 1998).

During and after World War II at the time when the advances of engineering and scientific technology developed, the real attention to maintenance was established (Corder, 1976; Longley, 1986; Shenoy and Bhadury 1998). People found that run-to-failure maintenance was not feasible all the time (Corder, 1976; Shenoy and Bhadury 1998). They developed other types of maintenance, which were much cheaper such as preventive maintenance (Corder, 1976; Shenoy and Bhadury 1998). In addition, people in this era classified maintenance as a function of the production system (Longley, 1986).

Nowadays, increased awareness of such issues as environment safety, quality of product and services makes maintenance one of the most important functions that contribute to the success of the industry (Corder, 1976; Shenoy and Bhadury 1998).

World-class companies are in continuous need of a very well organised maintenance programme to compete world-wide since these types of companies cannot afford unexpected delays in their operations (Steudel and Desruelle, 1992). Figure 2.2 illustrates the development of maintenance through out history.

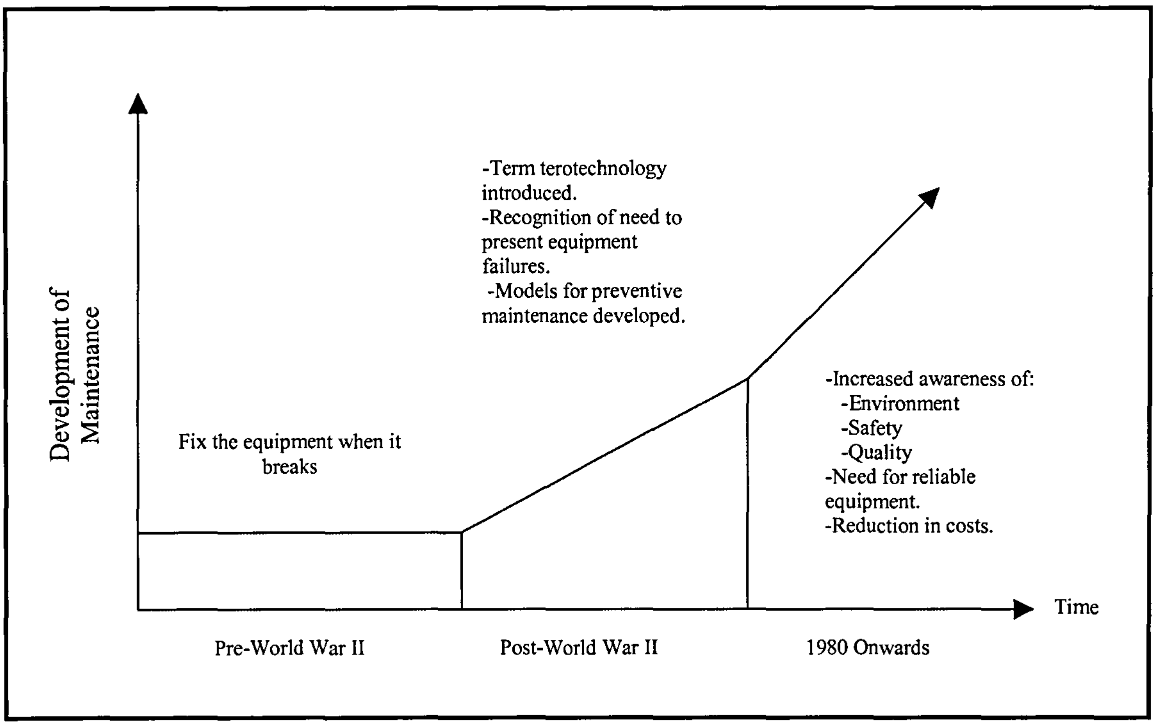

Figure 2.2 Maintenance History

(Adapted From Shenoy, Bhadury 1998)

2.2.2 Maintenance Definition:

There are several definitions for maintenance. Some of these definitions are complicated such as the one written by Higgins (1995) in which he stated that maintenance is:

> a science since its execution relies, sooner or latter, on most or all of the sciences. It is an art because seemingly identical problems regularly demand and receive varying approaches and actions and because some managers, foremen, and machines display greater aptitude for it than others show or even attain. It is above all a philosophy because it is a discipline that can be applied intensively, modestly, or not at all,

depending upon a wide range of variables that frequently transcend more immediate and obvious solutions.

Some of these definitions are simple such as the one written by Edwards, Holts and Harris (1998) who defined maintenance as:

> that which either retains mechanical plant and equipment in a safe operationally efficient condition or where plant items have broken down, restores them to safe operational status.

In addition, most maintenance definitions defined maintenance as a set of activities or actions that should be done in order to keep a given item in its best condition. Niebel (1985), for example, stated that:

> maintenance is a dynamic activity comprised of a great number of variables interacting with each other often in a random pattern.

Mann (1983) also defined maintenance as:

> the activities required to keep a facility in as-built, continuing to have its original productive capacity.

Shenoy and Bhadury defined maintenance as:

> a set of activities, or tasks, that are related to preserving equipment in a specified operating condition, or restoring failed equipment to a normal operating condition.

The best definition may be the one that has been developed by British Standard Glossary of terms (3811:1993) in which maintenance is defined as:

> the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function.

In summary, all of these definitions were valuable efforts that have been carried out to clarify the meaning of maintenance. They tried, in particular, to clarify that maintenance is a set of organised activities that are carried out in order to keep an item in its best operational condition with minimum cost acquired. Also, they tried to clarify that the activities of the maintenance function could be either repair or replacement activities, which are necessary for an item to reach its acceptable productivity condition and these activities, should be carried out with a minimum possible cost.

2.2.3 Maintenance Objectives:

Maintenance objectives should be consistent with and subordinate to production goals (Bullock, 1979; Dunlop 1990). The relation between maintenance objectives and production goals is reflected in the action of keeping production machines and facilities in the best possible condition. This relation is vital in order to support the overall production strategy while making the most economical use of total resources (Bullock, 1979 and Dunlop 1990). The maintenance objectives as they were mentioned by Bullock (1979) are the following:

1. Assuring the availability of production equipment and facilities.
2. Minimising the total downtime.
3. Improving machines and labour productivity.

Niebel (1985) added to the objectives mentioned by Bullock other useful objectives. He realised that assuring a safe and clean environment for plant employees, conserving the energy usage, and controlling the usage of spare parts and maintenance materials are very important objectives in order to have the most safe and economical maintenance program.

In addition to these objectives, there are other more detailed objectives that have been mentioned by other researchers, which could be summarised as follows (Clifton, 1974; Corder, 1976; Wireman, 1990):

1. Maximising production or increasing facilities availability at the lowest cost and at the highest quality and safety standards.
2. Reducing breakdowns and emergency shutdowns.
3. Optimising resources utilisation.
4. Reducing downtime.
5. Improving spares stock control.
6. Improving equipment efficiency and reducing scrap rate.

7. Minimising energy usage.
8. Optimising the useful life of equipment.
9. Providing reliable cost and budgetary control.
10. Identifying and implementing cost reductions.

Figure 2.3 illustrates these maintenance objectives.

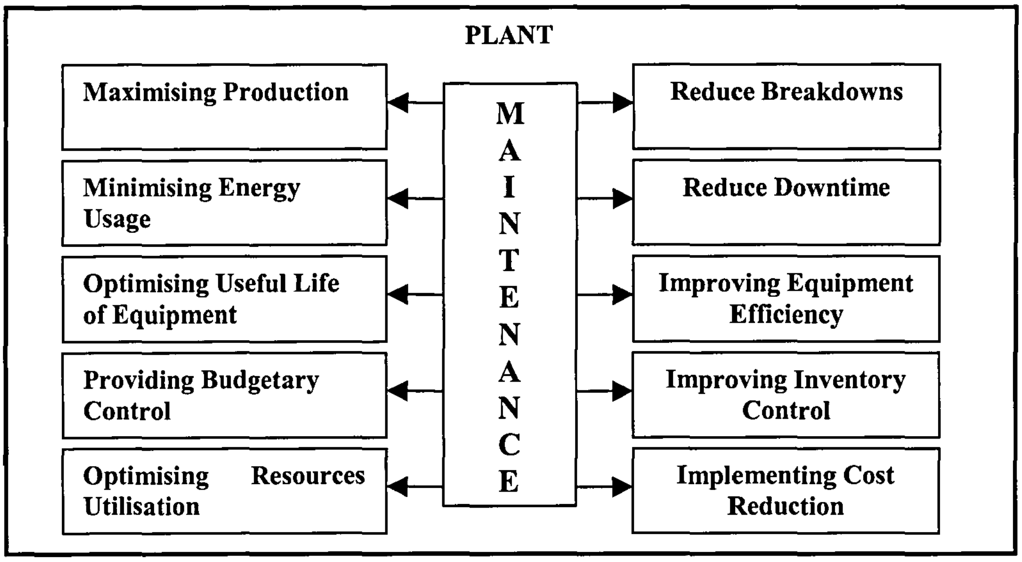

Figure 2.3 Maintenance Objectives

2.2.4 Types of Maintenance:

Researchers divided maintenance into different types. The division process was influenced by the experience of researchers in the area of maintenance. Bullock (1979), Clifton (1974), Corder (1976), Niebel (1985), and others divided maintenance into four types. The first type is the run to failure maintenance in which the required repair, replacement, or restore action will be performed on a machine or a facility after the occurrence of a failure in order to bring this machine or facility to at least its minimum acceptable condition (Bullock, 1979; Clifton, 1974; Corder, 1976; Mobley, 1990; Niebel, 1985). It is the oldest type of maintenance and it is subdivided into two types (Bullock, 1979; Clifton, 1974; Corder, 1976; Niebel, 1985). The first one is the emergency maintenance which is a set of activities that should be carried out as fast as possible in order to bring a failed machine or facility to a safe and operationally efficient condition (Corder, 1976; Dunlop, 1990; Edwards, Holt and Harris, 1998; Smith and Tate, 1998; Department of Education and Science, 1990). The second type is the breakdown maintenance which is a set of activities that are performed after the occurrence of an advanced considered failure for which advanced provision has been made in the form of repair method, spares, materials, labour and equipment (Clifton, 1974; Corder, 1976; Higgins, 1995).

Run to failure maintenance has several disadvantages. One of these disadvantages is that its activities are expensive in terms of both direct and indirect cost (Bullock, 1979; Henderson, Lothian, and Priest, 1998; Higgins, 1995; Smith and Tate, 1998). Also, by using this type of maintenance, the occurrence of a failure in a component can cause failures in other components in the same equipment, which leads to low production availability (Bullock, 1979; Henderson, Lothian, and Priest, 1998; Smith and Tate, 1998). In addition, run to failure maintenance activities are very difficult to plan and schedule in advance (Bullock, 1979; Higgins, 1995; Smith and Tate, 1998).

Despite all these disadvantages, this type of maintenance is useful in the following situations:

1. The failure of a component in a system is unpredictable (Bullock, 1979).
2. The cost of performing run to failure maintenance activities is lower than performing other activities of other types of maintenance (Smith and Tate, 1998).
3. The equipment failure priority is too low in order to include the activities of preventing it within the planned maintenance budget (Smith, 1993).

The second type of maintenance is preventive maintenance (PM) which is a set of activities that are performed on plant equipment, machinery, and systems before the occurrence of a failure in order to protect them and to prevent or eliminate any degradation in their operating conditions (Bullock, 1979; Clifton, 1974; Corder, 1976; Kelly and Harris, 1978; Niebel, 1985; Patton, 1995). British Standard 3811:1993 Glossary of terms defined preventive maintenance as:

> the maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning and the effects limited.

Preventive maintenance as policy is good for those machines and facilities which their failure would cause serious production losses (Loynnet, 1991). The aim of preventive maintenance activities is to maintain machines and facilities in such a condition that breakdowns and emergency repairs are minimised (Bullock, 1979; Clifton, 1974;

Corder, 1976; Kelly and Harris, 1978; Niebel, 1985; Patton, 1995; Department of Education and Science, 1990). These activities include replacements, adjustments, major overhauls, inspections and lubrications (Bullock, 1979; Clifton, 1974; Corder, 1976; Kelly and Harris, 1978; Niebel, 1985; Patton, 1995; Department of Education and Science, 1990). The advantage of applying preventive maintenance activities is to satisfy most of maintenance objectives. However, there are several factors that affect the efficiency of this type of maintenance. One of these factors is the support and commitment from executive management to the PM programme (Bullock, 1979; Lewis and Pearson, 1960). Another factor is the need for an adequate number of staff in the maintenance department in order to perform this type of maintenance (Bullock, 1979). In addition to these factors, there are other factors that affect this type of maintenance such as (Duffuaa, Raouf, and Campbell, 1999):

1. The right choice of production equipment and machinery that is suitable for the working environment and that can tolerate the workload of this environment.
2. The required staff qualifications and skills, which can be gained through training.
3. The proper planning and scheduling of PM programme.
4. The ability to properly apply the PM programme.

Researchers subdivided preventive maintenance into different kinds according to the nature of its activities (Clifton, 1974; Corder, 1976; Dunlop, 1990; Kelly, 1997; Kelly and Harris, 1978; Patton, 1995; Shenoy and Bhadury, 1998; Smith and Tate, 1998; Department of Education and Science, 1990; Wireman, 1990). These kinds are the following:

1. Routine maintenance which includes those maintenance activities that are repetitive and periodic in nature such as lubrication, cleaning, and small adjustment.
2. Running maintenance which includes those maintenance activities that are carried out while the machine or equipment is running and they represent those activities that are performed before the actual preventive maintenance activities take place.
3. Opportunity maintenance which is a set of maintenance activities that are performed on a machine or a facility when an unplanned opportunity exists during the period of performing planned maintenance activities to other machines or facilities.
4. Window maintenance which is a set of activities that are carried out when a machine or equipment is not required for a definite period of time.

5. Shutdown preventive maintenance, which is a set of preventive maintenance activities that are carried out when the production line is in total stoppage situation.

The third type of maintenance is the corrective maintenance in which actions such as repair, replacement, or restore will be carried out after the occurrence of a failure in order to eliminate the source of this failure or reduce the frequency of its occurrence (Corder, 1976; Higgins, 1995; Lyonnet, 1991; Moss, 1985; Smith and Tate, 1998). In the British Standard 3811:1993 Glossary of terms, corrective maintenance is defined as:

> the maintenance carried out after recognition and intended to put an item into a state in which it can perform a required function.

This type of maintenance could be subdivided into three types. The first type is the remedial maintenance, which is a set of activities that are performed to eliminate the source of failure without interrupting the continuity of the production process (Corder, 1976; Kelly, 1997; Patton, 1995; Shenoy and Bhadury, 1998; Wireman, 1990). The way to carry out this type of corrective maintenance is by taking the item to be corrected out of the production line and replacing it with reconditioned item or transferring its workload to its redundancy (Corder, 1976; Kelly, 1997; Patton, 1995; Shenoy and Bhadury, 1998; Wireman, 1990). The second type is the deferred maintenance, which is a set of corrective maintenance activities that are not immediately initiated after the occurrence of a failure but are delayed in such a way that will not affect the production process (Corder, 1976; Kelly, 1997; Moss, 1985; Wireman, 1990). The third and the last type of corrective maintenance is the shutdown corrective maintenance, which is a set of corrective maintenance activities that are performed when the production line is in total stoppage situation (Clifton, 1974; Duffuaa, Raouf, and Campbell, 1999; Kelly, 1997; Patton, 1995; Shenoy and Bhadury, 1998; Smith and Tate, 1998; Wireman, 1990).

The difference between corrective maintenance and preventive maintenance is that for the corrective maintenance, the failure should occur before any corrective action is taken (Higgins, 1995). Also, corrective maintenance is different from run to failure maintenance in that its activities are planned and regularly taken out to keep plant's machines and equipment in optimum operating condition (Higgins, 1995). The main objectives of corrective maintenance are the maximisation of the effectiveness of all critical plant systems, the elimination of breakdowns, the elimination of unnecessary repair, and the reduction of the deviations from optimum operating conditions (Higgins, 1995).

The way to perform corrective maintenance activities is by conducting four important steps (Moss, 1985). These steps start with fault detection which is followed by fault isolation, fault elimination, and finally, the verification of fault elimination (Moss, 1985). In the fault elimination step several actions could be taken such as adjusting, aligning, calibrating, reworking, removing, replacing or renovation (Moss, 1985).

Corrective maintenance has several prerequisites in order to be carried out effectively (Higgins, 1995). These prerequisites are the following:

1. Accurate identification of incipient problems.
2. Effective planning which depends on the skills of the planners, the availability of well developed maintenance database about standard time to repair, a complete repair procedures, and the required labour skills, specific tools, parts and equipment.
3. Proper repair procedures.
4. Adequate time to repair.
5. Verification of repair.

The fourth type of maintenance is the improvement maintenance, which aims at reducing or eliminating entirely the need for maintenance (Bullock, 1979; Clifton, 1974; Corder, 1976; Duffuaa, Raouf, and Campbell, 1999; Kelly, 1997; Kelly and Harris, 1978; Patton, 1995; Smith and Tate, 1998; Wireman, 1990). This type of maintenance has been subdivided into three types as follows (Bullock, 1979; Clifton, 1974; Corder, 1976; Duffuaa, Raouf, and Campbell, 1999; Kelly, 1997; Kelly and Harris, 1978; Patton, 1995; Smith and Tate, 1998; Wireman, 1990):

1. Design-out maintenance which is a set of activities that are used to eliminate the cause of maintenance, simplify maintenance tasks, or raise machine performance from the maintenance point of view by redesigning those machines and facilities which are vulnerable to frequent occurrence of failure and their long term repair or replacement cost is very expensive.
2. Engineering services which includes construction and construction modification, removal and installation, and rearrangement of facilities.

3. Shutdown improvement maintenance, which is a set of improvement maintenance activities that are performed while the production line is in a complete stoppage situation.

In addition to these four main types of maintenance, some researchers added another type, which is known as predictive maintenance. Predictive maintenance is a set of activities that detect changes in the physical condition of equipment (signs of failure) in order to carry out the appropriate maintenance work for maximising the service life of equipment without increasing the risk of failure (Higgins, 1995; Mobley, 1990; Smith and Tate, 1998). This type of maintenance has been classified into two kinds according to the methods of detecting the signs of failure (Edwards, Holt and Harris, 1998; Lyonnet, 1991; Moss, 1985). These kinds are the condition-based predictive maintenance and the statistical-based predictive maintenance (Edwards, Holt and Harris, 1998; Lyonnet, 1991; Moss, 1985).

Condition-based predictive maintenance depends on continuous or periodic condition monitoring equipment to detect the signs of failure (Edwards, Holt and Harris, 1998). On the other hand, statistical-based predictive maintenance depends on statistical data from the meticulous recording of the stoppages of the in-plant items and components in order to develop models for predicting failures (Edwards, Holt and Harris, 1998). The drawback of predictive maintenance is that it depends heavily on information and the correct interpretation of the information (The Tribology Group of the Institute of Mechanical Engineers, 1998).

Some researchers classified predictive maintenance as a type of preventive maintenance (Lyonnet, 1991; Mann, 1983; Moss, 1985; Parkes, 1978; Smith, 1993). However, the main difference between preventive maintenance and predictive maintenance is that predictive maintenance uses monitoring the condition of machines or equipment to determine the actual mean time to failure whereas preventive maintenance depends on industrial average life statistics (Mobley, 1990).

In addition to predictive maintenance, there is the total productive maintenance (TPM) which is a maintenance approach used in the manufacturing organisations. This approach evolved in the Japanese manufacturing industries as a part of their response to the changeable competitive market environment (Duffuaa et al, 1999; Rich, 1999).

The main objective of (TPM) is to make maintenance as a company-wide activity, which aimed at increasing the effectiveness of all the company machines, equipment and other assets to their highest potential, and to maintain them at that level through their entire lifecycle (Duffuaa et al, 1999; Rich, 1999). The results of doing this are the optimisation of the production process and the improvement to the overall success of the business (Duffuaa et al, 1999; Rich, 1999). The Japanese institute of plant engineers subdivided the main objective of (TPM) into five key goals in order to illustrate (TPM) importance to the business. These goals are (Duffuaa et al, 1999; Rich, 1999):

1. Increase the overall equipment effectiveness to its maximum level, through increasing equipment availability; process efficiency and product quality.
2. Establish preventive maintenance system for the economic lifetime of the equipment in order to ensure the required level of reliability, maintainability, and life cycle costs.
3. Involve other organisation departments such as production operations, materials management, industrial engineering, and administration in the implementation of (TPM).
4. Involve every employee at all levels of the organisation in the implementation of (TPM).
5. Increase the awareness of the (TPM) and its objectives through small group activities and team performance.

The focal point of (TPM) is the integration of the maintenance department (its strategies, structures and responsibilities for the maintenance of the equipment) with all other business departments, which affected the ability to maintain the equipment at optimal performance (Duffuaa et al, 1999; Rich, 1999). The most important department among the business departments that stimulated this integration is the production department with its teams of production operators (Duffuaa et al, 1999; Rich, 1999). As a result of this process of integration, the maintenance department delegates some of its traditional routines to other business departments (through the use of their resources such as the manpower) in order to increase its control and importance for the commercial success of the business (Duffuaa et al, 1999; Rich, 1999).

The TPM approach in the literature is classified as a management approach to maintenance rather than a type of maintenance (Duffuaa et al, 1999; Rich, 1999). It is used in the manufacturing industries to enhance the role of the maintenance function in the overall success of the organisation (Duffuaa et al, 1999; Rich, 1999).

In summary, maintenance could be classified into two types. The first type is the planned maintenance or the proactive maintenance, which includes preventive maintenance, predictive maintenance, corrective maintenance, improvement maintenance, and shutdown maintenance. The activities in this type of maintenance are characterised by their ability to be planned and scheduled. The second type of maintenance is the unplanned maintenance or the reactive maintenance, which includes breakdown maintenance, and emergency maintenance. In this type of maintenance, activities are very difficult to be planned and scheduled. Figure 2.4 illustrates the types of maintenance.

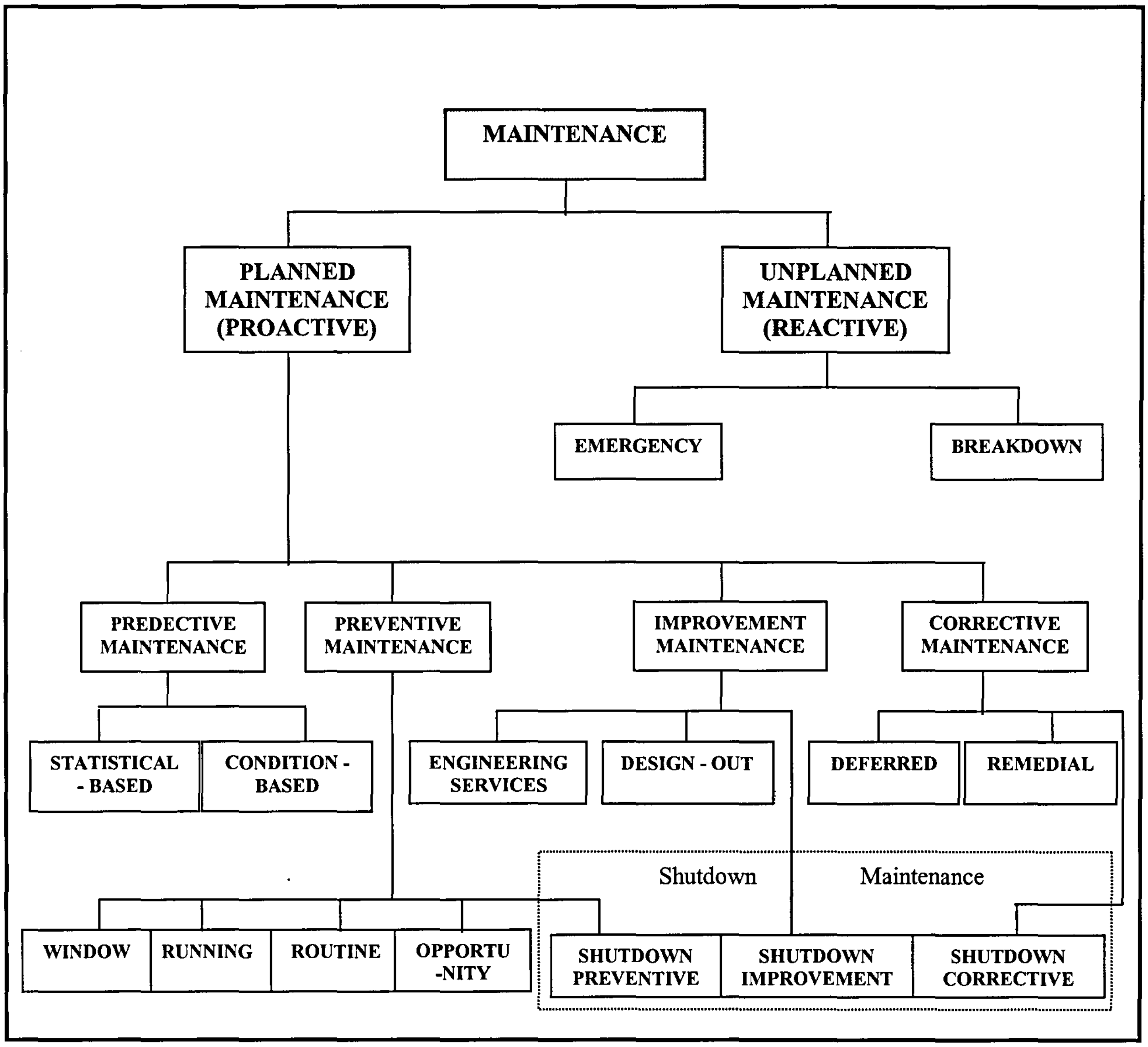

Figure 2.4 Maintenance Types

2.2.5 Shutdown Maintenance:

Shutdown maintenance is planned maintenance which is important and necessary for the rectification and the modification of plant equipment, machinery, and systems and which is impossible to be carried out during normal operation due to production requirements (Duffuaa, Raouf and Campbell, 1999; Dunlop, 1990; The Joint Development Board, 1997). According to the British Standard 3811:1993 Glossary of terms, shutdown maintenance has been defined as:

> maintenance that can be carried out only when the item is out of service.

This means that shutdown maintenance could include preventive maintenance activities as well as corrective maintenance activities by which minor and major repairs and overhauls are carried out while the whole plant is in a shutdown situation (Duffuaa, Raouf and Campbell, 1999; Shenoy and Bhadury, 1998; The Joint Development Board, 1997). It also could include improvement maintenance activities and engineering projects such as plant expansion, modifications, which are necessary for effective production (Duffuaa, Raouf and Campbell, 1999; Dunlop, 1990; Kelly, 1997; Kelly and Harris, 1978, Patton, 1995; The Joint Development Board, 1997).

Shutdown maintenance as a concept was initiated in the continuous process industries in order to reduce unplanned shutdowns through performing planned maintenance activities on those machines and equipment that could not be maintained while the production line is running (Ashayeri, Teelen and Selen, 1996; Duffuaa, Raouf and Campbell, 1999). Such machines and equipment are clearly found in these industries since the use of redundancies is very expensive and the operating of the production line with its partial capacity is unacceptable (Ashayeri, Teelen and Selen, 1996; Duffuaa, Raouf and Campbell, 1999; Iyer, 1996; Patton, 1995). In addition, they exist in these industries since the production system in these industries is represented by a single production line in which the machines and equipment are highly related to each other which means that they are needed to be available all the time (Ashayeri, Teelen and Selen, 1996; Duffuaa, Raouf and Campbell, 1999; Mann, 1983).

The main characteristic of shutdown maintenance is that its activities are planned and scheduled (Ashayeri, Teelen and Selen, 1996; Hildebrandt and Piccolo, 1992; Kelly and Harris, 1978; Mann, 1983; Patton, 1995). At the same time, the planning and scheduling of these activities are based on the operation condition and the production demand for the plant machines and facilities (Ashayeri, Teelen and Selen, 1996; Duffuaa, Raouf and Campbell, 1999; Hildebrandt and Piccolo, 1992; Kelly and Harris, 1978; Mann, 1983; Patton, 1995). This makes shutdown maintenance much cheaper than the old type of maintenance (Run to Failure) which is unplanned and which its activities are very difficult to be scheduled since they are unpredictable (Ashayeri, Teelen and Selen, 1996; Hildebrandt and Piccolo, 1992; Kelly and Harris, 1978; Mann, 1983; Patton, 1995).

The overall aim of shutdown maintenance is to make plant equipment, machinery and systems operate properly and safely, especially, in those industries that need a total stoppage of their production system in order to carry out planned maintenance activities (Ashayeri, Teelen and Selen, 1996; Duffuaa, Raouf and Campbell, 1999; Hildebrandt and Piccolo, 1992; Kelly and Harris, 1978; Mann, 1983; Patton, 1995). This means that the good application of shutdown maintenance will provide several benefits to the production system, which can be summarised as follows (Corder, 1976; Duffuaa, Raouf and Campbell, 1999; Iyer, 1996; Roberts and Mask, 1992; Wireman, 1990):

1. Reduces and better controls the risk of unplanned, costly major breakdowns and interruptions.
2. Increases plant availability for production, which creates a good environment for new manufacturing technologies such as just-in time manufacturing (JIT).
3. Minimises the consumption of energy in order to have an energy efficient production system.
4. Provides safe, clean and more organised environment.
5. Extends equipment useful life.
6. Extends the duration between overhauls.
7. Reduces the use of redundancy.
8. Improves equipment efficiency and product quality.

In spite of all these benefits, shutdown maintenance is expensive (Chareonsuk, Nagarur, and Tabucanon, 1997; Duffuaa, Raouf and Campbell, 1999; Mathew and Rajendran, 1993; The Joint Development Board, 1997). The reason for this is that it requires a total stoppage of the production system in order to be performed, which creates production losses (Chareonsuk, Nagarur, and Tabucanon, 1997; Duffuaa, Raouf and Campbell, 1999; Mathew and Rajendran, 1993; The Joint Development

Board, 1997). In addition, it needs when it is carried out a large amount of material and labour in a short period of time, which creates high maintenance cost (Chareonsuk, Nagarur, and Tabucanon, 1997; Duffuaa, Raouf and Campbell, 1999; Mathew and Rajendran, 1993).

2.3 MAINTENANCE IN MANUFACTURING SYSTEMS:

Maintenance policy and programmes can be applied to any operational systems such as construction systems, manufacturing systems, communication systems, health systems and services (Honey, 1994; Taylor, 1991; The Chartered Institute of Building, 1990). In each type of these systems, the type of maintenance policy and programme is determined according to the nature of the processes in that system (Honey, 1994; Taylor, 1991; The Chartered Institute of Building, 1990). Since the concentration in this thesis is to reduce the shutdown maintenance cost and frequency and the loss in production that occurs as a result of performing shutdown maintenance activities in continuous process industries, the subject of this section is the maintenance policy and programmes in the manufacturing systems. However, before discussing this issue, a quick review of the manufacturing systems will be presented in the following subsections.

2.3.1 Manufacturing Systems:

Manufacturing is a set of organised activities performed in order to transform raw materials into marketable goods (Browne, Harhen and Shivnan, 1996; Wu, 1992). When these activities are grouped together, they form a series of value-adding manufacturing processes that convert the raw materials into more useful forms. These manufacturing processes are called the manufacturing system (Wu, 1992).
Manufacturing systems are input-output systems where the outputs of one system may be used by another system as one of the inputs (Browne, Harhen and Shivnan, 1996; Wu, 1992). Therefore, the continuation of the flow of these inputs with high quality, in the right time and with minimum cost is important for the continuation of the manufacturing cycle (Wu, 1992). One of the most important factors that support the continuation of the flow of inputs in the manufacturing system is the existence of

effective and efficient maintenance programme (Ashayeri, Teelen and Selen, 1996; Mann, 1983; Steudel and Desruelle, 1992; Woodgate, 1991).

In addition to maintenance, there are other factors that affect the continuation of the manufacturing systems (Browne, Harhen and Shivnan, 1996; Steudel and Desruelle, 1992; Wu, 1992). These factors are the following:

1. Productive labours.
2. Production means.
3. Production information.

Figure 2.5 illustrates the relation between manufacturing systems.

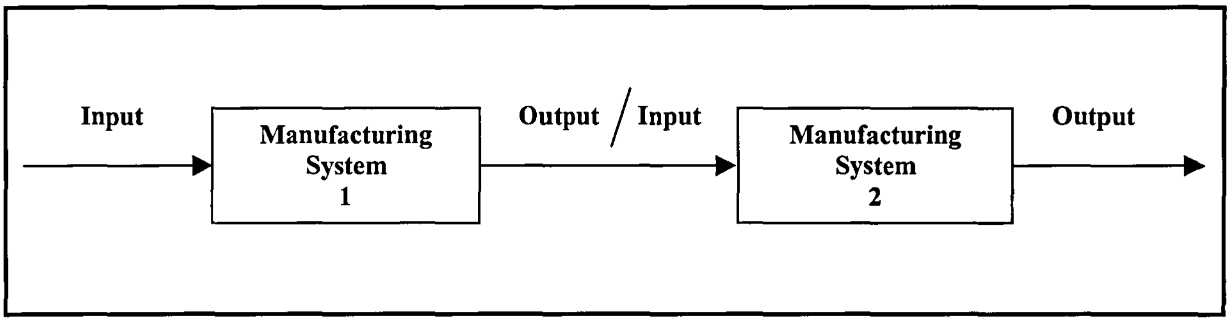

Figure 2.5 The Relation Between Manufacturing Systems

2.3.2 Types of Manufacturing Systems:

Manufacturing systems (industries) are classified differently according to different factors. Some of these factors are related to the product and the manufacturing system such as the method of manufacture being employed, the type of product involved (consumer good, capital good, etc.); the nature of the product being manufactured (mechanical, electrical, biological, chemical, etc.); and the technology involved (from simple to complex and highly sophisticated) (Wu, 1992). Others are related to product value and the market in which products will be sold such as the unit value of the product (from a few pence to millions of pounds); and the nature of the market concerned in terms of size, maturity, competitiveness, and so on (Wu, 1992). Among these factors, the factor that influences the traditional classification of manufacturing systems is the method of manufacture being employed (Ashayeri, Teelen and Selen, 1996; Browne, Harhen and Shivnan, 1996; Wu, 1992). According to this factor, manufacturing systems (industries) are classified into two types as illustrated in Figure 2.6 (Ashayeri, Teelen and Selen, 1996; Browne, Harhen and Shivnan, 1996; Wu, 1992). These are the continuous production industries and the discrete parts industries (Ashayeri, Teelen and Selen, 1996; Browne, Harhen and Shivnan, 1996; Wu, 1992).

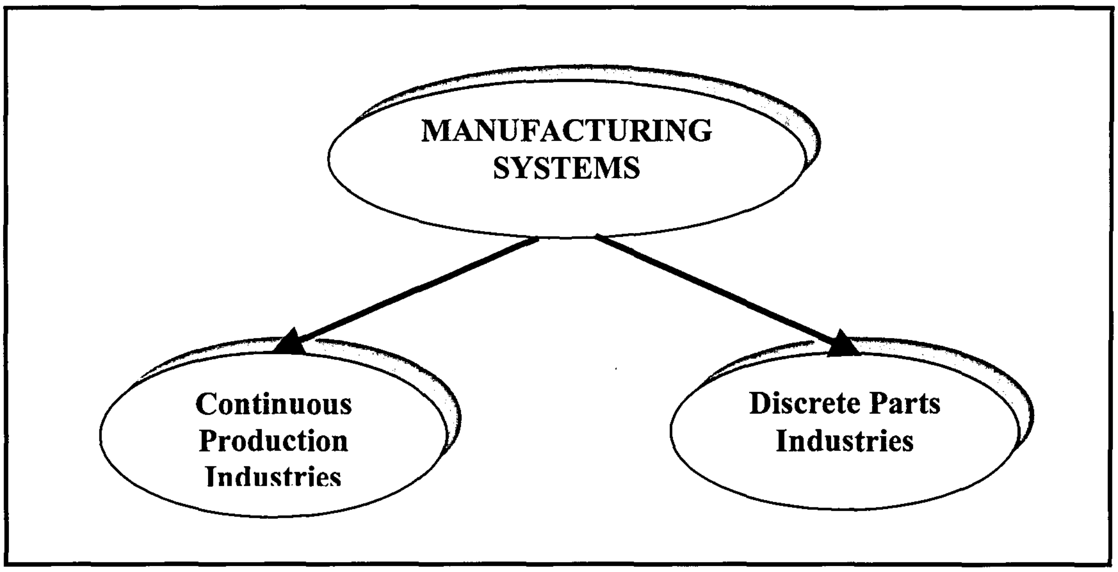

Figure 2.6 Types of Manufacturing Systems

Each type of these manufacturing systems (industries) has its own characteristics. In the discrete parts industries, for example, the production volume is in the range between medium to low and the types of products that are being produced range from many types of different products to a medium range of products (Browne, Harhen and Shivnan, 1996; Wu, 1992). This makes the level of product standardisation in these industries ranging from low to medium (Browne, Harhen and Shivnan, 1996; Wu, 1992). In addition, the production system in these industries is in the range between reasonably flexible to highly flexible (Browne, Harhen and Shivnan, 1996; Wu, 1992).

On the other hand, the characteristics of continuous production industries are completely different than the above characteristics. Production volume in these industries, for example, is high and the variety of products is low (Ashayeri, Teelen and Selen, 1996; Browne, Harhen and Shivnan, 1996; Wu, 1992). In addition, the products in these industries are highly standardised and the flexibility of the production system is very low and restricted (Ashayeri, Teelen and Selen, 1996; Browne, Harhen and Shivnan, 1996; Wu, 1992). These differences in the characteristics of the two types of manufacturing systems are illustrated in figure 2.7.

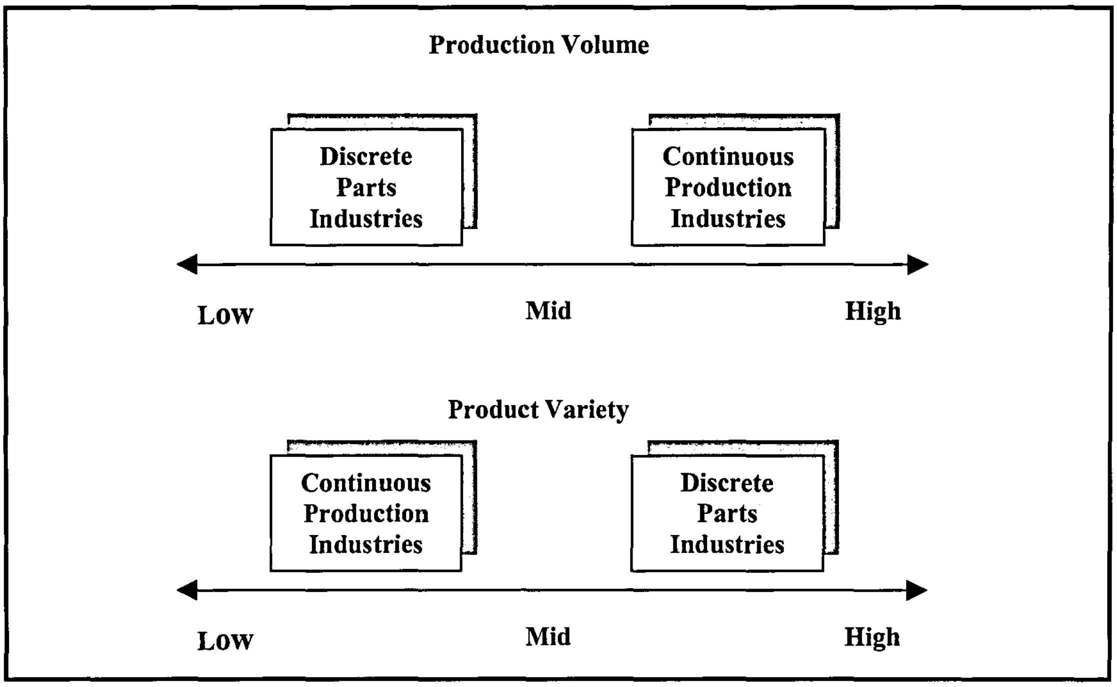

Figure 2.7 The Differences in The Characteristics of The Manufacturing Systems Types

Another useful and well-known classification of manufacturing systems is the one that divides the manufacturing systems into two types according to their operating structures (Browne, Harhen and Shivnan, 1996; Wu, 1992). These types are make-to-stock and make-to-order as illustrated in figure 2.8. In the make-to-stock system, a stock of finished products are made by either a stock of raw materials or raw materials from the source (supplier) and then shipped to the customer (Browne, Harhen and Shivnan, 1996; Wu, 1992). In the second type, which is the make-to-order the finished products are shipped directly to the customer after they have been made from either a stock of raw materials or from raw materials coming from the source (supplier) (Browne, Harhen and Shivnan, 1996; Wu, 1992).

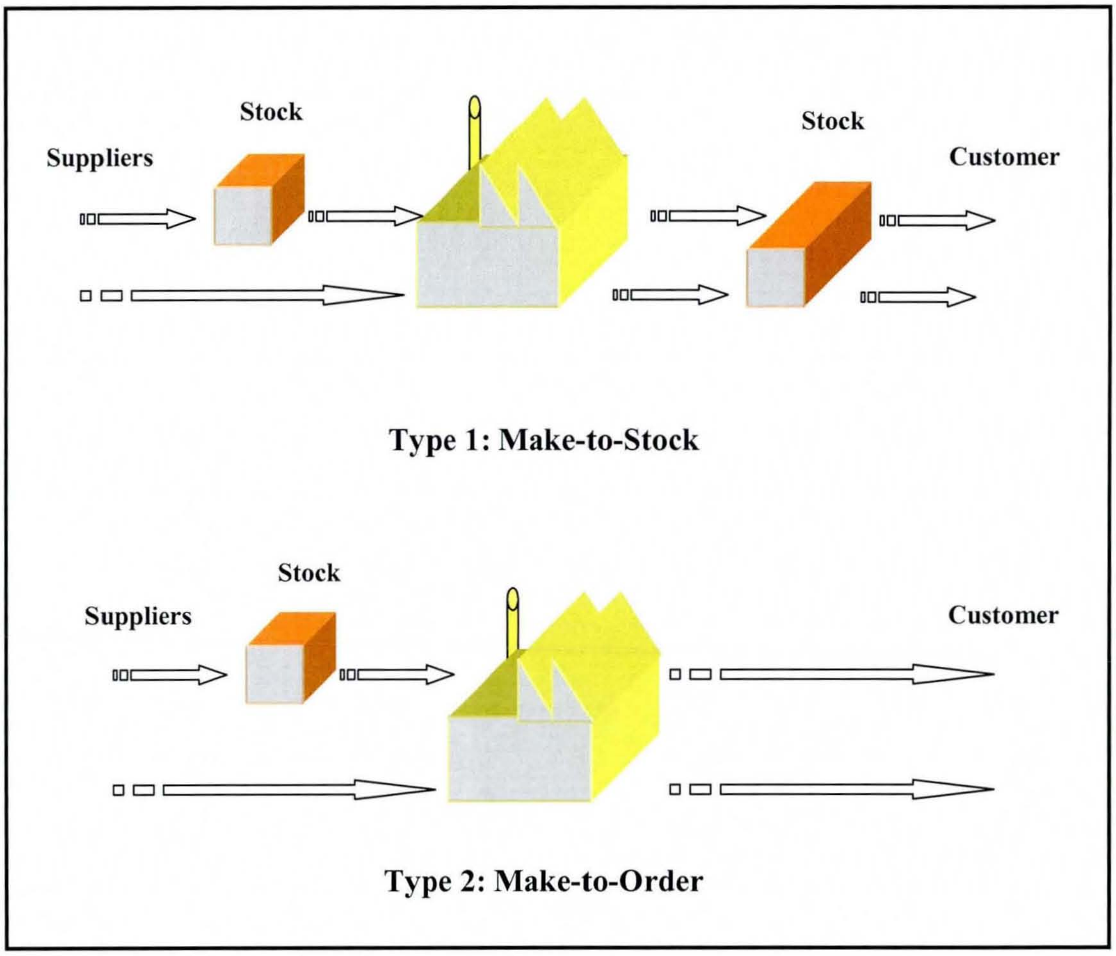

Figure 2.8 Make-to-Stock and Make-to-Order Manufacturing Systems (Adopted From Wu, 1992)

Some researchers added to these two types of manufacturing systems in this classification another two, which are, assemble-to-order and engineer-to-order (Browne, Harhen and Shivnan, 1996). In these two types, customers will take the control of the final structure of the product (Browne, Harhen and Shivnan, 1996). Therefore, they may request a new engineering design to be developed or they may request that the product be constructed by different core subassemblies (Browne, Harhen and Shivnan, 1996).

The classification of manufacturing systems (industries) that will be used in this thesis is the one by which manufacturing systems (industries) are classified into continuous production industries and discrete parts industries. The reason for this is that this classification is directly related to the subject of this thesis.

2.3.3 The Use of Maintenance in Manufacturing Systems:

Maintenance as a function is very important for any type of manufacturing industries. It keeps the continuation of manufacturing cycle (Ashayeri, Teelen and Selen, 1996; Mann, 1983; Steudel and Desruelle, 1992; Woodgate, 1991). Therefore, manufacturing industries usually search for the proper maintenance programme that achieves the purpose of using the maintenance function (Lyonnet, 1991; Moss, 1985; Smith, 1993; Smith and Tate, 1998). This proper maintenance programme is not necessary to be constructed from one type of maintenance but it is usually constructed from several types (Lyonnet, 1991; Moss, 1985; Smith, 1993; Smith and Tate, 1998). The selection process of the maintenance types that form the proper maintenance programme calls for a clear understanding of several issues (Smith and Tate, 1998). These issues are the following (Smith and Tate, 1998):

1. The reasons for having maintenance.
2. The industrial organisation business function.
3. The relationship between the business function, plant items, and plant systems.
4. The required plant performance and function.
5. The risk of plant failure and how it can fail.
6. The meaning of the failure to the business.
7. The ways to stop the failure and the ways to limit its effects.

In addition, it calls for the consideration of several factors that affect the way of determining the best maintenance types to be selected (Lyonnet, 1991; Moss, 1985; Smith, 1993; Smith and Tate, 1998). These factors are the type of the production system, the complexity of its machines and facilities, and the cost of the selected maintenance type (Lyonnet, 1991; Moss, 1985; Smith, 1993; Smith and Tate, 1998).

Based on all of this, manufacturing industries sometimes use well-known techniques in order to ensure the understanding of these issues and the consideration of these factors and in turn, to help in the selection of the correct maintenance types (Smith, 1993; Smith and Tate, 1998).

One of these techniques is that which was developed by Smith and Tate (1998) and by which industrial organisations can choose the maintenance types that are suitable for their systems. This technique has several steps that are necessary to be performed in order to select the correct maintenance types that form the overall maintenance programme of the industrial organisation. These steps are (Smith and Tate, 1998):

1. Identifying the maintenance needs of the industrial organisation.
2. Identifying the ways in which plant can fail and the risk of failure.
3. Choosing the maintenance type that matches the failure mode of the unit or system.
4. Performing a cost benefit analysis for the selected type and compare it with the cost of failure and the use of other maintenance types.
5. Reviewing the whole process.

In addition to this technique, there is another well-known technique that helps in this matter. This technique is called the reliability-centred maintenance (RCM) methodology which is centred around the principle that the best maintenance type to be used for maintaining systems in an industrial organisation is the one with the best safety, availability, and cost-effectiveness justifications (Smith, 1993).

RCM is a two parts analysis methodology. The first part covers the reliability side of the methodology which is concerned with the determination of the failure modes, sources, and the frequency of these modes (Smith, 1993). The second part covers the maintenance side of the methodology in which the determination of the proper maintenance type is performed through the use of a set of logical sequenced questions (Smith, 1993). The steps of the RCM that should be carried out through its two parts are the following (Smith, 1993):

1. Collection of information about the system.
2. Definition of system boundary.
3. Description and functional block diagram of the system.
4. Identification of system functions.
5. Identification of functional failures.
6. Identification of failure mode.
7. Performing effects analysis (FMEA).
8. Performing logic tree analysis (LTA).

2.4 SHUTDOWN MAINTENANCE IN CONTINUOUS PROCESS INDUSTRIES:

2.4.1 Continuous Production Industries:

Continuous production industries represent an important type of manufacturing industries. This type of industries is characterised by having production system that produces a small range of highly standardised products in large quantities (Browne, Harhen and Shivnan, 1996; Chryssolouris, 1992; Wild, 1972; Wu, 1992). Typically, the process in these industries is capital-intensive and the demand for products is stable (Browne, Harhen and Shivnan, 1996; Chryssolouris, 1992; Wu, 1992). In these industries, the changes in the product design is very little over the short to medium term (Browne, Harhen and Shivnan, 1996). In addition, the machinery and workers that are needed are highly specialised (Browne, Harhen and Shivnan, 1996; Chryssolouris, 1992; Wu, 1992).

Ashayeri, Teelen and Selen (1996) defined continuous production industries as:

> businesses that add value to materials by mixing, separating, forming or chemical reactions. Processes may be either continuous or batch and usually require rigid process control and high capital investment.

Examples of continuous production industries are chemical industry, petroleum industry, food and beverages industry, sugar manufacturing industry, and paper manufacturing industry (Ashayeri, Teelen and Selen, 1996).

Continuous production industries are subdivided into two types as illustrated in figure 2.9. The first type is the continuous process industries in which the production of products is continuous and the relation between the production operations is a serial relation (Ashayeri, Teelen and Selen, 1996; Browne, Harhen and Shivnan, 1996; Chryssolouris, 1992; Wild, 1972). Typical example of these industries is the chemical industry. The second type of continuous production industries is the batch continuous production industries or mass production industries in which products are produced continuously in batches (Browne, Harhen and Shivnan, 1996; Chryssolouris, 1992; Wild, 1972; Wu, 1992). However, the relation between the production operations in these industries is not necessary a serial relation (Browne, Harhen and Shivnan, 1996;

Chryssolouris, 1992; Wild, 1972; Wu, 1992). Typical example of these industries is the paper manufacturing industry.

In this thesis, the concentration is on continuous process industries where the use of shutdown maintenance as the main maintenance policy being practised.

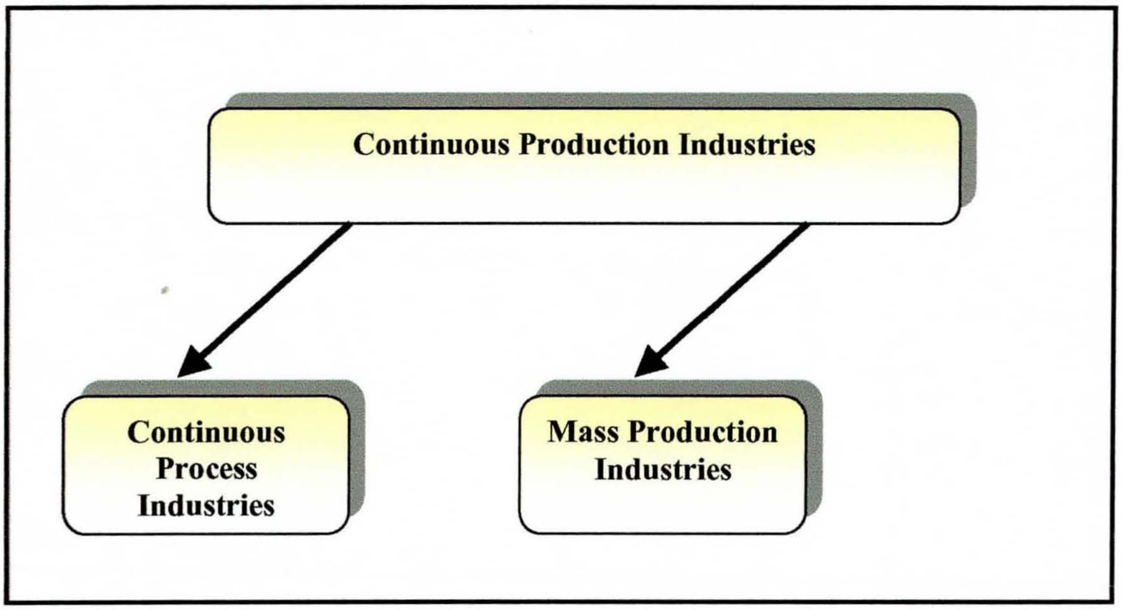

Figure 2.9 Types of Continuous Production Industries

2.4.2 Maintenance in Continuous Process Industries:

The moment in which machines or any forms of automation are introduced into the production environment, maintenance with all its applicable types becomes part of the manufacturing system and the maintenance programme has to be applied fully and by the same way as other manufacturing programmes (Hong, 1995; Woodgate, 1991). The need for maintenance and its programme is to assure that machines are correctly set-up and ready to go into production (Hong, 1995; Woodgate, 1991). At the same time, the proper application of the maintenance and its programme is necessary to keep the efficiency of using energy and other supportive facilities at the highest level (Broughton, 1994).

In continuous process industries where machines and facilities are specialised, highly sophisticated and expensive, the importance of maintenance becomes one of the most valuable priorities (Ashayeri, Teelen and Selen, 1996; Mann, 1983). In fact, maintenance in these industries is one of the major functions that can deal with the stringent environment of these industries (Ashayeri, Teelen and Selen, 1996; Mann, 1983).

One of the most important issues that reflects the importance of the maintenance function in these industries is the use of shutdown maintenance programme (Ashayeri, Teelen and Selen, 1996; Mann, 1983). This type of planned maintenance programmes is needed in these industries in order to maintain their production systems since they are not redundant systems (Ashayeri, Teelen and Selen, 1996; Mann, 1983). In addition, it is needed since the use of in-process maintenance programmes in these industries is very difficult because of the hazardous environment and the difficulty of reaching the parts of the production systems quickly and without causing any production, safety, or economic problems (Clifton, 1974; Lyonnet, 1991).

However, few facilities especially in the infrastructure systems in these industries could be maintained by using other type of planned maintenance programmes (Lyonnet, 1991; Shenoy and Bhadury, 1998). The reason behind this is that these facilities may have either one of the following (Lyonnet, 1991; Shenoy and Bhadury, 1998):

1. Marginal role in the production system, which allows them to be isolated for a specific period of time which, is enough to perform maintenance activities without affecting the entire production system.
2. Redundancies either active or passive through which performing other type of planned maintenance activities on the main facilities will not cause a stoppage in the entire system.

Failing to apply a suitable planned shutdown maintenance programme in these industries makes production systems more vulnerable to unforeseen shutdowns (Ashayeri, Teelen and Selen, 1996; Hildebrandt and Piccolo, 1992; Mann, 1983). These emergency unforeseen shutdowns are more expensive than the planned shutdowns since their associated cost is not a planned cost (Ashayeri, Teelen and Selen, 1996; Hildebrandt and Piccolo, 1992). In addition, emergency shutdowns create unsafe and dangerous environments, which are not acceptable by any type of manufacturing industries (Ashayeri, Teelen and Selen, 1996; Hildebrandt and Piccolo, 1992). Figure 2.10 illustrates the role of the maintenance function in continuous process industries.

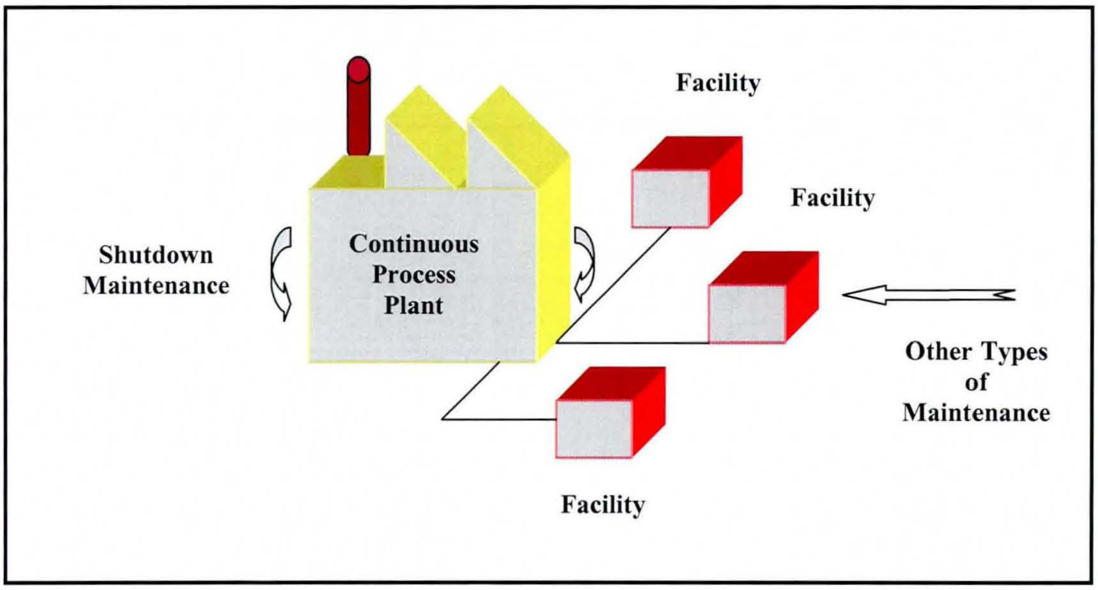

Figure 2.10 The Role of Maintenance Function in Continuous Process Industries

2.4.3 The Use of Shutdown Maintenance in Continuous Process Industries:

Shutdown maintenance programme is useful and necessary to improve production systems in continuous process industries by retrofitting and revamping their machines and facilities (Dunlop, 1990; Higgins, 1995; Iyer, 1996). It is also useful to modernise the production system in these industries through upgrading its technology (Dunlop, 1990; Higgins, 1995; Iyer, 1996). In addition, it is useful and necessary to achieve the following (Duffuaa, Raouf and Campbell, 1999; Iyer, 1996; The Joint Development Board, 1997):

1. Improving production performance through modifications.
2. Meeting the requirements of statutory inspection.
3. De-bottlenecking production system and removing load limitation.
4. Overhauling critical equipment.
5. Performing inspection for critical equipment.
6. Cleaning all equipment.

All of the above mentioned benefits of shutdown maintenance could be achieved only if the shutdown maintenance programme is performed properly (English, 1997; Woodcock, 1989). The way to do this is by applying an important set of steps during which organised communication of data, information and documents are facilitated (English, 1997; Iyer, 1996; Roberts and Mask, 1992; Gupta and Paisie, 1997; Woodcock, 1989). These steps as illustrated in figure 2.11 are necessary in order to have smooth shutdown maintenance work period and they are the following (English, 1997; Iyer, 1996; Roberts and Mask, 1992; Gupta and Paisie, 1997; Woodcock, 1989):

1. Preplanning: This step is subdivided into the following sub-steps:
    A. Formulation: In this sub-step, top management decides what major jobs should be included in the shutdown, and resources that are required for these jobs. In addition, top management decides the starting date, which depends on resources arrival.
    B. Preparing a job list: In this sub-step, each department prepares its own list of jobs that are proposed to be included in the shutdown. A master list of all jobs gathered from each department is discussed in periodic meetings.

2. Planning: This step is subdivided into the following sub-steps:
    A. Detailed planning: In this sub-step, the following should be prepared:
        a. Detailed plan for needed materials, manpower, maintenance equipment, and contractors.
        b. Actions for hiring external manpower, expatriate services, vendors' specialists, and external agencies.
        c. Estimating total manpower.
        d. Allocating jobs for engineers and company technicians.
        e. Creating movement charts for heavy maintenance equipment.
        f. Listing scaffoldings, prefabrication jobs and electrical items.

    In this sub-step, also, a planning manual should be prepared by the production department, which includes the following:
        a. The time of handing over the jobs.
        b. Step-by-step procedure of handing over the equipment to maintenance department safely.
        c. The necessary checks that should be carried out before issuing the work permit.
        d. The responsibilities for each process engineer.

B. Scheduling: In this sub-step, the definition of job activities is prepared and the evaluation of critical path activities is performed.

C. Follow-up: In this sub-step, the follow-up of the arrival of materials, manpower, maintenance equipment is conducted in order to prepare the plant for shutdown.

3. Execution: This step is subdivided into the following sub-steps:
   A. Execution and job monitoring: The actual execution of the plan should start in this sub-step during which the monitoring action of the work is being performed.
   B. Preparing for start-up: in this sub-step each section is checked to find out if any job is left out. Also, a trial run of equipment in each section is made if possible in order to make each section ready for start-up. In addition, housekeeping of sections is performed in this sub-step and safety surveys of sections is taken out by the safety department in order to point out any unsafe condition. Finally, insulation and painting jobs are completed in this sub-step.
   C. Start-up.

4. Evaluation and continuous improvement: This step is subdivided into the following sub-steps:
   A. Evaluation: In this sub-step, evaluation of shutdown maintenance materials, manpower, and equipment performance is conducted in order to make future shutdowns safer and more efficient.
   B. Continuous improvement: In this sub-step, improvement in the shutdown maintenance strategy, techniques, and operating equipment are discussed.

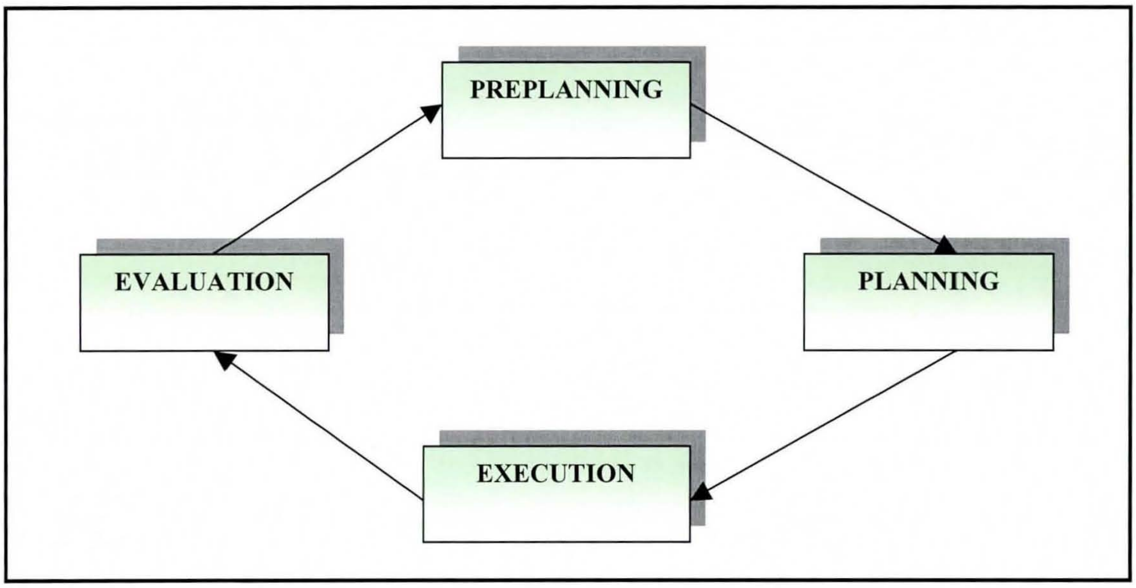

Figure 2.11 Shutdown Maintenance Steps

In spite of all these steps which their proper application is necessary in order to have a smooth shutdown maintenance work period, there are several factors that can cause shutdown maintenance programmes to fail (Iyer, 1996). Some of these factors are related to the materials and equipment used in the shutdown maintenance such as, the late arrival of spare parts and materials and the scarcity of tools, cranes, and other equipment (Iyer, 1996). Another group of factors are related to the contract, contractors and labour such as poor quality of contract workers, poor quality of workmanship, and poor contractor performance (Iyer, 1996). The rest of the factors are related to the way of carrying out the shutdown maintenance such as, unexpected scope of work, unrealistic planning, lack of smoothness in start-up, and lack of control (Iyer, 1996).

In addition to these factors, ignoring important issues such as the specific and firm starting date for the shutdown maintenance programme could have very dangerous consequences. In fact, postponement of shutdown maintenance after this date creates several problems, which may cause a failure of the shutdown maintenance programme. These problems can be summarised as follows (Adams, 1993):

1. Increasing the scope of shutdown maintenance because of backlogging of new maintenance jobs.

2. Changing in the list of critical jobs and reworking the entire timeline because of additional new jobs.
3. Changing in the availability of supervisors and manpower because of vacations, union business, etc.
4. Substantial alteration in people and job assignments.
5. Performing new meetings to update and prepare for the rescheduling shutdown.
6. Performing briefing for much of the crew in order to clarify the new changes.
7. Unavailability of contractors for rescheduled dates.
8. Creating disruption of crews in other departments.
9. Investing less time in preparations by supervisors and planners as a reacted behaviour to repetitive cancellations.
10. Affecting equipment reliability through postponing preventive maintenance and any other critical work.

Figure 2.12 illustrates the role of shutdown maintenance in continuous process industries.

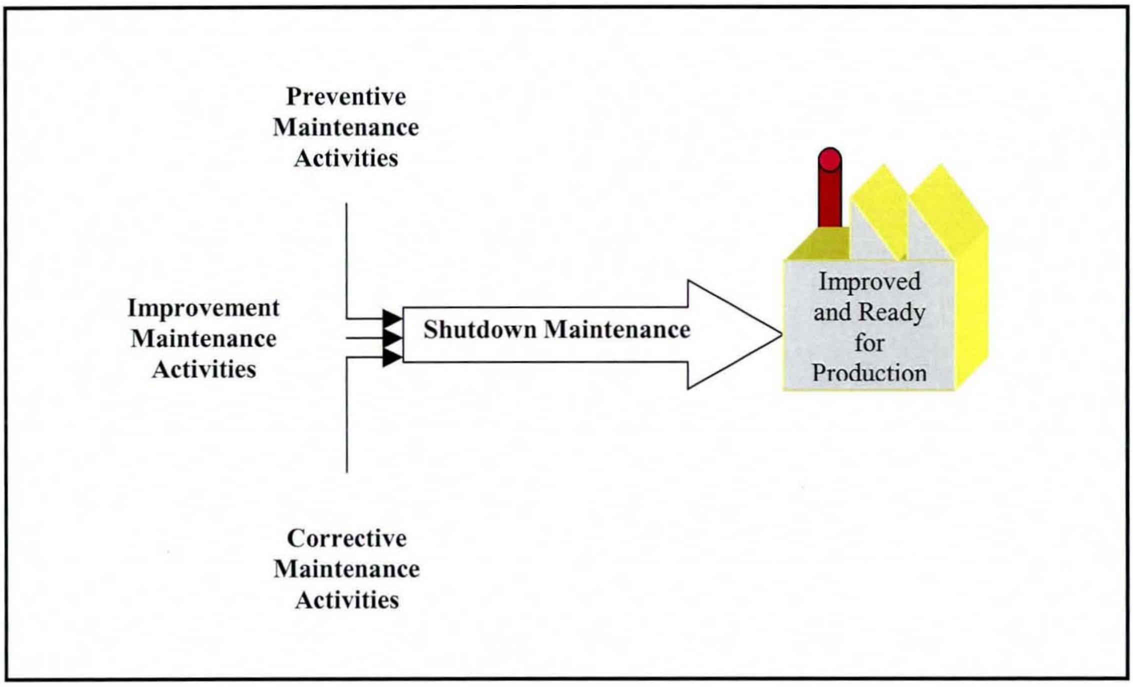

Figure 2.12 The Role of Shutdown Maintenance in Continuous Process Industries

2.5 PREVIOUS EFFORTS FOR REDUCING THE COST AND THE FREQUENCY OF SHUTDOWN MAINTENANCE AND THE LOSS IN PRODUCTION:

Shutdown maintenance as an expensive type of planned maintenance stimulated several studies in the literature to find ways or methods to make it less expensive and less frequent. In particular, it stimulated these studies to find ways or methods to reduce its cost and its frequency, in addition to, the loss in production that is caused by performing its activities without affecting the availability of machines and facilities and the level of performance. According to the approaches that have been used in this literature, the work in these studies could be classified in to three categories as follows:

1. Studies in which the work was concentrated on reducing shutdown maintenance frequency without increasing the unplanned shutdowns by means of searching for the optimum frequency that satisfies predetermined constraints.
2. Studies in which the work was concentrated on reducing shutdown maintenance cost and the loss in production that is caused by shutdown maintenance by means of reducing the shutdown maintenance duration.
3. A research in which the work was based on the reduction of the shutdown maintenance cost without increasing the loss in production that is caused by shutdown maintenance by the use of reliability, availability, and maintainability (RAM) principles.

These efforts are discussed in the following sub-sections to illustrate their approaches in achieving the above-mentioned aim. In other words, they are discussed to illustrate their approaches in making shutdown maintenance less expensive and less frequent.

2.5.1 Reducing Shutdown Maintenance Frequency Without Increasing Unplanned Shutdowns Through Searching for The Optimum Frequency:

The reduction of shutdown maintenance frequency without affecting the availability of machines and facilities and the level of performance (systematic reduction) is a very important issue that contributes to reducing the total cost of shutdown maintenance programme (the sum of the costs of the planned shutdowns that are associated with this programme and the losses in production that is caused by these planned shutdowns) which in turn contributes to the increase of the profit (Ashayeri, Teelen, and Selen, 1996; Chareonsuk, Nagarur and Tabucanon, 1997; Metcalfe et al., 1998). McCloskey from Electric Power Research Institute, Pollard from Carolina Power & Light Co. and Schimmels from Sargent & Lundy LLC (1995) illustrate the importance of the relationship between these variables in an article in which they showed that one way to reduce the total cost of the shutdown maintenance programme and in turn to contribute to the increase of the profit is by reducing (systematic reduction) the shutdown maintenance frequency. They also explained that a reduction (systematic reduction) of the shutdown maintenance frequency positively affects the production gain.

In the past, the importance of the systematic reduction of the shutdown maintenance frequency as a way to reduce the total cost of shutdown maintenance programme and in turn to contribute to the increase of the profit has not been realised (Sibley, 1991). As a result, there were no efforts to reduce the shutdown maintenance frequency at the time (Sibley, 1991). In fact, shutdown maintenance frequency was determined by assigning it to be performed in the holidays because that is how it has always been done (Sibley, 1991). In other words, holidays were used to be the best periods of time for performing shutdown maintenance (Sibley, 1991).

However, this has been changed since it has been realised that shutdown maintenance frequency depends on the frequency of each shutdown maintenance activity and how this variable interacts with the total cost of the shutdown maintenance programme (Bullock, 1979; Mann, 1983; Metcalfe et al., 1998; Sibley, 1991). This means that shutdown maintenance frequency affects the total cost of shutdown maintenance programme (Metcalfe et al., 1998; Sibley, 1991; Steudel and Desruelle, 1992). In addition, it is affected by the frequency of each shutdown maintenance activity, which in turn is affected by several factors (Sibley, 1991; Steudel and Desruelle, 1992). These factors are the way of using machines and facilities, the quality of performing shutdown maintenance activities in the last shutdown maintenance, the average service-life distribution and the complexity of machines and facilities, and the robustness of machine design (Bullock, 1979; Sibley, 1991; Steudel and Desruelle, 1992). All of this stimulates researchers in the field to use the relationship between the shutdown maintenance frequency and the total cost of the shutdown maintenance programme to reduce this total cost and in turn to contribute to the increase of the profit.

Ashayeri, Teelen, and Selen (1996) who represent some of these researchers showed how to reduce the shutdown maintenance frequency in the process industry. They developed a model that simultaneously plans preventive maintenance (shutdown maintenance) and production. Their model determines the frequency of shutdown maintenance through scheduling production jobs and maintenance jobs, whilst minimising costs associated with production, backorders, corrective maintenance and preventive maintenance (shutdown maintenance). In addition, their model considers the probability of breakdown given the date of the last maintenance period.

Ashayeri, Teelen, and Selen (1996) employed the ideas of the Bruvold and Evans model for minimising the number of binary variables. However, they modified the model, which formulates production scheduling with significantly less binary variables by extending it to take preventive maintenance (shutdown maintenance) decisions into account (Ashayeri, Teelen, and Selen, 1996). The resulting model formulation is flexible and can be adapted to several production situations.

In addition, some of the developed model's assumptions were very reasonable, especially, that which was related to the consideration of constant production rate throughout the planning period since it reflects the behaviour of the production rate in most of the continuous process industries. However, this model has several other assumptions, which weaken the model such as the following:

1. Market demand is deterministic.
2. High level of maintenance performance is achieved all the time.

Mathew and Rajendran (1993) covered these weaknesses through the development of their model. They first simulated the performance of shutdown maintenance by including an imperfectness rate in their simulation model. They found that the perfectness of the maintenance activities during shutdown maintenance depends on the duration of the shutdown maintenance and, accordingly, they characterised their model by the following:

1. Shutdown maintenance duration which depends upon the time between shutdowns. In other words, the more frequent is the shutdown, the less time is required to perform maintenance tasks.
2. Breakdown rate which increases after imperfect maintenance.

Then, they simulated the changing in demand and its reflection on the total production cost and incorporated them into their model. The model, after that, was ready to use. Mathew and Rajendran (1993) started their model by identifying the critical section or sections in the continuous process plant of their choice, which was a sugar plant. Then, they built and executed a simulation model of the selected section or sections which was based on the simulated shutdown maintenance performance, the simulated market demand, and the procedures of the simulation model that have been developed by them. The main aim of this simulation model was to find out the best frequency of periodic shutdown maintenance so as to minimise the total cost of the shutdown maintenance programme (the total downtime loss) (Mathew and Rajendran, 1993). The result of the model were a feasible and valid range of frequencies for periodic shutdown maintenance that satisfy the changes in demand, the reasonable level of shutdown maintenance cost and the loss in production and the required level of shutdown maintenance performance (Mathew and Rajendran, 1993).

This means that Mathew and Rajendran (1993) succeeded in developing a model that determines the proper shutdown maintenance frequency, which reduces the total cost of the shutdown maintenance programme. However, the model has several shortcomings. These are the following:

1. The criticality of plant sections was built around the downtime cost only.
2. A linear relationship was assumed between shutdown duration and the time between shutdowns while there are other factors such as the complexity of maintaining the machine or facility, the availability of manpower, the availability of materials and others that may change this relationship.
3. The model was not flexible enough to include other criteria because it dealt with the problem as single criteria decision making.

All of these shortcomings of the Mathew and Rajendran (1993) model have been overcome by a comprehensive model that has been built by Chareonsuk, Nagarur and Tabucanon (1997). These researchers developed a multicriteria decision-making model to solve the problem of identifying the optimal shutdown maintenance frequency, which in turn reduces the total cost of the shutdown maintenance programme. In their paper, they noted that maintenance is a supportive function, which has conflicting interests with other functions such as production and marketing. They also noted that the major portion of the total cost in production systems of the continuous process industries is due to production loss during downtime.

Their paper started by discussing the conventional approach of finding shutdown maintenance frequency, which in turn reduces the total cost of the shutdown maintenance programme. It has been found that the conventional approach was simply fixing the interval, which minimises the total expected costs and losses by looking at these costs and losses for a given planning horizon. The paper also discussed the way by which the conventional approach dealt with multicriteria decision problems. It showed that the conventional approach simply added the criteria together to form single criterion such as the addition of production losses to the cost of reliability. However, the researchers clarified that by doing this the individual criterion and the corresponding risks will lose their identity. They also noted that managers always insisted on having a direct control on the reliability, even though it was built into the objective function.

The developed model used the PROMETHEE method, which is based on pairwise comparisons of alternatives in a multicriteria environment. The advantage of the model is its ability to accept input criteria from the decision-makers. Applying the model could show the impact of decisions on the criteria. In addition, the model has the ability to examine the sensitivity of the decisions to the changes in the subjective weights given to the criteria.

Figure 2.13 illustrates these efforts that have been performed by researchers in the field of reducing shutdown maintenance frequency which in turn contributes to the reduction of total cost of the shutdown maintenance programme.

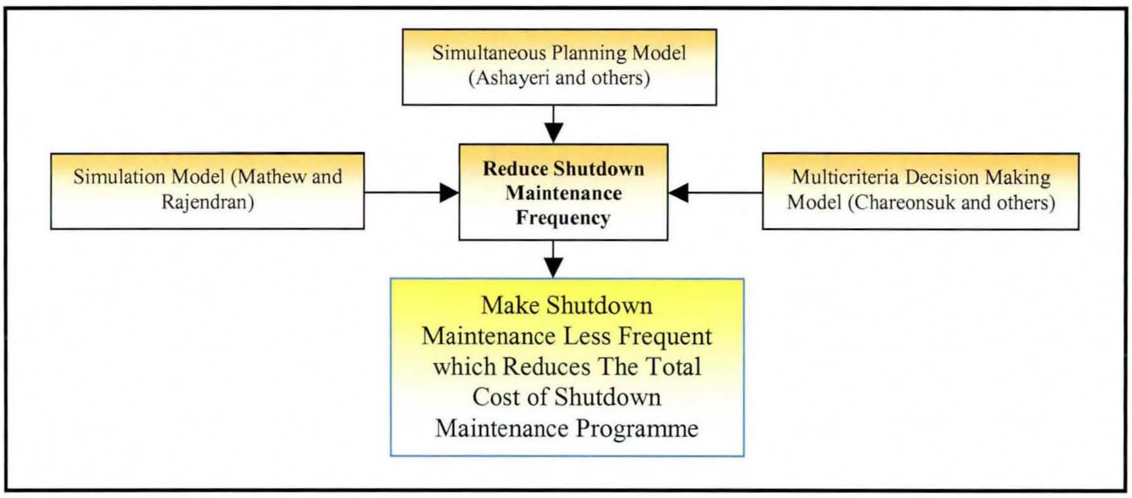

Figure 2.13 Reducing Shutdown Maintenance Frequency Without Increasing Unplanned Shutdowns Through Searching for The Optimum Frequency

2.5.2 Reducing Shutdown Maintenance Cost and The Loss in Production Through The Reduction of Shutdown Maintenance Duration:

Some researchers found another area of research in the field of making shutdown maintenance programme less expensive and less frequent. This area was the reduction of the shutdown maintenance cost and the loss in production that is caused by shutdown maintenance by means of reducing shutdown maintenance duration.

Owens (1998) who is one of the researchers working in this field stated that the best way to support the business plan is by seeking a process whereby shutdown maintenance leads to an increased output and a reduction in shutdown maintenance costs. He, then, clarified that this process should increase our ability to forecast and control the length of the shutdown maintenance in order to have short shutdown maintenance duration, followed by long period of operation.

The length of shutdown maintenance duration is affected by the time length of each shutdown maintenance activity, which is in turn affected by the machines and facilities design (Steudel and Desruelle, 1992). However, the major reason for long shutdown maintenance duration is the existence of poorly organised (poorly planned, scheduled, and controlled) maintenance activities (Steudel and Desruelle, 1992). The way to avoid this and to have a good organisation (planning, scheduling, and controlling) of shutdown maintenance activities calls for good organisation of shutdown maintenance information, materials, labour, tools and equipment that are needed for performing these activities (Capp, 1996; Owens, 1998; Steudel and Desruelle, 1992). Capp, the Heysham 2 station manager (1996) wrote an article in which he illustrates the importance of organising shutdown maintenance activities. He claimed that successful shutdown maintenance is based on successful planning, successful provision of high quality maintenance facilities, and successful empowerment of staff.

One way to organise shutdown maintenance activities and to reduce shutdown maintenance duration, which in turn contributes to the reduction of the shutdown maintenance cost and the loss in production that is caused by shutdown maintenance is the use of the project management software (Koppelman and Faris, 1994). The use of such software was an issue in several efforts that were performed by different researchers. One of the initial efforts in this field was performed by Woodcock

(1989). His effort was simply the use of the critical path scheduling software to schedule shutdown maintenance activities.

In addition to this initial effort, there was the effort of Koppelman and Faris (1994) who realised that organising shutdown maintenance activities is not only a matter of scheduling but also a matter of planning and control as well. Koppelman and Faris (1994) realised that shutdown maintenance activities are complicated by a number of constraints, which are the safety precautions, the priorities of the activities and the activities special needs. They found that the best way to perform these activities properly, safely and most effectively in terms of time and money is by using the project management software since this software enables the shutdown maintenance manager to define the activities, and the associated constraints and dependencies. In addition, it enables the shutdown maintenance manager to develop a plan that suits the stated period of time for the shutdown maintenance (Koppelman and Faris, 1994).

Koppelman and Faris (1994) also found that using project management software to plan, schedule and control shutdown maintenance activities provides the following benefits:

1. Reduces shutdown maintenance cost and the loss in production that occurs as a result of performing these activities.
2. Increases safety performance.
3. Gets plant's plan online with minimum downtime.
4. Keeps corporate executives, plant managers, and engineering contractors up to date on all aspects of a project status.
5. Satisfies requirements of plant managers in terms of tasks accomplishing time.

In addition, they illustrated that all of these benefits could be achieved by gaining the advantage of the following features of the software:

1. Rearranging the order of work to accommodate unforeseen developments and to keep the whole project on schedule.
2. Reflecting the real time realm of activity complexities because of its speed and everyday revision.
3. Reflecting the current realities of a project.
4. Scheduling resources effectively with no waste or under utilisation.
5. Scheduling changes in detail in response to real world expectations without losing clear sight of what is going to go on down the road.
6. Providing more control over the schedule.

7. Improving communication.
8. Revealing all the details, all the changes in schedule, and dependencies and constraints for future reference.

However, this effort and the other efforts that use this way of organising shutdown maintenance activities depend totally on information and the interpretation of this information. Therefore, if the wrong information is collected or an inaccurate interpretation is formed, the results will be inaccurate and it will cause several problems.

Another way of organising shutdown maintenance activities is the use of the Template Planning system (Baughman and Shah, 1996). This system links the creation of work orders in the Computerised Maintenance System (CMMS) with the controls of Primavera in order to provide efficient shutdown maintenance management (Baughman and Shah, 1996). In this system, templates are used to provide standard job task lists for specific equipment jobs (Baughman and Shah, 1996). In addition, templates use unit tables and environment modifiers to provide realistic time estimates and create accurate consistent labour estimates, which are entered into the planning and scheduling process (Baughman and Shah, 1996).

Through the use of templates, the entire shutdown maintenance project is organised into six unique phases by which better labour management and more effective progress reporting are achieved (Baughman and Shah, 1996). These six phases are the following:

1. Pre-shutdown.
2. Preparatory (install binds, open, etc.)
3. Inspection and disassembly.
4. Maintaining, testing, and reassemble.
5. Original restoration (close, remove blinds, etc.)
6. Post-shutdown.

In addition, by using these templates, the shutdown maintenance duration is represented by phases 2, 3, 4, and 5 which means that the shortest duration could be achieved by examining and testing these four phases against different shutdown maintenance constraints (Baughman and Shah, 1996). In other words, the efforts of organising shutdown maintenance activities in this way, which in turn contributes to the reduction of the shutdown maintenance duration, are concentrated on these four phases.

Though a different approach to those so far discussed, some researchers claimed that the organisation of shutdown maintenance activities is primarily achieved through team working and it is about people issues (Shuffleton, 1998). Shuffleton (1998) stated that the first issue that should be dealt with in order to organise shutdown maintenance activities and reduce shutdown maintenance duration is the organisation of people and not the technical issues.

Emmert and Sieracki (1990), Modhavan and Kirsten (1988) agreed on this and they stated that several issues in work force management influence the efficiency of carrying out the shutdown maintenance activities. These issues include not only managing the labour provided by the plant, but also managing the contract manpower (Emmert and Sieracki, 1990; Modhavan and Kirsten, 1988). In addition, they found that without proper management practices and procedures in place to demonstrate control of the plant and the contractor work force, shutdown maintenance would lose its efficiency.

Some other researchers went deeper in their discussion of this issue and they claimed that managing the contractor work force is not enough (Capp, 1994; Kuehn, 1996; Shuffleton, 1998). They stated that involving them in the planning process would simplify the handling of the shutdown maintenance and in turn reduce shutdown maintenance duration. Capp (1994) stated that sharing the plant's strategy with shutdown maintenance contractors by making them partners would drive them to plan their resources more efficiently and be more effective in carrying out the work.

Kuehn (1996) supported these ideas in his four "Ps" approach. He stated that the prevention of poor shutdown maintenance performance is based on good Planning, proper Preparation, good communication with People; and good Partnership with contractors.

Shuffleton (1998) from his side clarified the way to facilitate the partnership. He suggested that comprehensive team working should be performed in order to achieve efficient shutdown maintenance. He also suggested a list of the team attributes that is required to perform good shutdown maintenance performance. These attributes are the following:

1. Team goals and the way by which members of the team collaborate should be clearly understood.
2. Training of all team members should be performed so that they can collaborate in a good manner.

3. Ownership of the work that is being performed should be the natural feeling of the team.
4. A willingness to learn and to make improvement should be the team culture.
5. Reducing costs and duration whilst improving or maintaining safety should be the proactive looking and thinking of the team.
6. Flexibility in responding to emergent work issues and the ability to contribute to a resolution should be one of the team characteristics.

Shuffleton (1998) claimed that the consequences of these attributes become hard to reach when the majority of the team is contract staff. This is because of several reasons. The first reason is the difficulty of asking the contractors to train their staff on the operation procedures and processes because training is expensive (Shuffleton, 1998). The second reason is that some contract staff may be keen to see an extension to the shutdown maintenance because it means more work, which in turns means, more pay (Shuffleton, 1998). The last reason is the difficulty for the contractors to identify savings because savings are alien to their traditional way of business (Shuffleton, 1998).

However, Shuffleton (1998) stated that the best way to overcome these problems and achieve efficient shutdown maintenance is through facilitating long-term working relationships with the contract organisation. This relationship should be an open relationship so that each side understands each other's processes, procedures, costs and management expectations (Shuffleton, 1998). An example is Heysham 2 power station, which succeeded in improving its shutdown maintenance performance by implementing several new initiatives and changes in its working practices and relationships with its contractors (Edwards, 1998).

Figure 2.14 illustrates those efforts that have been performed by researchers in the field of reducing shutdown maintenance cost and the loss in production that occurs as a result of performing shutdown maintenance activities through the reduction of shutdown maintenance duration.

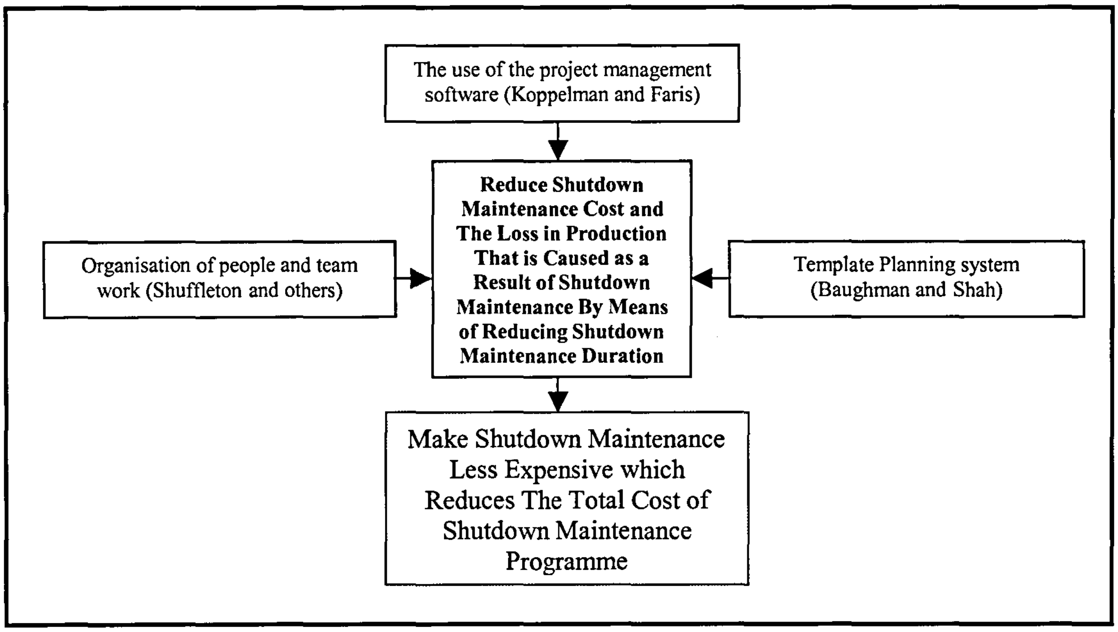

Figure 2.14 Reducing Shutdown Maintenance Cost and The Loss in Production Through The Reduction of Shutdown Maintenance Duration

2.5.3 Reducing Shutdown Maintenance Cost Without Increasing The Loss in Production Through The Use of RAM Principles:

Gupta and Paisie (1997) contributed to the field of making shutdown maintenance less expensive and less frequent by proposing a method in which a reduction of shutdown maintenance cost without increasing the loss in production is achieved through the use of reliability, availability, and maintainability (RAM) principles. The developed method is supported by reliable operational and maintenance data, economics, and has input from all the concerned personnel.

The method starts by receiving an initial work list of the shutdown maintenance candidate units. Then, a creation of small teams of individuals from each discipline is established in order to assess and analyse the condition of each unit and develop shutdown maintenance work recommendations. The assessment process consists of the following steps:

1. Breaking down each unit into one or more subsystem in order to address process concerns throughout the subsystem.

2. Reviewing and analysing all the machines and facilities throughout the subsystem by using an equipment assessment form in order to determine for each machine all possible maintenance work scenarios that could be used to maintain that machine. Then, each scenario is being treated as an individual alternative for maintaining that machine.
3. Predicting future failure rate for each alternative through the use of historical failure rate, maintainability data, and good understanding of current or expected equipment condition.
4. Evaluating potential alternatives in terms of their contribution to the reduction of the shutdown maintenance cost and in turn to the increase of the net savings.
5. Including winning alternatives to the final work list of shutdown maintenance.

After this, capital projects, if there is one or more, are added to the final list. The last step of this method is the review of the impact and the relationship of the units scheduled for shutdown maintenance with the rest of the production system in order to optimise the shutdown and production requirements during the shutdown period. In addition, this review action helps to meet management objectives.

This method succeeded in reducing the shutdown maintenance cost. However, there are several important problems that weaken the Gupta and Paisie method. The first problem is that this method is based on the reduction of the shutdown maintenance cost without increasing the loss in production, which means that there is no real effort to reduce the loss in production that is caused by performing the shutdown maintenance activities. The second problem is the method ignorance of the criticality of the shutdown maintenance activities. Therefore, the method may exclude some of the critical maintenance activities from the scope of work of shutdown maintenance because of their low contribution to the reduction of the shutdown maintenance cost. These activities could be costly, operationally or safety critical maintenance activities which when they are excluded, may create economic, operational, or safety problems which in turn could increase the cost of the overall maintenance by an amount higher than that when they are included in the shutdown maintenance. Also, the method may allow some of the non-critical maintenance activities to be included in the scope of work of shutdown maintenance because of their high contribution to the reduction of the shutdown maintenance cost. The inclusion of these maintenance activities could increase the overall maintenance cost because their shutdown maintenance cost is higher than the cost when these activities are maintained while the production line is running. The last important problem is the difficulty of getting historical data about failure rates, maintenance rates, and other important issues, which will force the process team to estimate this data. Estimating this data increases their uncertainty, which in turn increases the inaccuracy of the results. The main reason that creates all of these problems is that the analysis in this method basically depends on economic measures and does not include other important measures that are related to important issues such as the safety and the criticality of machines to the production system.

2.6 SUMMARY:

In this chapter, the literature that illustrates the importance of the maintenance function in the manufacturing industries and the importance of the shutdown maintenance programme in the continuous process industries was discussed. The discussion of this literature was an introduction to the discussion of the literature about the importance of reducing shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance. In addition, it was an introduction for the discussion of the literature about the previous efforts that were performed to accomplish the above mentioned reduction and which was divided in this chapter into three categories as follows:

1. The efforts that discuss the reduction of the shutdown maintenance frequency without increasing unplanned shutdowns through searching for the optimum frequency that satisfies predetermined constraints.
2. The efforts that discuss the reduction of shutdown maintenance cost and the loss in production which occurs as a result of performing shutdown maintenance activities through the reduction of the shutdown maintenance duration.
3. The effort by Gupta and Paisie (1997) in which the reduction of the shutdown maintenance cost without increasing the loss in production was achieved through the use of RAM principles.

In the next chapter, the discussion about making shutdown maintenance less expensive and less frequent will continue. Important subjects such as the current status of shutdown maintenance and the limitations of the current techniques in making shutdown maintenance less expensive and less frequent will be revealed. In addition, in the next chapter, the base for the new model to reduce the shutdown maintenance cost and frequency and the loss in production that occurs as a result of performing shutdown maintenance activities will be initiated. Finally, the next chapter will discuss the research methodology and design for developing the new model.

CHAPTER 3

THE IDEA OF THE NEW MODEL AND THE RESEARCH METHODOLOGY AND DESIGN

3

3.1 INTRODUCTION: THE CURRENT STATUS OF SHUTDOWN MAINTENANCE:

Shutdown maintenance is one of the most important types of maintenance that contributes to the development of an optimal maintenance policy in the continuous process industries (Roberts and Mask, 1992). It is useful for conducting preventive maintenance activities, corrective maintenance activities and engineering projects that are difficult to be carried out while the production line is running (Duffuaa et al, 1999; Roberts and Mask, 1992). In addition, it is important for reducing and better controlling the risks of unplanned and more costly major breakdowns (Roberts and Mask, 1992).

The current move toward planned maintenance programmes (including shutdown maintenance) and reliability-based philosophies has enabled continuous process industries to cut operation and maintenance costs by approximately 33% (Clark, 1995). A recent survey that was conducted by plant engineering and maintenance magazine on more than 400 companies showed that most of the panellists who respond to the magazine fax questionnaire saw plant shutdowns as a useful way of performing planned maintenance activities (Wu, 1997). In addition, some of the panellists commented that scheduled shutdowns prevent their plants from unscheduled, extremely expensive shutdowns (Wu, 1997). Another survey which was conducted by the plant performance group (a division of Technology and Energy Corporation) showed that 500 plants from different countries (Great Britain, United States, Canada, France, Australia) achieved an improvement in the reliability, availability, and operating cost after they successfully implemented the shutdown maintenance programme and other planned maintenance techniques (Mobley, 1990).

In recent years, continuous process industries realised that they have had to be operated in an increasingly commercial environment which leads them to focus more on shutdown maintenance (Owens, 1998). The reason behind this is that operating these high-value capital industries, which are in demand of increased performance and reduced costs, makes shutdown maintenance in many instances emerging as the single type of maintenance that can effect most the profitability of the asset or process (Owens, 1998).

This appears clearly in several continuous process industries. In glass industries, for example, a 10% reduction in unplanned downtime which will reduce production costs by approximately 3% is achievable by planning and implementing a replacement/repair procedure in conjunction with well-practised maintenance programme (Tyagi, 1991). Another example is the nuclear power stations where remarkable improvements in the operational performance can be achieved through a comprehensive shutdown maintenance programme (Hong, 1995).

Managers in these industries and in other continuous process industries noticed the importance of shutdown maintenance. They found that applying planned maintenance programme can save more than 10 times the original investment (Bates, 1996). These savings are represented as an improvement in the following areas (Bates, 1996):

1. 45% reduction in machine downtime.
2. 25% reduction in spares inventories.
3. 30% increase in skilled productivity.

At the same time, they noticed that the achievement of the improvement in these areas needs a well practice of shutdown maintenance. Therefore, they searched for ideas and methods that are easy to implement and have the ability to achieve the well practice of shutdown maintenance with minimum cost and minimum loss in production.

One of the efforts in this area was the work of Hong (1995) who is the general manager of Korea Electric Power Corp (KEPCO). Hong (1995) stated that according to his company experience, effective maintenance could be achieved when special attention is given to the following:

1. Development of optimum maintenance plans.
2. Preparation of maintenance procedures and instructions.
3. Co-operation and co-ordination between maintenance groups.
4. Application of modern maintenance techniques and tools.

Hong (1995) also found that good practice of shutdown maintenance depends on the determination of the appropriate frequencies of shutdown maintenance and the minimisation of shutdown maintenance duration. Hong (1995) suggested two factors that contribute to the achievement of short duration and appropriate frequencies of shutdown maintenance. These factors are systematic shutdown planning and the development of improved maintenance techniques and working conditions (Hong, 1995). Hong (1995) also stated that according to his company experience all maintenance activities in KEPCO are performed according to the appropriate procedures and managed systematically through the use of well-planned maintenance and quality control programmes.

In addition to Hong (1995), Roberts (1990) who works with Weyerhaeuser Paper company, Springfield, found that good practice of shutdown maintenance requires the concentration of vast and varied skilled resources over a short period of time. In addition, he found that it also requires co-operation between the people who work during the shutdown maintenance. Roberts (1990) observed that a successful approach to manage shutdown maintenance should be based on principles of sound project management.

Moreover, Tony Capp (1996), manager of Heysham 2 station visited power plants in Sweden, Finland, and France searching for good practice of shutdown maintenance. He found that the secret of successful shutdown maintenance practice lies in the following:

1. Successful planning.
2. The provision of high quality shutdown maintenance facilities.
3. The empowerment of staff.

In addition to all of this, some other researchers such as Shuffleton (1998) looked forward in time and investigated the future practice of shutdown maintenance. The result of the Shuffleton (1998) investigation was that the future practice of shutdown maintenance is to make shutdown maintenance:

1. Safe with minimum impact on the environment so that injuries, death, and pollution rates will reduce to the lowest possible level.
2. Short to minimise shutdown maintenance cost, the loss in production and the loss in sales.
3. Cost effective in terms of good utilisation of shutdown maintenance resources while maintaining good availability level for machines and facilities.

In summary, shutdown maintenance becomes one of the most challenging issues in the development of an optimal maintenance policy in the continuous process industries (Gupta and Paisi, 1997; Roberts and Mask, 1992). It is being practised in these industries in order to perform planned maintenance activities and engineering projects and to reduce the risks of unplanned major breakdowns (Gupta and Paisi, 1997; Roberts and Mask, 1992). At the same time, it is an expensive type of maintenance that stimulates managers in these industries and researchers to search for new ideas and methods to reduce its cost and its frequency, in addition to, the loss in production that occurs as a result of performing shutdown maintenance activities while maintaining its purpose and without creating any operational, safety or economic problems. Figure 3.1 illustrates the effect of the current practice of shutdown maintenance.

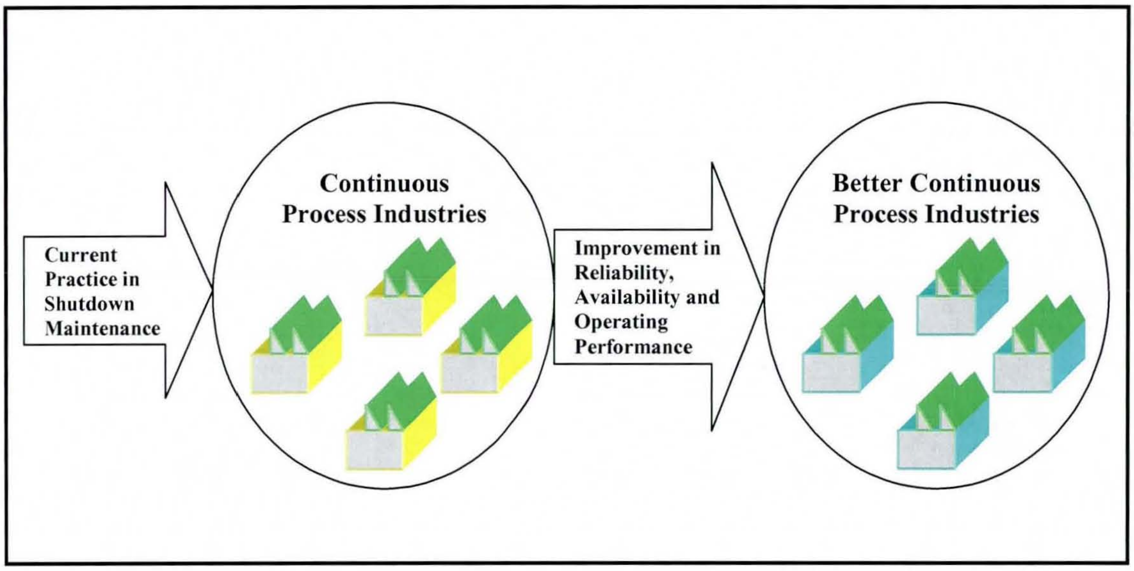

Figure 3.1 Current Practice of Shutdown Maintenance

3.2 THE LIMITATIONS IN THE CURRENT METHODS OF REDUCING SHUTDOWN MAINTENANCE COST AND FREQUENCY AND THE LOSS IN PRODUCTION:

As mentioned in the last section, the current status of shutdown maintenance stimulates managers and researchers to find ways and methods to reduce the cost and the frequency of shutdown maintenance and the loss in production that is caused by performing shutdown maintenance activities without creating any operational, safety or economic problems. At some stage the result of this stimulation, was the development of the current methods that have been discussed in the last chapter and the use of these methods to reduce the cost and the frequency of shutdown maintenance and the loss in production that is caused by shutdown maintenance. In general, this makes current practice of shutdown maintenance much cheaper and better than the past. However, it was not enough.

The reason behind this is that these current methods, as it has been mentioned in the last chapter concentrated on reducing one of the above variables (shutdown maintenance cost, shutdown maintenance frequency or the loss in production) or at most two while preventing the other two variables or the other one variable from increasing. In other words, the reduction of one of the above variables in these methods is limited by that level at which the other two variables start to increase.

Moreover, these methods do not distinguish between the critical maintenance activities which are important to be included in the scope of work of shutdown maintenance in order to avoid the creation of any economic, operational, or safety problems and the non-critical maintenance activities which their inclusion in the scope of shutdown maintenance could increase the overall maintenance cost. Also, most of these methods depend on estimating historical data, which increases data uncertainty and which in turn increases the inaccuracy of the results of these methods. All of these limit the net savings in profit to a certain level.

Furthermore, current methods for reducing the cost and the frequency of shutdown maintenance and the loss in production were mainly based on the reduction of either the duration or the frequency of shutdown maintenance. These reductions depend heavily on organising those jobs and activities that constitute the scope of work of shutdown maintenance. This means that any arbitrary increase or decrease in the number of activities of shutdown maintenance will affect the optimum solution of these methods. The reason behind this is that these methods do not have a mechanism to control the number of activities or jobs in the shutdown maintenance and they deal with each job or activity as a critical item even if it is not.

In addition, the current methods treat the problem of reducing the shutdown maintenance cost and frequency and the loss in production as a one-sided problem. This means that developers of some of these methods saw that the contribution to the reduction of shutdown maintenance cost and frequency, in addition to, the loss in production could be achieved through the reduction of the frequency of shutdown maintenance without directing any attention to the effects of reducing the shutdown maintenance cost and the loss in production that is caused by shutdown maintenance. This leads to a limited contribution to the reduction of the shutdown maintenance cost and frequency and the loss in production since the reduction of the cost of shutdown maintenance and the loss in production can not be achieved through these methods.

On the other hand, other developers of other methods saw the problem of reducing the shutdown maintenance cost and frequency and the loss in production as a problem of reducing the cost of shutdown maintenance and the loss in production that is caused by shutdown maintenance only. Therefore, they did not direct their attention to the effects of reducing the shutdown maintenance frequency, which could cause more reduction. The result was also a limited contribution to the reduction of the shutdown maintenance cost and frequency and the loss in production. In summary, there are no real efforts in these methods to reduce all of the above three variables at the same time. Figure 3.2 illustrates the efforts of researchers in developing these methods.

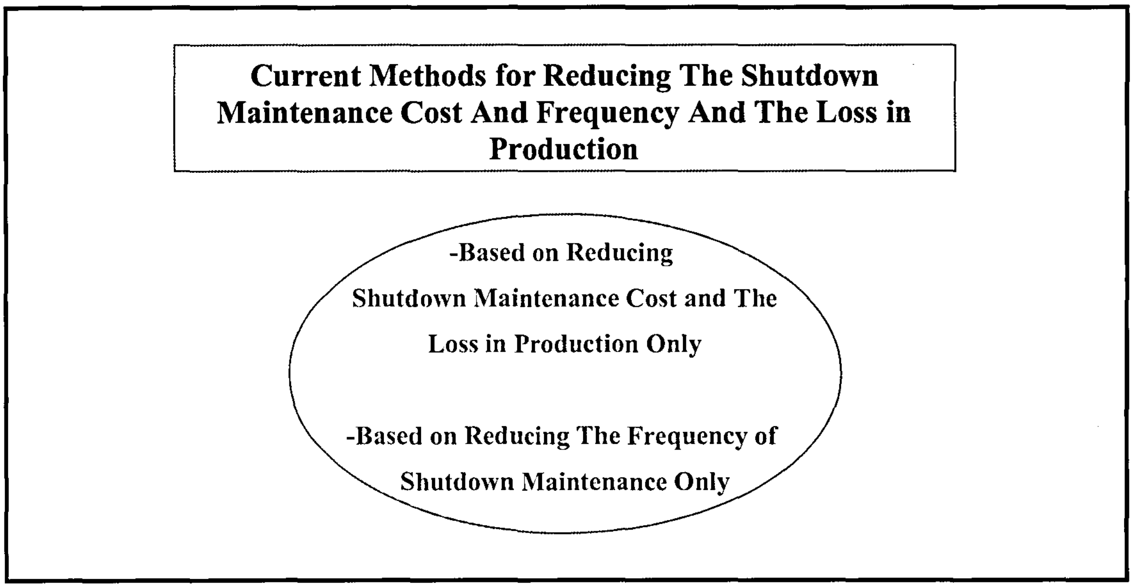

Figure 3.2 The Current Methods for Reducing The Shutdown Maintenance Cost and Frequency and The Loss in Production That is Caused by Shutdown Maintenance

3.3 REDUCING SHUTDOWN MAINTENANCE COST AND FREQUENCY AND THE LOSS IN PRODUCTION THROUGH THE REDUCTION OF THE SCOPE OF SHUTDOWN MAINTENANCE WORK (THE NEW MODEL):

In all the efforts that have been discussed so far, the reduction that was accomplished is the reduction of either the shutdown maintenance cost, the shutdown maintenance frequency or the shutdown maintenance cost and the loss in production that is caused by shutdown maintenance. In addition, this reduction was based on the reduction of either shutdown maintenance duration or frequency, or the use of the RAM principles. All of this as mentioned in the last section limits this reduction by that level at which any of the above variables starts to increase and by the fluctuations in the number of shutdown maintenance activities that constitute the work of shutdown maintenance. This means that the increase of the net savings in the profit is limited by the increase in the level of this reduction.

In the literature, it was stated that a key element in successful shutdown maintenance is the definition and the control of the scope of work of shutdown maintenance which is nothing other than the number of activities that constitute the work of shutdown maintenance (Owens, 1998). It was also mentioned that doing less work without increasing the shutdown maintenance frequency and while maintaining overall plant availability means commitment to short shutdown maintenance which means less shutdown maintenance cost and less production loss (Owens, 1998).

In addition, Opfer (1997) stated that a systematic and well-organised reduction in the scope of work of shutdown maintenance leads to a reduction in the cost of shutdown maintenance. He also added that increasing the scope of work of shutdown maintenance by 10 to 20% before starting shutdown maintenance causes most of the problems that are related to shutdown maintenance delays.

Recent surveys also showed that one third of all maintenance costs including shutdown maintenance cost is a result of unnecessary or improperly performed maintenance activities (Mobley, 1990). This means that reducing the overall maintenance cost (maintenance cost and the loss in production) by a systematic reduction of the maintenance activities and through practising good maintenance management techniques would provide a measurable improvement in the profit (Andrica, 1984; File, 1991; Gupta and Paisie, 1997; Henderson et al., 1998).

All of the previous signs lead to the claim that the real reduction of the shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance, which makes a huge increase in the net savings and hence the profit of the business is achieved by a systematic reduction of the scope of work of shutdown maintenance (number of shutdown maintenance activities). The reason behind this is that any reduction in the scope of work of shutdown maintenance while maintaining shutdown maintenance purpose and without creating any operational, safety, or economic problems will lead to a reduction in shutdown maintenance duration, frequency, direct and overhead maintenance costs. If this claim and its supporting reason are proved to be valid, then this claim will provide the base for a new model to reduce the cost and the frequency of shutdown maintenance and the loss in production that occurs as a result of performing shutdown maintenance.

The investigation process to proof the validity of this claim, in addition to, the way of implementing this claim through a new model and the testing process of the new model will be the subject of discussion in the rest of this thesis. However before starting this discussion, the following section, which represents the research methodology and design of this thesis will summarise the main points of this discussion. Figure 3.3 illustrates this thesis effort to reduce the cost and the frequency of shutdown maintenance and the loss in production that occurs as a result of performing shutdown maintenance activities (the idea of the new model).

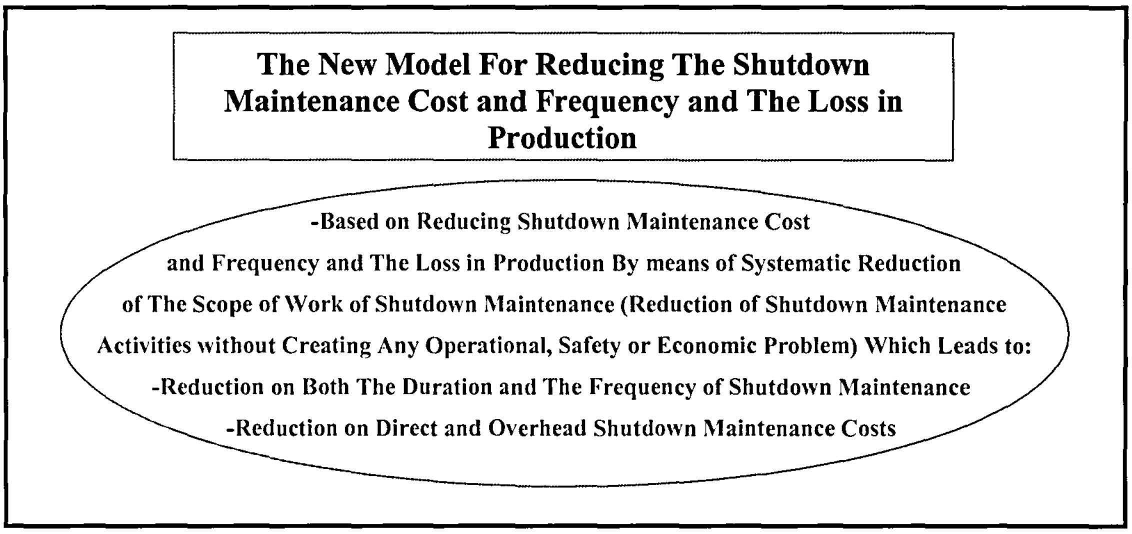

Figure 3.3 Reducing The Cost of Shutdown Maintenance, The Frequency of Shutdown Maintenance and The Loss in Production Through The Reduction of Shutdown Maintenance Scope of work (The New Model)

3.4 THE RESEARCH METHODOLOGY AND DESIGN OF THE THESIS:

In general, the research methodology and design of a study is the actual planning process of that study (Badiru, 1996; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). It includes such aspects as the purpose of the study, the duration of the study, the type of investigation, the type of the method used to facilitate the selected type of investigation and the design of the selected method (Badiru, 1996; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992).

In this thesis, the research methodology was designed to facilitate the investigation of creating a model that reduces shutdown maintenance cost and frequency and the loss in production that is caused by performing shutdown maintenance activities through the reduction of the scope of work of shutdown maintenance and without creating any operational, safety, or economic problems. The scope of work of shutdown maintenance as defined in the first chapter is the number of shutdown maintenance activities that constitute the total work of shutdown maintenance.

The structure of the research methodology and design of this thesis was divided into three major stages as illustrated in figure 3.4. The reason behind this is to ease the flow of the progression toward the accomplishment of the thesis main aim. For each one of these stages, a separate subsection in this chapter is provided in order to discuss a summary of the main issues in the research design of each stage whereas the full discussion of the research design of these stages will be provided in the following chapters of this thesis. The discussion in each of the following subsection will illustrate (if it is applicable) the purpose of the stage, the type of investigation, the data-collection method or research instruments, measurements, and the sampling design.

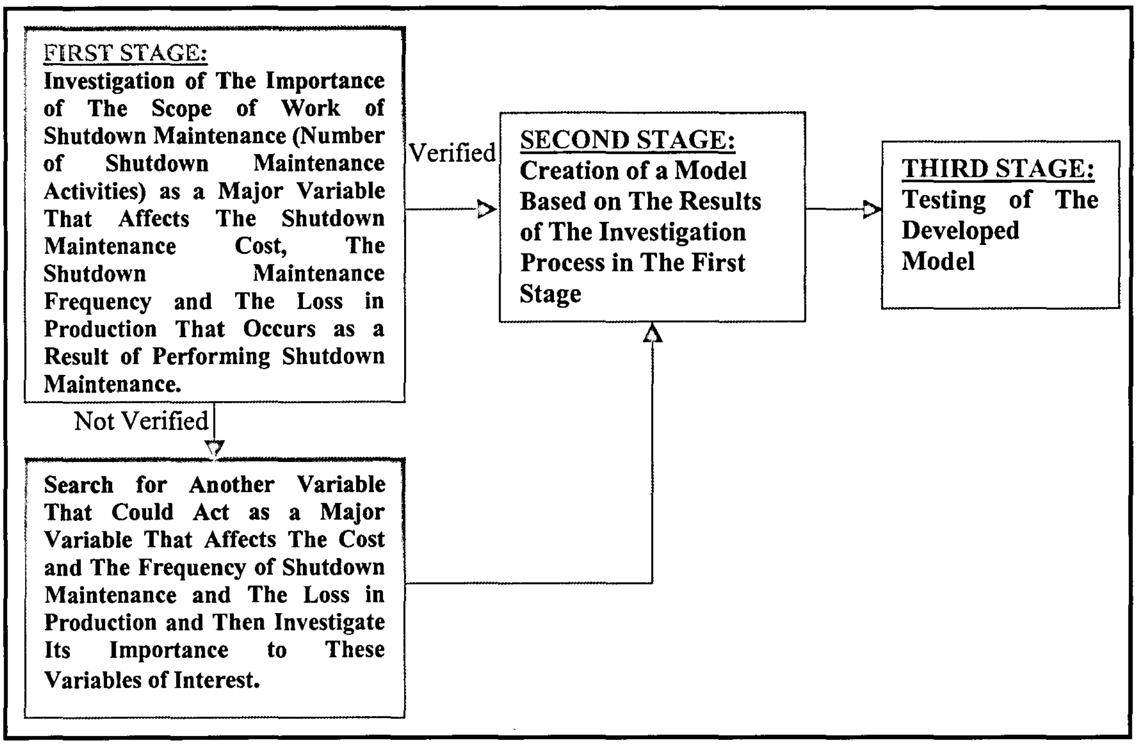

Figure 3.4 The Stages of The Research Methodology and Design of The Thesis

3.4.1 The Research Design of The First Stage:

The purpose of this stage is to investigate the importance of the scope of work of shutdown maintenance as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency, and the loss in production that is caused by performing shutdown maintenance activities. The first part of this stage is the creation of the theoretical framework that describes the relationships between the scope of work of shutdown maintenance and each one of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production. This part of this stage starts with the discussion of the main points in the literature review that describe these relationships and all the variables that either constitute, intervene in or moderate these relationships. Then, further description from the industrial field of these relationships and all related variables is performed as a completion step in order to reach the targeted theoretical framework. The way to carry out this step is through conducting interviews with those people who are responsible for dealing with the cost and the frequency of shutdown maintenance and the loss in production that is caused by performing shutdown maintenance activities. The next part in this stage is the design, the test and the implementation of the survey and the data collection method that will be used to gather data about the above mentioned relationships and all of the related variables for the investigation process. This part includes (if applicable) the sampling design, the measurements of the variables of interest, the scaling techniques used to facilitate these measurements, the general organisation of the data collection method, the test used to refine the design of the data collection method, the test used to refine the survey procedures and the implementation of the main survey. The final part of this stage, which is the final step of the investigation process, is the analysis of the data that has been collected in the second part of this stage. This part includes the descriptive and the inferential analysis of the collected data from the second part and the results of the investigation process. An illustration of these parts is shown in figure 3.5.

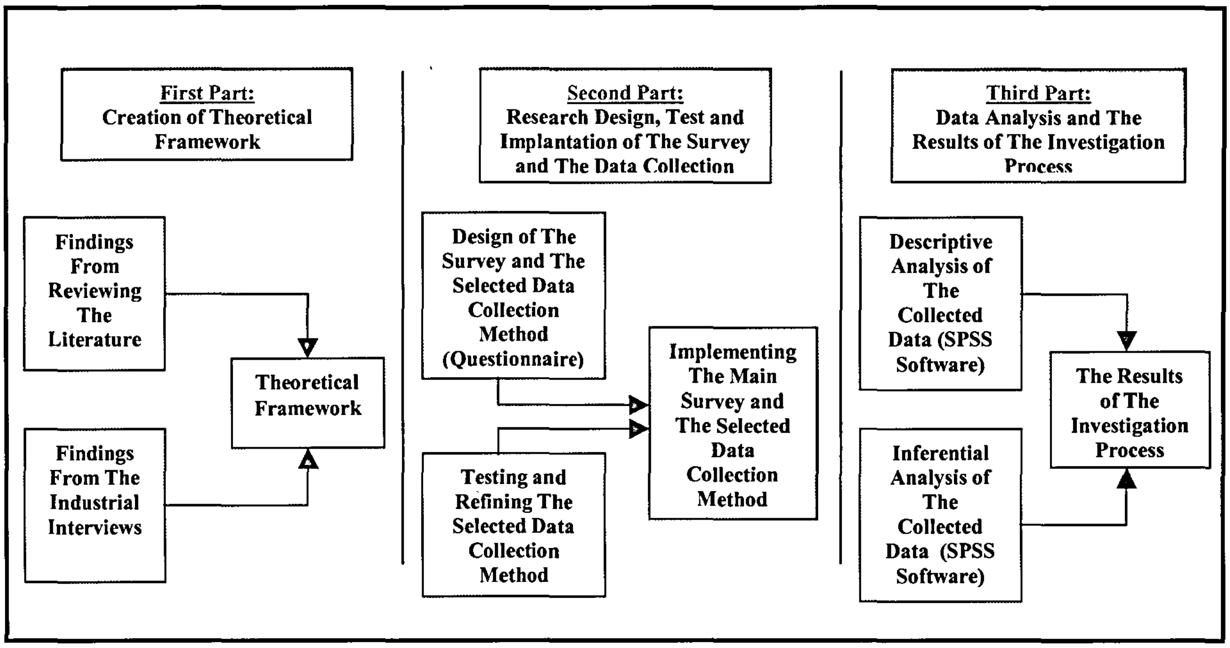

Figure 3.5 The Research Design of The First Stage

3.4.2 The Research Design of The Second Stage:

By completing the first stage, the way is clear to carry out the second stage of this thesis research methodology. The aim of the second stage is to create a model that uses the results of investigation process from the first stage to reduce the shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance whilst maintaining the purpose of shutdown maintenance and without creating any operational, safety, or economic problem. In other words, the aim is to create a model that reduces the shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance without increasing the number of unplanned shutdowns or creating interruptions for the production line. The proposed way to accomplish this aim is by dividing the research methodology and design of this stage into two parts.

The first part of this stage deals with the selection of the modelling method or methods for developing the structure of the proposed model. In this part, specific characteristics of the proposed model such as the model type and the model use are discussed in order to understand the nature of the proposed model and to help with the selection of an appropriate modelling method that will be used to develop its structure. In addition, the different types of modelling methods are also discussed in order to form the base for the selection of the appropriate modelling method or methods.

The second part of this stage deals with the development of the structure of the proposed model. This part includes a description of the model elements that should be considered during the development of the proposed model. In addition, it includes the description of the development process and the structure of the proposed model. Figure 3.6 illustrates the two parts of this stage.

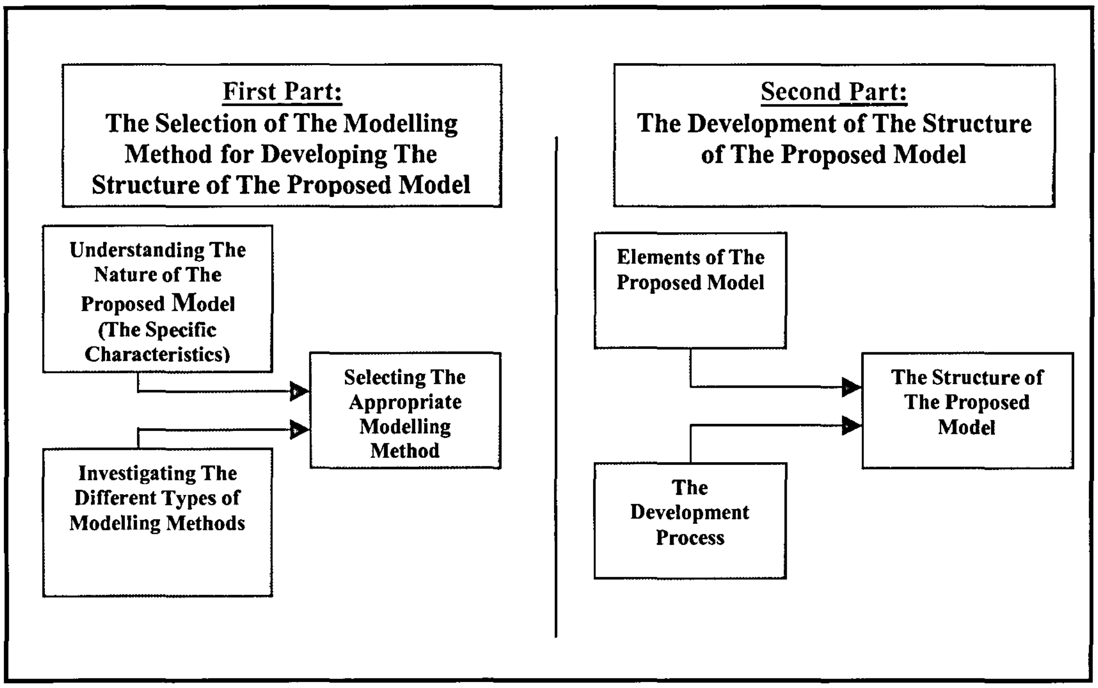

Figure 3.6 The Research Design of The Second Stage

3.4.3 The Research Design of The Third Stage:

The purpose of this stage is to test and refine the developed model in order to reach its final version that satisfies the research objectives of building this model. It involves testing the model in the real working environment in order to ensure that the developed model is accurate and performs in accordance with expectations and to ensure that all parts of the model are compatible and complete enough for the implementation in the real operating system of continuous process industries.

The way to start this stage is through testing the developed model on continuous process plants. During the testing process, the analysis of the changes in different parts of the model and in the expected model results is performed. Based on the results of this analysis, several modifications to the model (if there are any) are suggested for implementation in order to reach the final version of the model. Figure 3.7 illustrates the research design for this stage.

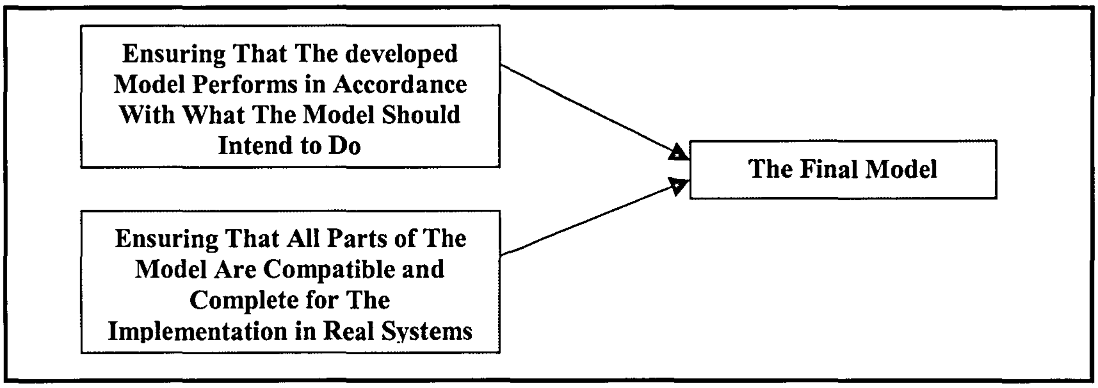

Figure 3.7 The Research Design of The Third Stage

3.5 SUMMARY:

In this chapter, the current practice of shutdown maintenance and the limitation of the current techniques used to reduce its cost and its frequency and the loss in production that is caused by performing its activities were discussed. In addition, this chapter established the base for a new model by revealing the new way of reducing the shutdown maintenance cost and frequency and the loss in production that is caused by performing shutdown maintenance activities. At the same time, it discussed the research methodology and design of this thesis, which will be used to facilitate the creation of the model that will achieve the main aim of the thesis. The discussion of the research methodology and design was basically a summary of the main issues in the stages that constitute the structure of the research methodology and design of this thesis.

In the following chapters, the development of the new model will be the main issue and the full discussion of the stages of the structure of this thesis research methodology and design will be performed. The best way to start all of this is by discussing the investigating process of the importance of the scope of work of shutdown maintenance (number of shutdown maintenance activities) as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by shutdown maintenance. In particular, the best way is to start with the discussion of the first part of the investigation process, which will represent the subject of the next chapter.

CHAPTER 4

THE INVESTIGATION PROCESS: CREATION OF THEORETICAL FRAMEWORK

4

4.1 INTRODUCTION:

In this part of the first stage of the research methodology and design of this thesis, the aim is to create a theoretical framework that describes the relationship between the shutdown maintenance cost and the scope of work of shutdown maintenance, and the relationship between the scope of work of shutdown maintenance and the shutdown maintenance frequency, in addition to, the relationship between the scope of work of shutdown maintenance and the loss in production that is caused by performing shutdown maintenance activities. The purpose of this theoretical framework, as discussed in the last chapter, is to understand the pattern of these relationships and the characteristics of all the variables that constitute, intervene in or moderate them which in turn helps in the investigation of the importance of the scope of work of shutdown maintenance as a major variable that affects the above mentioned variables of interest. The use of the theoretical framework in this part as a tool to describe these relationships and their related variables is an important issue. The reason behind this is that the theoretical framework, as mentioned in the literature, is a useful tool for elaborating the relationships between the variables that have been identified through such processes as interviews, observations, and literature survey (Badiru, 1996; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). In addition, it is useful for describing the nature and direction of these relationships, and explains the theory underlying them (Melville and Goddard, 1996; Sekaran, 1992). In fact, the theoretical framework, as it has been considered in the literature, is the foundation on which the entire research rests and it has been defined as (Sekaran, 1992):

> a conceptual model of how one theorises the relationships among the several factors that have been identified as important to the problem.

This means that developing a theoretical framework helps to test the relationships between the variables of interest in order to see whether these relationships are valid or not and based on the results of this testing process, the extent to which the problem can be solved through the findings of the research becomes evident (Melville and Goddard, 1996; Sekaran, 1992).

In this part of the first stage of the research methodology and design of this thesis, the proposed way that was used to develop the theoretical framework that describes the above mentioned relationships and all related variables was based on dividing the development process into three parts. Each one of these parts was concerned with an important issue of the development process such as the discussion of the main points in the literature review that describe these relationships and all related variables, the description of these relationships and all related variables by important individuals in the industrial field and the discussion of the theoretical framework structure. The explanation of the content of these parts and their related issues will be discussed in the following sections of this chapter. However, before starting the explanation of these parts, the industrial environment in which the studying process of these relationships was performed, is discussed in the next section.

4.2 THE INDUSTRIAL ENVIRONMENT IN WHICH THE INVESTIGATION PROCESS TOOK PLACE:

The industrial environment that was used for the investigation process of the effects of the scope of work of shutdown maintenance (number of shutdown maintenance activities) on the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production was the industrial environment of Saudi Arabia. The selection of this environment as the industrial environment in which the investigation process will take place was based on the following:

1. The existence of different types of continuous process industries in this environment such as the refinement petroleum, petrochemicals, plastics, industrial gases and chemicals industries (Ministry of Planning-Kingdom of Saudi Arabia, 1995; Riyadh Chamber of Commerce &Industry, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999).
2. The industrial plants in this environment are not different from those in other parts of the world, since they were built following the same international standards

(Council of Saudi Chambers of Commerce and Industry, 2001; Ministry of Planning-Kingdom of Saudi Arabia, 1995).

3. The shutdown maintenance practice in some of the plants in the industries of this environment are performed sometimes by foreign maintenance companies which means that shutdown maintenance programmes in these plants are not different from those in the other parts of the world (Council of Saudi Chambers of Commerce and Industry, 2001; SABIC, 2001).
4. Most of the plants in the industries of this environment are willing to provide the researcher access to their facilities because of the strong co-operation between these plants and the organisation (King Saud University) where the researcher works.

In summary, the selection of this industrial environment was basically based on two important issues. One of these issues is that this environment includes plants of the continuous process industries that use shutdown maintenance as one of their maintenance programmes which in turn helps in the investigation process since the relationships that are used in this process are between variables that are related to the shutdown maintenance. The other issue is the willingness of the continuous process plants in this environment to provide the researcher an easy access to the data that is needed to be collected and to the information that is necessary for the thesis subject which in turn helps to provide the investigation process with the necessary information and data. The following subsections will illustrate several aspects of this environment.

4.2.1 The Manufacturing Industry in Saudi Arabia:

All of the development plans of Saudi Arabia were focused on the importance of the manufacturing industry as one of the significant industries in the country that could participate in achieving the country's aims (Ministry of Planning-Kingdom of Saudi Arabia, 1995). In particular, these development plans were focused on the development of this type of industry in order to achieve the following (Ministry of Planning-Kingdom of Saudi Arabia, 1995):

1. Expand the production base of the country.
2. Reduce the country's dependency on oil production.
3. Increase the participation of the private sector in the development process.

4. Establish a strong technological base.
5. Provide new jobs.
6. Develop well-trained national manpower in the manufacturing field.

As a result of these plans, the manufacturing industry in Saudi Arabia was developed to include three major sectors (Ministry of Planning-Kingdom of Saudi Arabia, 1995; Riyadh Chamber of Commerce &Industry, 1999; The Saudi Arabian Information Resource- Factories Licensed, 1999). Each sector includes a wide spectrum of plants that produce different products (Ministry of Planning-Kingdom of Saudi Arabia, 1995; Riyadh Chamber of Commerce &Industry, 1999; The Saudi Arabian Information Resource- Factories Licensed, 1999).

The first sector is the refinement petroleum industry where refined petroleum products are produced. This sector represents the biggest industrial sector in this field (Ministry of Planning-Kingdom of Saudi Arabia, 1995; The Saudi Arabian Information Resource- Factories Licensed, 1999). In addition, it enhances the country's exports of the industrial products (Ministry of Planning-Kingdom of Saudi Arabia, 1995).

The second sector is the petrochemicals industry where the production of plastics, chemical fertilisers and other petrochemical products are performed (Ministry of Planning-Kingdom of Saudi Arabia, 1995; The Saudi Arabian Information Resource- Factories Licensed, 1999). This sector represents the corner stone of the manufacturing development in Saudi Arabia because it supplies foreign plants as well as small domestic plants with these materials (Council of Saudi Chambers of Commerce and Industry, 2001; Ministry of Planning-Kingdom of Saudi Arabia, 1995).

The last sector represents a huge number of small production plants in which different materials are fabricated into finished products. This sector includes those plants that produce such products as food and beverages, textile, wearing apparel and leather, wood and wood products including furniture, paper products, construction materials, chinaware and glass, fabricated metal products, machinery and equipment (Ministry of Planning-Kingdom of Saudi Arabia, 1995; The Saudi Arabian Information Resource- Factories Licensed, 1999).

In addition to these sectors, the government of Saudi Arabia signed eight agreements with the governments of Great Britain and France and with some of the biggest American companies that are specialised in the aeroplanes, electronics, and other high tech industrial fields (Ministry of Planning-Kingdom of Saudi Arabia, 1995). The focus of these agreements was on the technological aspects in the fields of aerospace and aeroplanes, electronics and communications, petrochemicals, medical, pharmaceutical, and food industry (Ministry of Planning-Kingdom of Saudi Arabia, 1995). The aims of these agreements are to (Ministry of Planning-Kingdom of Saudi Arabia, 1995):

1. Transform the modern technologies in these fields.
2. Achieve the quality and the profitability in these industries.
3. Achieve the ability to grow in these fields and has the ability to export the products.
4. Facilitate job and training opportunities for the national manpower in these fields.

The result of these agreements was the establishment of nine industrial companies (Ministry of Planning-Kingdom of Saudi Arabia, 1995). Almost all of these companies are working now (Ministry of Planning-Kingdom of Saudi Arabia, 1995).

4.2.2 Continuous Process Industries in Saudi Arabia:

Continuous process industries in Saudi Arabia represent 61.2% of the total capitalisation of industrial production facilities in the country (Ministry of Industry and electricity, 1999; Riyadh Chamber of Commerce &Industry, 1999; The Saudi Arabian Information Resource- Factories Licensed, 1999). This has been reflected in the number of plants in this sector which has risen lately to reach 368 manufacturing facilities (Ministry of Industry and electricity, 1999; Riyadh Chamber of Commerce &Industry, 1999; The Saudi Arabian Information Resource- Factories Licensed, 1999). These facilities produce different products such as chemical products, refined petroleum products, petrochemicals, plastics and others.

A major producer in this sector is the Saudi Arabian Basic Industries Corporation (SABIC) (SABIC, 2001; The Saudi Arabian Information Resource- SABIC Related News Releases, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). This corporation has manufacturing facilities which represent 19.8% of the total number of the producing plants in Saudi Arabia (The Saudi Arabian Information Resource- SABIC Related News Releases, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). These manufacturing facilities produce such products as petrochemicals, chemicals, fertilisers, metals, plastics, industrial gases, and polyester (SABIC, 2001; The Saudi Arabian Information Resource- SABIC Related News Releases, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999).

Another major producer in this sector is Saudi Arabian Oil Company (SAUDI ARAMCO) which has almost the same percentage of the total number of producing plants (Saudi ARAMCO, 2001; U.S. Department of Commerce – National Trade Data Bank, 1999). However, the production of these plants is refined petroleum products.

Continuous process industries, as an industrial sector is one of the fastest growing industrial sectors in Saudi Arabia. It has obtained the highest number of issued industrial licenses (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). The Saudi Ministry of Industry and Electricity has issued lately 995 licenses for building new plants that are related to this industrial sector (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999).

In addition, this sector is in the first place of financed joint ventures, which are important for satisfying the need of the plants in this sector for advanced high technology (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). These joint ventures are represented by 132 producing joint venture facilities which were capitalised at $30 billion (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). The capitalisation of these facilities represents 86.2% of the total finances invested in producing joint venture projects (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999).

Furthermore, the value of Saudi exports of the products from this sector is one of the biggest values of all sectors (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). It was estimated in 1996 at $4.29 billion (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). This represents 68% of the total value of Saudi exports (The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999).

4.2.3 Shutdown Maintenance at Continuous Process Industries in Saudi Arabia:

In the last ten years, the Saudi Arabian economy has been affected by the reduction of the oil prices in the world market (Al-Sultan, 1996). This reduces the dependencies on the policy of replacing ageing facilities with new ones and increases the importance of maintenance including shutdown maintenance in order to keep these ageing facilities in good working condition (Al-Sultan, 1996). As a result, maintenance expenditure increases due to the increase of the age of these facilities and the effect of inflation (Al-Sultan, 1996). Therefore, the government of Saudi Arabia and the private sector have tried to find ways of reducing the costs of performing the maintenance programmes while keeping the same quality of maintenance services delivered (Al-Sultan, 1996).

In this respect, the government of Saudi Arabia stated in its sixth five-year development plan (the latest plan) that one of the major objectives of the plan is better management of the operations and maintenance (Ministry of Planning-Kingdom of Saudi Arabia, 1995). In addition, three of the strategic principles in this plan were about the importance of maintenance at this stage of the Kingdom's development and the importance of the efforts that should be exerted to improve its effectiveness (Ministry of Planning-Kingdom of Saudi Arabia, 1995).

Shutdown maintenance, which is one type of maintenance, has the same degree of importance as maintenance in the continuous process industries in Saudi Arabia. In SABIC which owns 19.8% of the continuous process plants in Saudi Arabia, one of the most important maintenance programmes that has been used to maintain the facilities is the shutdown maintenance programme (SABIC, 2001). These plants use shutdown maintenance in order to achieve the following (SABIC, 2001):

1. Reduce emergency shutdowns.
2. Protect external and internal environment from disasters as a result of breakdowns.
3. Extend the useful life of the equipment.
4. Increase machines and equipment availability.
5. Minimise the consumption of energy.

Furthermore, ARAMCO, which is another big company in the country and the major producer of refined petroleum products, has considered shutdown maintenance as one of the major maintenance programmes that are used to maintain its facilities (Saudi

ARAMCO, 2001). This degree of importance of shutdown maintenance has been realised not only in these two companies which own almost 40% of the continuous process plants in Saudi Arabia but also in other smaller companies (Ikhwan and Burney, 1994; Ministry of Planning-Kingdom of Saudi Arabia, 1995).

4.3 THE DESCRIPTION OF THE RELATIONSHIPS OF INTEREST IN THE LITERATURE REVIEW:

One source of information that provides a solid foundation for developing a comprehensive theoretical framework from which the description of the relationships between the variables of interest can be extracted for testing is the literature review (Badiru, 1996; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). The literature review as source of information identifies the important variables that are determined by previous research findings as important and necessary for the subject under study (Melville and Goddard, 1996; Sekaran, 1992).

In this thesis, the literature review provided a discussion of several important issues that could be used in the development of the theoretical framework. It provided a discussion on the important variables that constitute, moderate and intervene in the relationship between the scope of work of shutdown maintenance and shutdown maintenance cost and the relationship between this scope and the shutdown maintenance frequency, in addition to, the relationship between this scope and the loss in production that occurs as a result of shutdown maintenance. In addition, it provided a discussion on the relationships among these variables and the direction of these relationships. The results of these literature review discussions that were used in this thesis theoretical framework are summarised in the following:

1. One of the variable that affects shutdown maintenance cost and frequency and the loss in production that is caused by performing shutdown maintenance activities was claimed to be the number of shutdown maintenance activities (Emmert and Sieracki, 1990; Gupta and Paisie, 1997; Owens, 1998; Opfer, 1997).
2. The number of shutdown maintenance activities is nothing other than the scope of work of shutdown maintenance (Gupta and Paisie, 1997; Owens, 1998).

3. The frequency of each shutdown maintenance activity was claimed to influence the frequency of the whole shutdown maintenance (Metcalfe et al., 1998; Sibley, 1991; Steudel and Desruelle, 1992).
4. It has been claimed that shutdown maintenance duration has a relationship with the loss in production that is caused by performing shutdown maintenance activities and with the shutdown maintenance cost (Baughman and Shah, 1996; Koppelman and Faris, 1994; Shuffleton, 1998).
5. The time length of each shutdown maintenance activity and the accuracy of the planning and the scheduling of the shutdown maintenance activities were claimed to be the factors that affect the duration of shutdown maintenance (Sibley, 1991; Steudel and Desruelle, 1992). In other words, the reduction (the increase) of the time length of any shutdown maintenance activity and (or) the more (the less) accurate planning and scheduling of the shutdown maintenance activities contribute to the reduction (the increase) of shutdown maintenance duration (Sibley, 1991; Steudel and Desruelle, 1992).
6. It has been claimed that a reduction in the number of shutdown maintenance activities (scope of work of shutdown maintenance) without creating any operational, safety or economic problems contributes to the reduction of the duration and the frequency of shutdown maintenance (Owens, 1998). In other words, doing less work in shutdown maintenance while maintaining overall plant availability contributes to make shutdown maintenance short and less frequent (Owens, 1998).
7. Good practice of shutdown maintenance that minimises the shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance depends on the determination of the appropriate equipment maintenance frequencies and the minimisation of shutdown maintenance duration (Hong, 1995).

4.4 THE DESCRIPTION OF THE RELATIONSHIPS OF INTEREST BY INDIVIDUALS IN THE INDUSTRIAL FIELD:

Another source of information that provides a solid foundation for developing a comprehensive theoretical framework from which the description of the relationships between the variables of interest can be extracted for testing is the environment in which these relationships occur (Badiru, 1996; Czaja and Blair, 1996; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). The way to get the necessary information from this environment is by conducting an exploratory study that uses either interviewing, observational survey, or both to gather data about the variables of interest and the relationships between them (Badiru, 1996; Czaja and Blair, 1996; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992).

In this thesis, the exploratory study that was used to get the necessary information on the relationships between the variables of interest was conducted on the industrial environment in Saudi Arabia. In particular, it was conducted on the continuous process industry in this environment, which has been discussed at the beginning of this chapter together with the reason of using it in this thesis. In addition, the technique that has been selected to collect the necessary data for this exploratory study was the interviewing since it is less expensive and less time consuming compared with the observational survey. The observational survey is more suitable for collecting data that is related to behavioural studies rather than studies that are concerned with objective variables such as the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production. A complete discussion of this exploratory study is presented in the following subsections.

4.4.1 The Design of The Interviewing process:

At this stage of the thesis, interviews were conducted in order to provide more in-depth information about the important variables that constitute, moderate and intervene in the relationship between the scope of work of shutdown maintenance and the shutdown maintenance cost and the relationship between this scope and the shutdown maintenance frequency, in addition to, the relationship between this scope and the loss in production that is caused by the shutdown maintenance. The type of interviews that were conducted to obtain the required information was structured interviews. Structured interviews were chosen because the type and the nature of most information needed about the variables of interest was known from the literature review and a list of questions which lead to more information about these variables was easy to develop.

These structured interviews were held as mentioned at the beginning of this section in the continuous process industry in Saudi Arabia. This industry includes 368 continuous process plants (Ministry of Industry and electricity, 1999; The Saudi Arabian Information Resource- Factories Licensed, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). These plants were represented in this survey by the planners and (or) the managers in the maintenance departments. The choice of planners and managers as representatives of the plants for these interviews was based on their responsibility for dealing with the cost and the frequency of shutdown maintenance and the loss in production that is caused by performing shutdown maintenance activities.

A sample for these interviews was drawn from the above population of plants through the use of simple random sample design in order to give each plant in this population equal chance to be in the sample. The sample was chosen at random from an updated list (dated October, 1999) of the continuous process plants in Saudi Arabia that has been provided through the home page of the Saudi chambers of commerce and industry. In addition, the determination of the size of this sample was based on the achievement of sufficient information about the variables of interest and the relationships between them. In other words, the interviews were terminated when it has been noticed that there was no new information emerging about the variables and the relationships of interest. This way of determining the sample size was used in order to reduce the cost and the time of the interviews. The result of this way was a simple random sample of 28 plants that took part in the interviewing process.

The way in which these interviews were conducted was face to face interviews because all participants were in Saudi Arabia. The advantage of face to face interviews is that they can help the researcher to adapt and adopt questions as necessary, clarify doubts, and ensure that the responses are properly understood by repeating or rephrasing the questions (Badiru, 1996; Czaja and Blair, 1996; Frey and Oishi, 1995; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). They also provide rich data, offer the opportunity to establish rapport with interviewees and help to explore and understand complex issues (Czaja and Blair, 1996; Frey and Oishi, 1995; Melville and Goddard, 1996; Sekaran, 1992). In addition, they help to pick up non-verbal cues from the respondent, provide more detailed answers to the open ended questions and provide good sample coverage and a good response rate (Badiru, 1996; Czaja and Blair, 1996; Frey and Oishi, 1995; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992).

As a first preparation step to these face to face structured interviews, two types of letters were sent to participants. The first type of these letters was introductory in nature in which the clarification of important issues such as the identity of the interviewer, the identity of the sponsoring organisation of the survey, the purpose of the interview and the approximate date and length of the interview were revealed. These letters were sent to the participants in order to describe the purpose of the survey and to stimulate their co-operation. The second type of these letters was more detailed. In these letters, more important issues such as the assurance of complete confidentiality of the provided information and the importance of participant views for the end results of the survey were included in order to establish rapport and trust with participants. These two types of letters were sent together to the participants' plants first and then copies of which were sent to the participants. Samples of these letters are given in Appendix 1.

The physical settings of these interviews were the second preparation step and one of the important factors that affected the communication flow with the participants. Therefore, different physical settings were chosen depending on the participants feeling of comfort. For example, some of the interviews took place in the workplace, whilst others took place in the participants' homes or public coffee shops.

4.4.2 The Design of Interviewing Questions:

The questions that have been asked in these interviews were about the scope of work of shutdown maintenance, shutdown maintenance cost, shutdown maintenance frequency, the loss in production that is caused by shutdown maintenance, the relationships among these variables and the other variables that affect these relationships. The language that has been used in these questions was the English language with some technical maintenance terms. This language and these terms were used because they are easy to understand by the participants (maintenance department managers and planners) who use them in their every day work.

These interviewing questions were of two types. The first type was the closed-ended questions with exhaustive and mutually exclusive response categories. The questions of this type dealt with investigative subjects such as the existence of relationships between the variables of interest, the existence of other variables that affect these relationships and the existence of other variables that affect the variables of interest and the relationships between these variables. Also, the questions of this type were used to investigate the knowledge of the participants on certain term such as the shutdown maintenance cost. The other type of the interviewing questions was the open-ended questions, which were used to give the participants the chance to elaborate on their knowledge of certain maintenance terms and to describe the relationships between the variables of interest and the relationships between these variables of interest and other variables. In addition, the questions of this type gave the participants the chance to list all the variables that affect the variables of interest and those that affect the relationships between them.

With both types of these interviewing questions, illustrative cards were used. The purpose of these cards was to help the participants to visualise the response categories of the closed-ended questions in order to reduce the response order bias and to simplify the answer of the open-ended questions by asking the participants to draw the relationships between the different types of variables on these cards.

In the list of these questions, the efforts were made to keep questions in these interviews as concrete, specific, short and simple as possible. Therefore, double-barrelled and ambiguous questions such as those that mention two or more issues at the same time or those that confuse the participants about their meaning were avoided. Also, leading and loaded questions such as those that suggest to the participant that one answer is preferable to another or those that are phrased in an emotionally charged manner were avoided as well. In addition to these efforts, the funnel technique was used in order to guide the participants through complex subjects by using a series of questions that progress from general to specific issues.

The arrangement of these interviewing questions was started by placing easy questions that are related to the topic of the interview as expressed in the introductory statement at the beginning of the interviewing questions list. The reason behind this is to maintain participant interest and to make responding easy. Then, more specific and complex questions such as those about the variables and the relationships among them were introduced. This arrangement process was concluded by placing easy-to-answer questions such as demographic questions at the end of the list in order to minimise inadequate responses due to participant fatigue.

In addition to this general arrangement, interviewing questions were logically organised into seven sections according to their relation to the topics of these sections. These sections were personal information section; shutdown maintenance cost section, the loss in production section, shutdown maintenance frequency section, shutdown maintenance duration section, problems that are associated with the reduction of the scope of work of shutdown maintenance section, and the general information section. The arrangement of these sections and the transition statements that were used to facilitate this arrangement were made in such a way that makes each section consistent with previous and subsequent sections.

In each one of these sections, the questions were logically arranged from general to specific in a manner that makes sense to the participants and prevents the interviewer from paging back and forth during the interview. The instructions that have been used to guide the interviewer through these questions were written in bold face and italic font style and they were enclosed between two parenthesises in order to distinguish them from the questions. Also, the definitions that were used to illustrate the meaning of some of maintenance terms were written in bold face and italic font style and they were placed in boxes in order to distinguish them from the instructions and from the interviewing questions. This process of grouping the interviewing questions into sections allows the participants to recognise the relationships amongst these questions. In addition, it minimises response fatigue. A sample of these interviewing questions is illustrated in Appendix 2.

4.4.3 The Pre-testing and The Pilot Study of The Interviewing process:

Before starting the interviews, the list of the interviewing questions, in addition to, the introductory letters and the interviewing administrative procedures were tested in order to make sure that they are suitable for these interviews. The way that has been used to test these important parts of the interviewing process was based on conducting two types of tests. The first type was the pre-testing of the introductory letters and the list of the interviewing questions (Frey & Oishi, 1995; Litwin, 1995). This type was conducted in order to overcome the design problems of these parts of the interviewing process and to identify and correct the errors in them (Frey & Oishi, 1995; Litwin, 1995). The second type was a pilot test of the interviews, which also was conducted in order to determine whether the parts of the interviewing process work in a manner that satisfy the purpose of these interviews (Frey & Oishi, 1995; Fink, 1995d; Litwin, 1995). Both of these types of tests and their results are summarised in the following points:

1. **Pre-testing of the introductory letters and the interviewing questions:**

The way that has been used to perform the pre-testing of these important parts of the interviewing process was started by sending them to a group of research methodology professionals and shutdown maintenance experts in order to get their comments on the design of these parts and their suggestions on the best way to improve them. Then, these comments and suggestions were discussed with each one of these professionals and experts in order to refine the design of these parts in such a way that can help in satisfying the purpose of the interviews.

The reason for using this way of pre-testing was because it is very effective and efficient in identifying respondents' problems with these parts of the interviewing process (Czaja and Blaire, 1996). In addition, it leads to recommendations that stem from these experts and professionals experience and knowledge of interviewing and subject matter rather than from the reactions of pre-test respondents (Czaja and Blaire, 1996).

The number of times for conducting this way of pre-testing in this part of the thesis was two times. In the first time, the comments and the suggestions on the design of these important parts of the interviewing process were collected and the necessary correction actions were performed. Whereas, in the second time, the confirmation process of performing these correction actions and responding to the comments that were suggested in the first time was accomplished.

The group of professionals and experts who were invited to participate both times consisted of one research methodology professional, two shutdown maintenance experts from the industry and two shutdown maintenance experts from the academic environment. The reason for using this number of professionals and experts was because it was the maximum number that would not increase the cost and the time of the pre-testing of these parts of the interviewing process. At the same time, it was within the range of three to eight professionals and experts that has been suggested in the literature (Czaja and Blaire, 1996).

The specific purpose of this way of pre-testing was to test very important aspects of these parts of the interviewing process. In particular, the purpose was to test the following:

1. The simplicity and the clearness of the words and the phrases that were used in the introductory letters.
2. The smoothness of the flow of the introductory letters format.
3. The quality of the introductory letters layout.
4. The simplicity and clearness of the instructions in the list of the interviewing questions.
5. The accuracy and adequacy of these instructions.
6. The clearness and adequacy of the procedures for recording responses that are related to the interviewing questions.
7. The accuracy and the clearness of the definitions of the technical maintenance terms that have been used in the list of the interviewing questions.
8. The simplicity of the skip patterns (ways used to skip from a question to another certain question) that have been used in the list of the interviewing questions.
9. The simplicity and clearness of the words and phrases of the interviewing questions.
10. The appropriateness of the vocabulary used in these questions for the level of the understanding of the participants.
11. The smoothness of these questions flow.
12. The appropriateness of the order of these questions for the level needed to reflect the focus of the research and for the necessary need to reduce participants' fatigue.
13. The quality of grouping these questions into sections.
14. The appropriateness of the order of the sections in the list of the interviewing questions for the necessary support needed to reflect the focus of the interviews and to reduce the participants' fatigue.
15. The comprehensiveness of the response categories.

The results of this way of pre-testing these parts of the interviewing process were represented by important comments and suggestions that were implemented by taking the necessary correction actions. These comments and suggestions, in addition to, the correction actions that were taken to implement them are summarised in the following tables:

Introductory Letter	Comments and Suggestions	Actions Taken
First Letter	No comments or suggestions	No action has been taken.
Second Letter	No comments or suggestions	No action has been taken.

Table 4.1 The Results of The Pre-testing of The Introductory Letters

Section in The List of Interviewing Questions	Comments and Suggestions	Actions Taken
Section one: Personal Information	No comments or suggestions	No action has been taken.
Section Two: General Information	• It is preferred to move this section to the end of the list of questions since most of its questions are easy-to answer items which helps to minimise inadequate responses due to respondent fatigue at the end of the interviews.	• It has been moved.
Section Three: Shutdown Maintenance Cost	• It is good to add codes to the response category of the first question of this section. • It is preferred to add the following closed-ended question between questions two and three in this section in order to reveal the percentage of those participants who believe that there is a relationship between these important variables. The question is: "Is there a relationship between the number of shutdown maintenance activities and the shutdown maintenance cost?" • It is preferred to add the following closed-ended question between questions three and four in this section in order to reveal the percentage of those participants who believe that there is at least one factor that affects the relationship between the number of shutdown maintenance activities and the shutdown maintenance cost. This question is: "Is/are there (a factor/factors) that (affects/affect) this relationship? "	• It has been added. • It has been added. • It has been added.

Continued in the next page

Section in The List of Interviewing Questions	Comments and Suggestions	Actions Taken
	• It is preferred to add to question five in this section the following instruction: " Read the following question without the words (another) and (other) if you are transferred from (the new) Q#2. Otherwise, read the question as it appears below."	• It has been added.
Section Four: The loss in production	• It is preferred to add the following closed-ended question as a first question in this section in order to reveal the percentage of those participants who believe that there is a relationship between these important variables: "Is there a relationship between the number of shutdown maintenance activities and the loss in production that is caused by performing shutdown maintenance? " • It is preferred to add the following closed-ended question between questions one and two in this section in order to reveal the percentage of those participants who believe that there is at least one factor that affects the relationship between the number of shutdown maintenance activities and the loss in production: "Is/ are there (a factor/factors) that (affects/affect) this relationship? ". • It is preferred to add to question four in this section the following instruction: "Read the following question without the words (another) and (other) if you are transferred from (the new) Q#1. Otherwise, read the question as it appears below."	• It has been added. • It has been added. • It has been added.
Section Five: Shutdown Maintenance Frequency	No comments or suggestions	No action has been taken.
Section Six: Shutdown Maintenance Duration	No comments or suggestions	No action has been taken.
Section Seven: Problems Associated with Reducing the shutdown maintenance Activities	No comments or suggestions	No action has been taken.

Table 4.2 The Results of The Pre-testing of The List of The Interviewing Questions

2. The pilot test of all parts of the interviewing process:

After refining the design of the introductory letters and the list of the interviewing questions by pre-testing them, these parts, in addition to, the other parts of the interviewing process were ready for the pilot test. This pilot involved conducting a set of interviews in the same manner and with the same procedures as in the main interviewing survey in order to make sure that the parts of the interviewing process work in a manner that satisfies the purpose of the interviews (Frey & Oishi, 1995; Fink, 1995d; Litwin, 1995).

In this part of the thesis, the pilot test was conducted by using the first eleven interviews. The reason for using this number of interviews as a sample for this test was because this number represented the maximum number that would not increase the cost and the time of this test. In addition, the purpose of this pilot test was similar to the purpose of the pre-test. The only difference was that in this pilot test more aspects of the interviewing process such as the following were tested:

1. The appropriateness of the administrative procedures for the way that has been used to send the introductory letters.
2. The appropriateness of the administrative procedures for the way that has been used to carry out the interviews.

The results of this pilot test in this part of the thesis were a set of correction actions that were implemented in the interviewing process in order to overcome the difficulties that faced the researcher during the interviews. In particular, they were the following:

Parts of The Interviewing Process	Difficulties	Actions Taken
First Introductory Letter	No difficulties	No action has been taken.
Second Introductory Letter	No difficulties	No action has been taken.

Continued in the next page

Parts of The Interviewing Process	Difficulties	Actions Taken
The List of The Interviewing Questions	• The definitions were hardly recognised since they were written in the same font and type of letters as the instructions.	• They were placed in boxes in order to distinguish them from the instructions and from the interviewing questions.
	• In question #3 in section one, the phrase " the number of shutdown maintenance activities" was confused with the phrase "shutdown maintenance cost".	• The phrase "Scope of work of shutdown maintenance" was added in order to clarify the question.
The Administrative Procedures	• Since the introductory letters were sent separately to the participants and their organisations, some of the participants or their organisation did not receive the first introductory letter whereas other some did not receive the second introductory letter and in some cases, some of the participants did not receive any letter at all.	• Both types of these letters were sent together to the participants' plants first and then copies of which were sent to the participants.
	• Some of the participants preferred to hold the interview in places away of their offices either because they did not have enough time for the interview or because they feel more comfortable to hold the interview in some other places.	• Different physical settings were chosen depending on the participants feeling of comfort. For example, some of the interviews were taking place at the workplaces, and others were taking place at the participants' homes or public coffee shops.

Table 4.3 The Results of The Pilot Test of The Interviewing Process

3. The validity of the interviewing questions:

During the pilot test and the pre-testing of the interviewing process, the validity of the interviewing questions was assessed in order to make sure that these questions covered the variables and the relationships that are intended to be covered. The way that has been used to asses the validity of these questions was based on asking the shutdown maintenance experts who participated in the pre-test and the maintenance planners and managers who participated in the pilot test to rate each item and scale for the appropriateness and relevance to the issues that have been measured and to list any areas that are pertinent to the subject matter of the interview but not covered in the items.

The reason behind using this way of assessing the validity of these questions was because it was the least time consuming way that could be used to assess the validity of these questions. In addition, it was the cheapest way that could achieve the validity process purpose.

The result of this way of validating these interviewing questions was a set of comments, which stated that the questions in the list of the interviewing questions were valid in their face and content.

4. The reliability of the interviewing questions:

In addition to assessing the validity of the interviewing questions, the reliability of these questions was assessed as well in order to make sure that these questions are stable and consistent in covering the variables and the relationships that are intended to be covered. The way that has been used to asses the reliability of these questions was based on sending the list of interviewing questions in a form of questionnaire to all the participants who participated in the pilot test and asking them to answer the questions. Then, their answers to this list of questions were compared with their answers in the interviews and the association coefficients, which showed the magnitude of the correlation between the two sets of answers, were calculated in order to measure the reliability of these questions.

This way (alternate-form reliability or parallel-form reliability) of assessing the reliability of these questions was used in this part of the thesis because it was the cheapest and the least time consuming way that could be used to measure the reliability of these questions. In addition, it was the best way to avoid what is called the practice effect which is the familiarity of the participants with the items that makes them simply answer these items again based on their memory of what they answered last time.

The result of this way was a set of association coefficients with values exceeding the value of 0.8 (in particular, between 0.83 and 0.89) which indicated according the literature (Litwin, 1995; Sekaran, 1992) that the interviewing questions in this part of the thesis were reliable. The final and refined list of the interviewing questions is illustrated in Appendix 2.

4.4.4 The Interviews Findings:

After refining the design of all parts of the interviewing process, the interviews were implemented and several results were found. These results were very important to the understanding of the variables of interest and the relationships between them and they are summarised in the following points (the data of the interviews from which these results were extracted is shown in Appendix 5):

1. The size and the age of participating plants:

Two questions were asked to the maintenance planners and managers (the participants) of the twenty-eight participating plants in order to measure the size and the age of these plants which in turn help in the understanding of the demographic characteristics of the sample. These questions were the following:

- How old is the plant?
- How many machines and equipment does the plant have as a part of the production facilities?

The answers to the first question showed as illustrated in table 4.4 that the participating plants were related to different age categories. These categories were ranged from 5 years old and under to 31 years old and over. Each one of these categories had a frequency, which showed the number of plants in this category, and a percentage, which showed the percentage of these plants in the sample of the participating plants. Based on these frequencies and percentages, the highest frequency in table 4.4 belonged to the category of plants with ages ranging from 16 to 20 years old whereas the lowest frequency belonged to the categories of plants with ages ranging from 26 to 30 years old and from 31 years old and over. These categories of the participating plants represented 28.6% and 3.6% of the sample of the interviewing process respectively.

In addition to this, the answers to the second question showed as illustrated in table 4.5 that these plants have different sizes. These sizes were classified and measured using the number of machines and equipment as a classification measure. According to maintenance perspective, the reason for using this measure was that other classification measures for the plant size such as the number of maintenance activities and the number of maintenance staff depend on the number of machines and equipment and on the right application of maintenance programmes in order to be determined. In addition, the production capacity of each plant, which is one of the plant size classification measures, was difficult to use in this case because of the differences in the unit of production capacity that has been used in each plant.

According to the above used classification measure, the highest frequency in table 4.5 was associated to the group of those plants, which have a number of machines ranging from 751 to 1000 machines. This group of plants represented 25% of the participating plants in the sample. Also, the next highest frequency was the one, which was associated with the group of plants that have a number of machines ranging from 501 to 750 machines. The plants in this group represented 21.4% of the participating plants in the sample. In addition to these two groups, the third largest group was the group of plants that have a number of machines ranging from 1001-1250 machines. The plants in this group represented 17.9% of the participating plants in the sample.

In summary, these results of these two questions showed how different the participating plants were in terms of their ages and sizes. In particular, they showed the diversity of the sample of the interviewing process of this thesis in terms of the size and the age of the participating plants which helped in minimising the bias and in increasing the credibility of the results of these interviews.

Age Category	Frequency	Percentage
Under 5	5	17.85
6-10	6	21.4
11-15	5	17.85
16-20	8	28.6
21-25	2	7.1
26-30	1	3.6
Over 31	1	3.6
Total	**28**	**100**

Table 4.4 The Frequencies and The Percentages of The Age Categories of The Participating Plants

Total Number of Machines in The Plant	Frequency	Percentage
Less Than 250	2	7.15
251-500	3	10.7
501-750	6	21.4
751-1000	7	25.0
1001-1250	5	17.9
1251-1500	3	10.7
1501-over	2	7.15
Total	**28**	**100**

Table 4.5 The Frequencies and The Percentages of The Categories That Represent The Total Number of Machines in The Participating Plants

2. Shutdown maintenance cost and the signs that describe its change:

The participants (the twenty-eight maintenance planners and managers who represented the twenty-eight participating plants in these interviews) defined shutdown maintenance cost as the sum of the direct maintenance cost and the overhead cost. This was an answer to the following question:

- Which one or more than one of the following (is/are) (a component/components) of shutdown maintenance cost?
  - A. Direct cost
  - B. Overhead cost
  - C. Others (Ask the participant to specify)

In addition, they defined the direct maintenance cost as the sum of all costs that can be traced directly to shutdown maintenance activities and it includes the direct cost of labour, experts, materials, spare parts, tools and equipment that are used to perform shutdown maintenance activities. They also agreed that overhead cost is the sum of all costs related to shutdown maintenance other than those that constitute the direct cost of shutdown maintenance and it includes the indirect cost of labour, materials, tools, equipment, and other expenses that is allocated to the shutdown maintenance programme.

The participants also answered the question about the signs that describe the changes in the shutdown maintenance cost by claiming that these signs could be summarised in the following:

A. Changes in the number of (direct, indirect) labour, materials, spare parts, tools and equipment.

B. Changes in the number of (direct, indirect) labour and equipment working hours.
C. Changes in the number of (direct, indirect) technologically advanced maintenance materials, spare parts, tools and equipment.
D. Changes in the number of skilful labour.
E. Changes in the prices of the direct and the indirect resources that are used in shutdown maintenance.

3. The relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the shutdown maintenance cost:

Five questions were asked to understand this relationship. These questions were:

- Is there a relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the shutdown maintenance cost? If the answer to this question was "Yes", then the following two questions were asked.
- How do you explain this relationship?
- (Is/Are) there (a factor/factors) that (affects/affect) this relationship? Again, if the answer to this question was "Yes", then the following two questions were asked.
- What (is/are) (this factor/these factors) that (affects/affect) this relationship?
- How do you explain the effect of (this factor/ each one of these factors) on this relationship?

All the participants (the twenty-eight maintenance planners and managers who represented the twenty-eight participating plants) answered these questions and they claimed that there are four relationships between the number of shutdown maintenance activities and the shutdown maintenance cost. In addition, they claimed that these relationships are indirect relationships. In other words, they stated that these relationships are affected by other variables. These variables are the shutdown maintenance direct cost, the shutdown maintenance overhead cost, and the shutdown maintenance duration. They said that the effects of these variables on these relationships are based on describing the influence of the number of shutdown maintenance activities on the shutdown maintenance cost. In particular, they said that the reduction of the shutdown maintenance cost by reducing the number of shutdown maintenance activities is achieved through the reduction of these variables first.

4. The other factors that affect the shutdown maintenance cost:

This subject was covered in the interviews by five questions. These questions were:

- (Is/Are) there (another factor/other factors) that (affects/affect) the cost of shutdown maintenance? If the answer was "Yes", then the following two questions were asked.
- What (is/are) (this factor/these factors)?
- How do you explain the relationship between (this factor/each one of these factors) and the shutdown maintenance cost? If there were more than one factor, then the following question was asked.
- Do these factors have relationships with each other? If the answer was "Yes", then the next question was asked.
- How do you explain these relationships?

The twenty-eight maintenance planners and managers who represented the twenty-eight participating plants claimed as a general answer to these questions that in addition to the number of shutdown maintenance activities, the cost of each shutdown maintenance activity and all the factors that affect the duration of shutdown maintenance (they will be discussed later) are the other variables that affect the shutdown maintenance cost. They claimed that these variables have indirect relationships with the shutdown maintenance cost. In this respect, they said that the two relationships between the cost of each shutdown maintenance activity and the cost of shutdown maintenance are affected by other variables such as the shutdown maintenance direct cost and the shutdown maintenance overhead costs. In addition, the relationships between the variables that affect the duration of shutdown maintenance and the shutdown maintenance cost are affected by the shutdown maintenance duration. In particular, they said that the effects of the shutdown maintenance direct cost, the shutdown maintenance overhead cost and the shutdown maintenance duration on these relationships are based on describing the influence of the cost of each shutdown maintenance activity and the variables that affect the duration of shutdown maintenance on the shutdown maintenance cost.

In addition to this, the participants concluded this section by illustrating other relationships between these variables. They stated that the only other relationships between these variables are the following:

A. The relationship between the number of shutdown maintenance activities and the shutdown maintenance duration.
B. The relationship between the shutdown maintenance duration and the direct cost of shutdown maintenance.
C. The relationship between the shutdown maintenance duration and the overhead cost of shutdown maintenance.

They described these relationships by claiming that all of them are direct relationships. In addition, they added that the two relationships between the duration of shutdown maintenance and the shutdown maintenance cost are indirect and they are affected by of the shutdown maintenance direct and overhead costs. In other words, the shutdown maintenance direct and overhead costs act as intervening variables in these relationships.

5. The relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the loss in production that occurs as a result of performing shutdown maintenance:

Five questions were asked to the participants in order to cover this subject and they were the following:

- Is there a relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the loss in production that is caused by performing shutdown maintenance? If the answer to this question was "Yes", then the following two questions were asked.
- How do you explain this relationship?
- (Is/Are) there (a factor/factors) that (affects/affect) this relationship? Again, if the answer to this question was "Yes", then the following two questions were asked.
- What (is/are) (this factor/these factors) that (affects/affect) this relationship?
- How do you explain the effect of (this factor/ each one of these factors) on this relationship?

All the participants, who participated in these interviews, answered these questions and they claimed that there is a relationship between the number of shutdown maintenance activities and the loss in production that occurs as a result of performing shutdown maintenance. In addition, they claimed that this relationship is an indirect relationship. In other words, they stated that the shutdown maintenance duration affects this relationship by describing the influence of the number of shutdown maintenance activities on the loss of production that occurs as a result of performing shutdown maintenance. In particular, they said that the reduction of the loss in production that occurs as a result of performing shutdown maintenance by reducing the number of shutdown maintenance activities is achieved through the reduction of the shutdown maintenance duration first.

6. The other factors that affect the loss in production that occurs as a result of performing shutdown maintenance:

This subject also was covered by five questions as follows:

- (Is/Are) there (another factor/other factors) that (affects/affect) the loss in production that is caused by performing shutdown maintenance? If the answer was "Yes", then the following two questions were asked.
- What (is/are) (this factor/these factors)?
- How do you explain the relationship between (this factor/each one of these factors) and the loss in production that is caused by performing shutdown maintenance? If there were more than one factor, then the following question was also asked.
- Do these factors have relationships with each other? If the answer was "Yes", then the next question was asked.
- How do you explain these relationships?

In addition to these questions, if the answer to the first question included the duration of shutdown maintenance another set of questions was asked about this variable which their analysis will be discussed in the next following point.

According to the answers of these questions, the twenty-eight maintenance planners and managers who represented the participating plants were classified into two groups. The first group represented the maintenance planners and managers of twenty-three participating plants (82.1% of the sample) who started their answers by claiming that the loss of production that is caused by shutdown maintenance is affected by the variables that affect the shutdown maintenance duration and by the level of the demand of the production process during the period of performing shutdown maintenance. Whereas, the second group represented the maintenance planners and managers of the remaining five participating plants (17.9%) who started their answers of the same questions by stating that the loss of production that is caused by performing shutdown maintenance is affected only by the variables that affect the shutdown maintenance duration.

Both groups of participants stated that the relationships between the variables that affect the duration of shutdown maintenance and the loss in production are indirect relationships. In particular, they said that these relationships are affected by the duration of shutdown maintenance, which acts as an intervening variable in these relationships. In addition to this, the maintenance planners and managers of the twenty-three participating plants (82.1% of the sample) stated that the relationship between the level of the demand of the plant's production processes during the period of performing shutdown maintenance and the loss in production is a direct relationship.

7. The factors that affect the duration of shutdown maintenance which in turn affect the shutdown maintenance cost and the loss in production that occurs as a result of performing shutdown maintenance:

Five questions were used to cover this subject. These questions were:

- (Is/Are) there (a factor/factors) that (affects/affect) the duration of shutdown maintenance? If the answer was "Yes", then the following two questions were asked.
- What (is/are) (this factor/these factors)?
- How do you explain the relationship between (this factor/each one of these factors) and the duration of shutdown maintenance? If there were more than one factor, then the following question was also asked.
- Do these factors have relationships with each other? If the answer was "Yes", then the next question was asked.
- How do you explain these relationships?

Again, the representatives (the maintenance planners and managers) of the participating plants were divided into two groups according to their answers to these questions. In the first group, the representatives of twenty five participating plants

(89.3% of the sample) stated that the duration of shutdown maintenance is influenced by the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, the number of shutdown maintenance activities, the inaccuracy of scheduling the shutdown maintenance activities and by the unavailability of the shutdown maintenance resources when required. In addition, they stated that the effects of these variables on the duration of shutdown maintenance are direct effects. Whereas, the representatives of the second group who represented the remaining three participating plants (10.7% of the sample) stated that the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, and the number of shutdown maintenance activities are the only real factors that affect the duration of shutdown maintenance. These representatives claimed that the chance of having a lack in the availability of maintenance labour, materials, spare parts, tools and equipment is negligible because generally the preparation stage for performing shutdown maintenance is done carefully and precisely. In addition, they claimed that the chance of having non-accurate scheduling of the shutdown maintenance activities is also negligible since the scheduling procedures are performed according to high standards and the used scheduling techniques are the best ones that suit the purpose of scheduling these activities.

8. The relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the shutdown maintenance frequency:

Five questions were asked to cover this subject. These questions were:

- Is there a relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the shutdown maintenance frequency? If the answer to this question was "Yes", then the following two questions were asked.
- How do you explain this relationship?
- (Is/Are) there (a factor/factors) that (affects/affect) this relationship? Again, if the answer to this question was "Yes", then the following two questions were asked.
- What (is/are) (this factor/these factors) that (affects/affect) this relationship?

- How do you explain the effect of (this factor/ each one of these factors) on this relationship?

All the participants (the twenty-eight maintenance planners and managers who represented the twenty-eight participating plants) answered these questions and they claimed that there is a positive relationship between the number of shutdown maintenance activities and the shutdown maintenance frequency. In addition, they claimed that this relationship is a direct relationship. In other words, there is no other variable that affects this relationship.

9. The other factors that affect the frequency of shutdown maintenance:

This subject was covered by five questions as follows:

- (Is/Are) there (a factor/factors) that (affects/affect) the frequency of shutdown maintenance? If the answer was "Yes", then the following two questions were asked.
- What (is/are) (this factor/these factors)?
- How do you explain the relationship between (this factor/each one of these factors) and the frequency of shutdown maintenance? If there were more than one factor, then the following question was also asked.
- Do these factors have relationships with each other? If the answer was "Yes", then the next question was asked.
- How do you explain these relationships?

The representatives of the twenty-eight participating plants answered these questions and they claimed that in addition to the number of shutdown maintenance activities the frequency of shutdown maintenance is affected by the frequency of each shutdown maintenance activity. They said that the relationship between the frequency of each shutdown maintenance activity and the frequency of the whole shutdown maintenance is a direct positive relationship.

10. The problems that are associated with the reduction of the number of shutdown maintenance activities (scope of work of shutdown maintenance):

The questions that were used to cover this subject were the following five questions:

- (Is/Are) there (any problem/problems) that (is/are) associated with the reduction of the number of shutdown maintenance activities (scope of work of shutdown maintenance)? If the answer was "Yes", then the following two questions were asked.

- What (is/are) (this problem/these problems)?
- How do you explain the relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and (this problem/each one of these problems)? If there were more than one problem, then the following question was also asked.
- Do these problems have relationships with each other? If the answer was "Yes", then the next question was asked.
- How do you explain these relationships?

All the representatives of the participating plants answered these questions and stated that there are three (equally critical) types of problems that are associated with the arbitrary reduction of the number of shutdown maintenance activities. They claimed that these problems are the safety, the operational and the economic problems. In addition, they stated that these problems emerge as a result of unplanned shutdowns and frequent emergency stoppages that are caused by either leaving out the eliminated shutdown maintenance activities without being performed in any other maintenance programme or by transferring these activities to another unsuitable maintenance programme.

11. Discussion:

From the results of the interviews, it has been found that the definition of the shutdown maintenance cost that was discussed in the interviews is similar to that which was defined in the literature review. The only difference is that in the literature review more information about this term was revealed. This means that the concept of this term is well known in the industry as well as in the literature.

Also, from the results of the interviews, new important issues were added to those, which were mentioned in the literature review. These issues were the signs that describe the change in the shutdown maintenance cost and which were very useful in explaining the relationships between the variables of interest and the shutdown maintenance cost; in addition to, the effects of the time length of each shutdown maintenance activity on the critical path and the time length of each shutdown maintenance activity not on the critical path on the shutdown maintenance cost and on the loss in production.

Moreover, the interviews revealed the effects of several factors that also help in describing the relationship between the variables of interest. This was the case of the effects of the shutdown maintenance direct cost, overhead cost, and duration on the relationship between the number of shutdown maintenance activities and the shutdown maintenance cost. Similarly, it was also the case of the effects of the shutdown maintenance duration on the relationship between the number of shutdown maintenance activities and the loss in the production that is caused by performing shutdown maintenance.

In conclusion, from the above interviews results, the relationships of interest that need to be described, in addition to, the variables that constitute these relationships were illustrated and discussed. This discussion and the other findings from the interviews are similar to those in the literature review. This means that an agreement exists between these two sources about these relationships and the variables that constitute them. However, a more detailed description about these variables and the relationships between them was revealed in the interviews.

The following section will further discuss the findings of the literature review and the interviews. In addition, it will summarise the findings of this discussion in a theoretical framework (conceptual model).

4.5 THE THEORETICAL FRAMEWORK:

Since the theoretical framework provides the conceptual foundation to proceed with the research by identifying the network of relationships among the variables considered essential to the study, it is important to understand first what variable means. Sekaran (1992) defined variable as:

> any thing that can take on differing or varying values.

In addition, Sekaran (1992) claimed that there are four main types of variables that are used in research. These types of variables are:

1. The dependent variable which is the variable of primary interest to the research.

2. The independent variable which is the one that influences the dependent variable in either a negative or a positive way.
3. The moderating variable, which is the one that has a strong contingent, effect on the independent variable-dependent variable relationship.
4. The intervening variable, which is the one that appear between the time the independent variables operate, to influence the dependent variable and the independent variables impact on the dependent variable.

In addition, it has been found that a good theoretical framework identifies and labels the study's important variables and elaborates the relationship between them (Czaja and Blair, 1996; Sekaran, 1992).

The theoretical framework in this stage is considered to be the first step in the investigation process of the importance of number of shutdown maintenance activities (scope of work of shutdown maintenance) as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production. This makes the variables of primary interest to be the dependent variables of shutdown maintenance cost, shutdown maintenance frequency and the loss in production that is caused by performing shutdown maintenance. The change in these variables could be explained as it has been realised from the literature review and the interviews through the change in the number of shutdown maintenance activities (scope of work of shutdown maintenance) which represents the main independent variable in this study.

In addition to this variable, it has been found from the above-mentioned sources that there are seven other independent variables that affect these variables of primary interest. One of these variables is the cost of each shutdown maintenance activity, which affects the cost of shutdown maintenance only. Another variable is the frequency of each shutdown maintenance activity, which affects the shutdown maintenance frequency only. A third variable is the level of the demand for the plant's production processes during the period of performing shutdown maintenance (timing of shutdown maintenance) which affects only the loss in production that is caused by performing shutdown maintenance. The other four variables, on the other hand, affect both the loss in production that is caused by performing shutdown maintenance and the shutdown maintenance cost. These variables are the inaccuracy of scheduling the shutdown maintenance activities, the unavailability of shutdown maintenance resources, the time length of each shutdown maintenance activity on the critical path and the time length of each shutdown maintenance activity not on the critical path. Moreover, there are three other variables at this stage that have been found in the literature and in the interviews acting as intervening variables. These variables are the shutdown maintenance direct cost, overhead cost and duration.

The following subsections explain how all these variables interact with each other to construct the relationships between the number of shutdown maintenance activities and the three dependent variables of shutdown maintenance cost, shutdown maintenance frequency and the loss in production that is caused by performing shutdown maintenance.

4.5.1 The Description of The Relationships That Illustrate The Influence of The Number of Shutdown Maintenance Activities (Scope of Work of Shutdown Maintenance) on The Shutdown Maintenance Cost:

In chapter one of this thesis and in both the literature review and the interviews, shutdown maintenance cost is defined as the combination of shutdown maintenance direct and overhead costs. The way to describe the changes in these costs is by the changes in the variables that affect them.

In the interviews, it has been found that one of the variables that affect these costs is the number of shutdown maintenance activities. It has been found that this variable has a direct relationship with the shutdown maintenance direct and overhead costs and indirect relationships with the shutdown maintenance cost. In particular, it has been found that the first two relationships are part of the relationships between the number of shutdown maintenance activities and the shutdown maintenance cost. In other words, shutdown maintenance direct and overhead costs act as intervening variables in the relationships between the number of shutdown maintenance activities and the shutdown maintenance cost.

In addition to this, it has been found in the interviews that the cost of each shutdown maintenance activity and the variables that affect the duration of shutdown maintenance are the other variables that positively affect these costs. In particular, it has been found that each one of these variables has a different relationship with these costs. In other words, the cost of each shutdown maintenance activity has direct relationship with the shutdown maintenance direct and overhead costs and indirect relationships where the shutdown maintenance direct and overhead costs act as intervening variables with the cost of shutdown maintenance. In addition, each one of the variables that affect the duration of shutdown maintenance has an indirect relationship with the direct, overhead and the overall shutdown maintenance costs. These indirect relationships are affected by the duration of shutdown maintenance, which acts as an intervening variable in these relationships.

Moreover, it has been found in the interviews and the literature review that the number of shutdown maintenance activities has two indirect relationships with the shutdown maintenance cost through the duration of shutdown maintenance. These relationships are also affected by the shutdown maintenance direct and overhead costs. The effects of these variables on these relationships are based on describing the influence of the number of shutdown maintenance activities on the overall shutdown maintenance cost. Figure 4.1 illustrates all the above relationships.

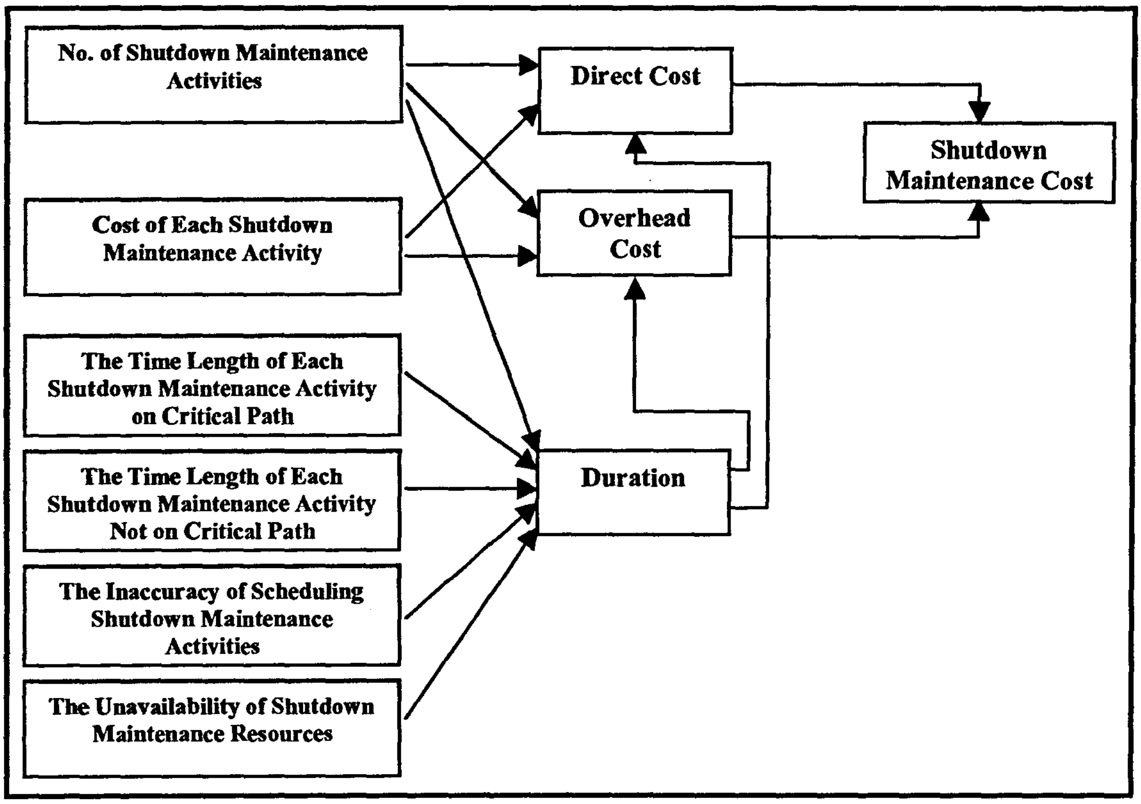

Figure 4.1 The Influence of The Number of Shutdown Maintenance Activities and The Other Variables on The shutdown Maintenance Cost

4.5.2 The Description of The Relationships That Illustrate The Influence of The Number of Shutdown Maintenance Activities (Scope of Work of Shutdown Maintenance) on The Loss in Production That is Caused by Performing Shutdown Maintenance:

Following the lines of the preceding arguments, the loss in production that occurs as a result of performing shutdown maintenance is described in chapter one of this thesis as the loss of the opportunity to produce products as a result of closing the production line in order to perform the shutdown maintenance activities. It has been shown in the literature review and in the interviews that the loss in production that is caused by performing shutdown maintenance is positively affected by the shutdown maintenance duration and by the timing of shutdown maintenance. In other words, each one of these two variables has a direct and positive relationship with the loss in production. Figure 4.2 illustrates these relationships.

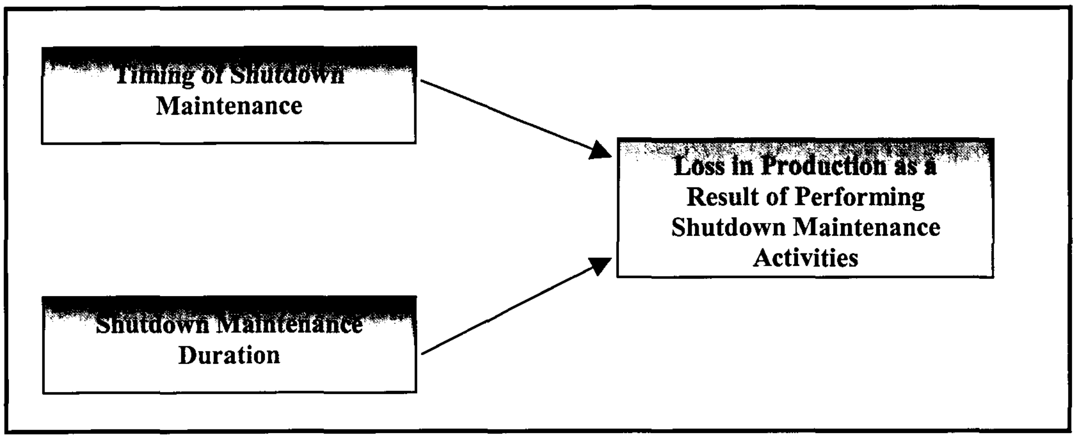

Figure 4.2 The Effects of Shutdown Maintenance Duration and The Timing of Shutdown Maintenance on The Loss in Production

In the literature review and in the interviews, the duration of shutdown maintenance is mainly affected by the time length of each shutdown maintenance activity and by the number of shutdown maintenance activities. In addition, the duration could also be influenced by the inaccuracy of scheduling the shutdown maintenance activities and by the unavailability of the shutdown maintenance resources when required. In particular, each one of these variables has a direct relationship with the duration. Figure 4.3 illustrates the effects of these variables on the duration.

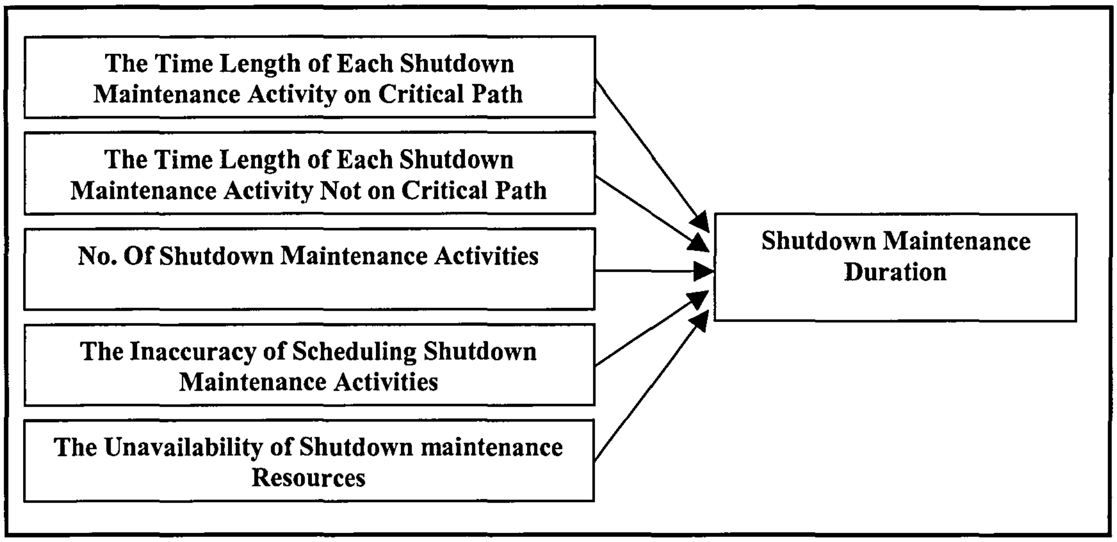

Figure 4.3 The Effects of Different Variables on Shutdown Maintenance Duration

All of this leads the discussion in the interviews to claim that each one of the variables that affect the duration of shutdown maintenance including the number of shutdown maintenance activities has also a relationship with the loss in production that occurs as a result of performing shutdown maintenance. This relationship is an indirect relationship in which the duration of shutdown maintenance acts as an intervening variable.

This concludes the arguments by claiming that that there is only one relationship between the number of shutdown maintenance activities and the loss in production that is caused by performing shutdown maintenance. This relationship is an indirect relationship, which is affected by the duration of shutdown maintenance. The effects of the duration of shutdown maintenance on this relationship are based on describing the influence of the number of shutdown maintenance activities on the loss in production. Figure 4.4 shows all the relationships that illustrate the influence of the number of shutdown maintenance activities on the loss in production that is caused by performing shutdown maintenance.

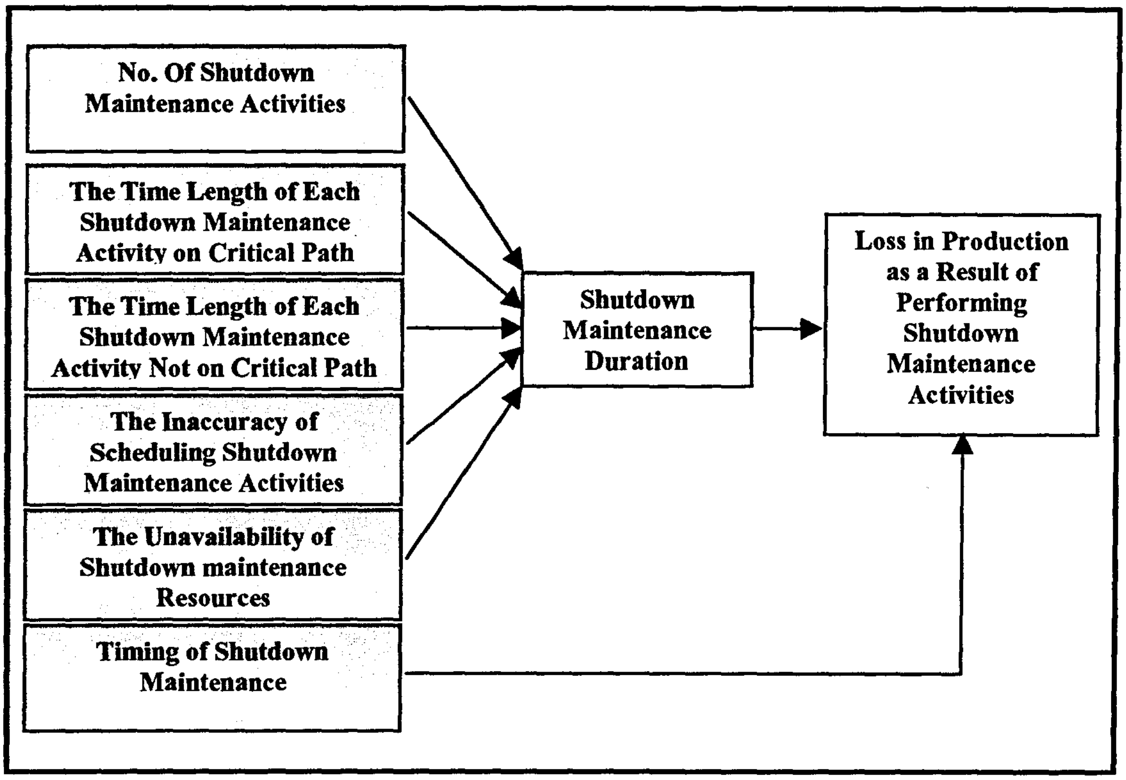

Figure 4.4 The Influence of The Number of Shutdown Maintenance Activities and The Other Variables on The Loss in Production

4.5.3 The Description of The Relationships That Illustrate The Influence of The Number of Shutdown Maintenance Activities (Scope of Work of Shutdown Maintenance) on Shutdown Maintenance Frequency and on The Problems That Are Associated With The Arbitrary Change in This Number:

From the literature review together with the interviews, it has been found that the frequency of the shutdown maintenance is influenced by two variables. One of these variables is the number of shutdown maintenance activities. This variable has a positive relationship with the frequency of shutdown maintenance. In addition, the relationship between this variable and the shutdown maintenance frequency is not affected by other variables, which means that it is also direct relationship. The other variable that affects the shutdown maintenance frequency is the frequency of each shutdown maintenance activity. This variable also has a direct and positive relationship with the shutdown maintenance frequency. Figure 4.5 illustrates the effects of these variables on the shutdown maintenance frequency.

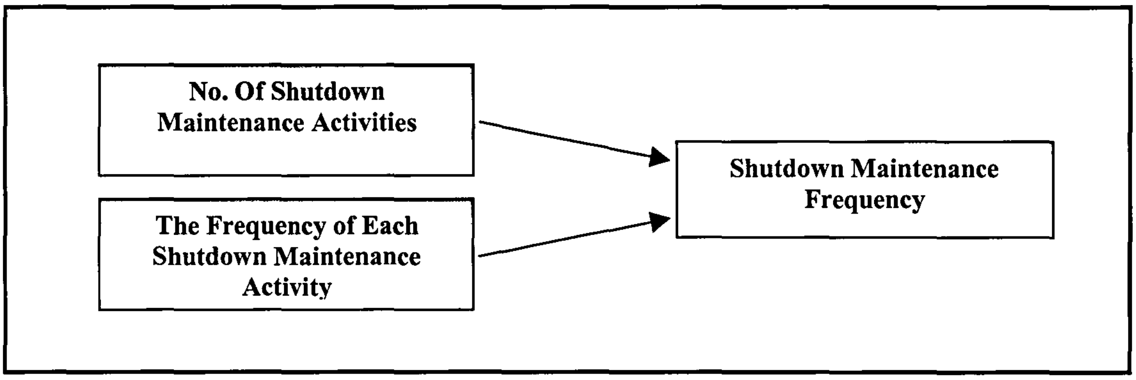

Figure 4.5 The Effects of The Number of Shutdown Maintenance Activities and The Other Variables on The Shutdown Maintenance Frequency

In addition and from the same two sources, the change in the number of shutdown maintenance activities has negative relationships with the problems that are associated with the arbitrary change in this number. In particular, these problems which are the safety, the operational and the economic problems are affected directly by the change in this number. Figure 4.6 illustrates all of these relationships.

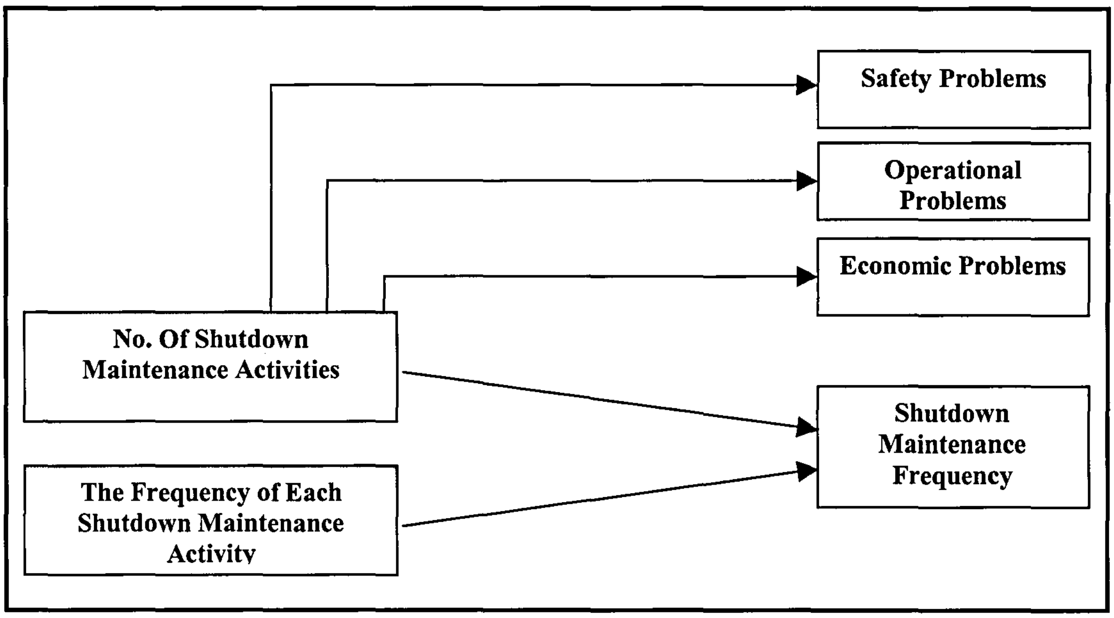

Figure 4.6 The Influence of The Number of Shutdown Maintenance Activities on The Frequency of Shutdown Maintenance and on The Problems That Are Associated with The Change in This Number

4.5.4 The Structure of The Theoretical Framework:

The above arguments, which are represented by several relationships between the variables of interest in each of the above subsections, represent the structure of this thesis first stage theoretical framework (conceptual model). The way that has been used to present this theoretical framework (conceptual model) is through a figure that shows all of the arguments in a form of relationships. Figure 4.7 illustrates the structure of this thesis first stage theoretical framework (conceptual model).

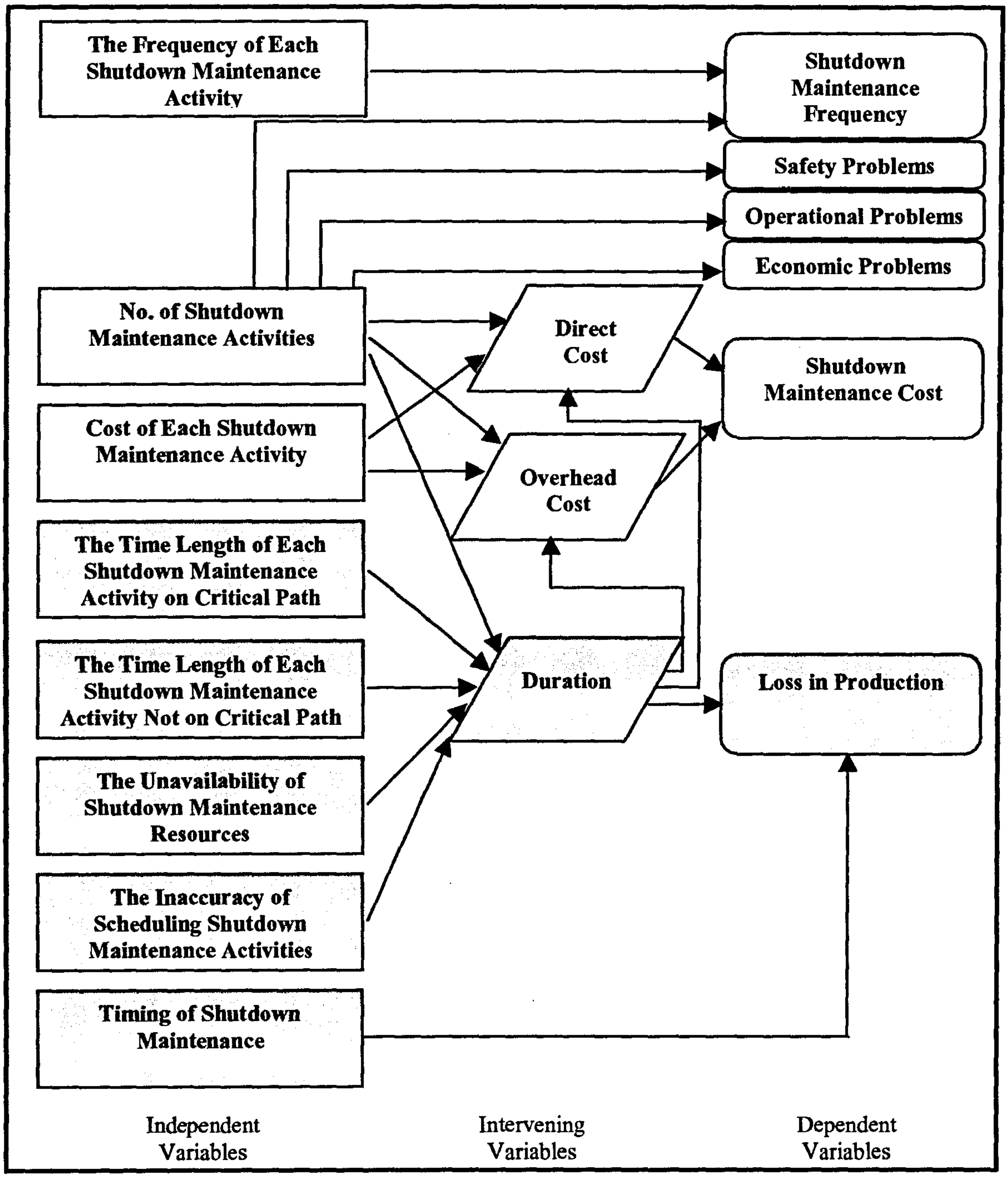

Figure 4.7 First Stage Theoretical Framework

4.6 SUMMARY:

The creation of a theoretical framework (conceptual model) for the first stage of this thesis (the investigation process of the importance of number of shutdown maintenance activities as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production) was discussed in this chapter. The discussion includes the proposed way that has been used to develop the above-mentioned theoretical framework, which was based on dividing the creation process in to three parts. Each one of these parts was discussed in this chapter and it was designated to concern with one of the following issues of the creation process:

1. The discussion of the literature review main points that describe the relationships of interest and the variables that constitute these relationships.
2. The description of the relationships of interest and the variables that constitute these relationships by interviewing individuals in the industrial field.
3. The discussion of the theoretical framework structure.

In the next chapter, the second part of the first stage of the research methodology and design of this thesis (the second part of the investigation process) will be discussed. The discussion will include the research design of the survey and the data collection method used to collect data about the relationships of interest for the analysis process of these relationships. In addition, it will include the test that has been used to refine the design of the survey procedures and the developed data collection method before their actual implementation. Finally, the discussion will include the results of the final implementation of the data collection method and the procedures that have been used to carry out the survey.

CHAPTER 5

5

THE INVESTIGATION PROCESS:

THE DESIGN, THE TEST AND THE IMPLEMENTATION OF THE SURVEY AND THE DATA COLLECTION METHOD

5.1 INTRODUCTION:

After the completion of the first part of the investigation process of the importance of the number of shutdown maintenance activities which dealt with the creation of the theoretical framework that describes the relationships of interest and the variables that constitute them, the second part of this process was carried out. The purpose of the second part was to design, test and implement the survey and the data collection method used to collect data about the relationships of interest and the variables that constitute them in order to help in answering the research questions.

The way that has been used to design, test, and implement the survey and the data collection method was aimed at reducing the bias in the collected data. In other words, the concentration in this way was to design, test and implement all parts of the survey and the data collection method in such a way that errors (sampling and non-sampling) in collecting data were reduced to its minimum level.

The discussion in this chapter will show the design of all parts of the investigation process survey as well as the design of all parts of the data collection method. Also, it will show the results of the pilot test and the pre-test that have been used to test these parts in order to refine their designs before they are implemented. In addition, the discussion in this chapter will also describe the results of the final implementation process of these parts.

5.2 THE GENERAL DESIGN OF THE INVESTIGATION PROCESS SURVEY:

In the literature, the general design of a survey deals with the determination of important survey issues in order to get the required survey results and to increase the scientific rigor of the research study (Czaja and Blair, 1996; Sekaran, 1992). In particular, it deals with the determination of the survey purpose, the survey setting, the survey time horizon, the type of the survey investigation, and the extent of researcher interference with the survey (Czaja and Blair, 1996; Sekaran, 1992).

In this part of the thesis, the determination of these survey issues and in turn the general design of the survey were influenced by the aim of the investigation process since the survey was a part of this process. In other words, they were influenced by the aim of investigating the significance of the effects of the number of shutdown maintenance activities (scope of work of shutdown maintenance) on the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by performing shutdown maintenance. Therefore, the focal point of the determination of the survey issues and in turn the survey design was the focal point of the investigation process. This focal point was the change in the number of shutdown maintenance activities (the independent variable which the nature of its effects on the dependent variables of interest need to be found). All of this meant that the best design of the investigation process survey was the one which allows the change in the number of shutdown maintenance activities to occur in the natural environment first and then the data about the effects of this change on the relationships and the dependent variables of interest to be collected in order to produce reliable and general survey results.

The design of the investigation process survey that was used to achieve this, was represented by carrying out the survey as a cross-sectional field study. This design was used because it was accepted by the participating plants in the survey as the satisfactory design for carrying out the survey in their facilities. In addition, it was the least expensive and time-consuming design that could achieve the aim of the investigation process.

By using this design, the concentration in the survey was on the point of time when the change in the number of shutdown maintenance activities occurs naturally in order to compare the changes in the variables of interest before and after this change. In addition, the above survey issues were represented by the following as a result of selecting this design:

1. The purpose of the survey was the general purpose of the investigation process which was the desire to explain the importance of the number of shutdown maintenance activities as a major variable that affects the shutdown maintenance

cost, the shutdown maintenance frequency and the loss in production that occurs as a result of performing shutdown maintenance.

2. The type of survey investigation was represented by studying the relationships between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the other variables of interest of shutdown maintenance cost, shutdown maintenance frequency and the loss in production that is caused by performing shutdown maintenance.
3. The researcher interference with the natural flow of events in the survey was minimal and it was represented by collecting the data about the changes in all variables of interest after the change in the number of shutdown maintenance activities naturally occurred.
4. The survey setting was represented by the field study where the data about all variables of interest including the number of shutdown maintenance activities was gathered in the natural environment in which all events especially the change in the number of shutdown maintenance activities normally occur.
5. The survey time horizon was represented by carrying out the survey as a cross-sectional study where the data about the changes in all variables of interest was gathered over a single period of time when the change in the number of shutdown maintenance activities naturally occurred and through comparing the values of these variables before and after this change.

5.3 THE POPULATION AND THE SAMPLE OF THE INVESTIGATION PROCESS SURVEY:

The target population for the investigation process survey was the continuous process plants in Saudi Arabia. These plants were discussed at the beginning of chapter four together with the reason behind using them in this thesis. They were found in that chapter (in the interview findings, subsection (4.4.4) in that chapter) to be different in their size. In particular, they can be classified according to the interview findings in that chapter into large, medium, and small plants based on the number of machines and equipment in them. In addition to this, most of these plants were found to be located in three provinces of Saudi Arabia. Out of the 368 continuous process plants in Saudi Arabia, 114 are located in the Central Province, 104 are located in the

Eastern Province, and 103 are located in the Western Province (Ministry of Industry and electricity, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999). The rest of the plants (47 plants) are located in other Saudi Provinces (Ministry of Industry and electricity, 1999; U.S. Department of Commerce – National Trade Data Bank, 1999).

Unlike the interviews in chapter four where both planners and managers were chosen as representatives of the participating plants, in the investigation process survey, only one of these persons was needed for participation. The reason for this is that the type of most questions at this stage needs precise objective answers that one of these persons can give but would be duplicated if they are also given by the other person.

The choice of which person to participate was based on the experience of dealing with the cost and the frequency of shutdown maintenance and the loss in production that is caused by performing shutdown maintenance activities. In this survey, the choice was for the planner because his every day work involves more in the practical issues of shutdown maintenance.

The sample that represented this population was drawn through the use of simple random sampling design from an updated list of the continuous process plants in Saudi Arabia that has been provided by the Saudi Chambers of Commerce and Industry. This type of design was used in order to give each element of the population equal chance to be in the sample and to help in getting high generalisation of the findings (Fink, 1995a; Melville and Goddard, 1996; Sekaran, 1992). The subjects in this sample were represented by the continuous process plants that have been selected by using the above probability sampling method, which were in turn represented by the planners in the maintenance departments in these plants.

The total number of participating plants in this sample that were selected from the total number of 368 plants in the population by using the above design was 188 plants. This number of participating plants was determined by using the Krejcie and Morgan (1970) table for determining sample size from a given population. This table uses the formula that has been published by the research division of the National Education Association with (95%) confidence level which represents how much chance of making errors in estimating the population parameters and (0.5) population proportion which provides the maximum sample size that ensures sufficient precision. However, the total number of participating plants was increased to 208 in order to increase the return rate of the participants' responses. This number was chosen because it was the maximum number that could be used without increasing the cost and the time of the investigation process survey. At the same time, it coincided with the guidelines of Roscoe (1975) for determining sample size which stated that the appropriate sample size should be between 30 and 500 subjects and it is preferably to be 10 times or more as large as the number of variables in the survey.

5.4 THE SELECTION OF THE DATA COLLECTION METHOD:

In the first part of this stage (the theoretical framework of the investigation process), different variables of interest to the investigation process and the relationships between them were revealed and described. These variables are objective in nature which means that the best way to collect data related to them is by extracting this data from the maintenance department records of the participating plants. However, it was difficult to get these records in the case of the investigation process survey (the survey in this part of this thesis) since they were considered by the participating plants in this survey as confidential records that included some information for the company use only. Therefore, an alternative and efficient measuring and data-collection mechanism to measure these variables was needed. Czaja and Blair (1996), and Sekaran (1992) suggested that in a case such as this the interviews (face-to-face or telephone), the questionnaires (personally administrated or mailed), the observations or a mixture of some or all of them could be used.

However, according to the selected investigation process survey design in section (5.2), if observations were used, they would be considered as an expensive and time consuming data-collection method. The reason behind this is that they would require a long period of waiting for the number of shutdown maintenance activities to change followed by another long period of observing the changes in other variables. Furthermore, and as it has been mentioned in chapter four, observations are more suitable for collecting data that is related to subjective variables rather than data related to objective variables such as the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production. In addition to observations, the use of the interviews as a data-collection method in this part of the thesis was also considered to be expensive because the sample that has been chosen for the investigation process survey was very big. Also, interviews as it has been used in the first part of this thesis are best suited to the exploratory stages.

All of these led to the use of the questionnaires as a useful technique for collecting data in this part of the thesis since they help to collect standardised and precise information about the variables of interest from a large number of participants economically (Badiru, 1996; Czaja and Blair, 1996; Fink, 1995a; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). In addition, they save a lot of time and they have a good contribution to simplifying the analysis of the data that will be collected (Badiru, 1996; Czaja and Blair, 1996; Fink, 1995a; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). Furthermore, the use of the questionnaires as a data collection method in this part of the thesis coincided with the suggestion of Sekaran (1992) which stated that when the variables for the study have been identified and their measures have been found or could be developed, questionnaires are a convenient data-collection method.

The type of questionnaires that was used in this part of the thesis was the mail questionnaires because of their ability to cover a large number of geographically dispersed continuous process plants in Saudi Arabia. They are also relatively easy, cheap and they are not time-consuming (Badiru, 1996; Czaja and Blair, 1996; Fink, 1995a; Gary Publishing, 1996; Melville and Goddard, 1996; Sekaran, 1992). In addition, they suit those participants who are busy in such a way that they could complete the questionnaire at their own convenience, in their homes, and at their own places.

However, mail questionnaires have two disadvantages. These are the low return rates of responses and the difficulty of clarifying any doubts the participants might have. The way to overcome these disadvantages in the questionnaires of the investigation process survey was by:

1. Using the latest updated population frame of the continuous process plants in Saudi Arabia that provides updated information about the participating plants.
2. Increasing the number of the subjects in the sample, which in turn increased the number of questionnaires that were sent.
3. Sending follow-up letters (Fink, 1995a; Melville and Goddard, 1996; Sekaran, 1992).
4. Providing participants with self-addressed and stamped return envelopes in order to encourage them to respond (Melville and Goddard, 1996; Sekaran, 1992).

5. Making the questionnaire as short as possible (Fink, 1995a; Melville and Goddard, 1996; Sekaran, 1992).
6. Conducting pre-test and a pilot survey in order to clarify any vagueness in the questionnaire (Melville and Goddard, 1996; Sekaran, 1992).

5.5 THE DESIGN OF THE SELECTED DATA COLLECTION METHOD:

The design of the mail questionnaire in this stage of the thesis was the design of the following important parts of the questionnaire:

1. The advance letter that has been sent to each participant before the distribution of the questionnaire in order to introduce the subject of the investigation process survey and to give the participant an early notice that he has been chosen as one of the special individuals who will receive the questionnaire.
2. The cover letter that has been sent with the questionnaire to each participants in order to explain the purpose of the survey, the importance of the participation, the importance of the participant to the survey subject, the way to complete the questionnaire and the way to return it.
3. The list of the questions which represents the major part of the questionnaire.

The design of the first two parts (The advanced and the cover letters) was based on explaining the purpose of the investigation process survey, how and why a participant was selected, and the reasons why an individual's participation is important. Also, it was based on providing information about the sponsoring organisation of the survey, the name and phone number of the person who will be available to answer questions about the questionnaire, and the assurance of complete confidentiality of the provided data and how this data will be handled. Moreover, the design of the cover letter was also based on providing information on when and how to return the questionnaire and on the realistic estimate of the time required to complete the questionnaire. In addition to all of this, the design of these two parts of the questionnaire also included, as shown in Appendix 3, the issues that are related to the general appearance of these letters. In particular, it included issues such as the use of letterhead papers, appropriate salutation and proper closing of these letters. The reason of designing these two important parts of the questionnaire in this way was to establish some rapport with the participants and motivate them to respond to the questions in the questionnaire as it has been suggested by Bourque and Fielder (1995), Melville and Goddard (1996) and Sekaran (1992).

The design of the third and the last part of the mail questionnaire (the list of the questions) was based as well on three major areas of design issues. The first area referred to the measuring procedures and scaling techniques that have been used to measure the variables of interest. The purpose of this area was to ensure that the data collected about these variables were appropriate for the test and the evaluation of the relationships between them (Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982). In addition, it was useful to ensure that direct and easy to understand questions about these variables were asked and appropriate scales that provide the required type of data for the analysis process were used (Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982).

The second area of the design of the list of the questionnaire questions was related to the type, wording, and the sequencing of the questions in the questionnaire. This area concentrated on issues such as the content of the questions, the level of sophistication of the questionnaire language, the proper sequencing of the questions and the right form and type of the questions (Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982). The last area in the design of the list of the questionnaire questions was the general appearance which dealt with the questionnaire's introduction, instructions, order and format (Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982). All these important design issues of this part of the questionnaire (the list of the questions) will be discussed in the following subsections.

5.5.1 The Measurements of The Variables of Interest and The Scaling Techniques That Have Been Used to Facilitate These Measurements:

The mail questionnaire in this part of this thesis consisted of 21 questions. These questions explain the change in the variables of interest through the comparison of their values before and after the occurrence of the change in the number of shutdown maintenance activities in order to coincide with the focal point of the investigation process survey that has been mentioned in section (5.2). In addition, the strategy that has been used in structuring these questions was based on making them as direct as possible. The reason behind doing this was to ease the analysis process (Bourque and

Fielder, 1995; Melville and Goddard, 1996; Sekaran, 1992). Several sets of these questions were used to measure the main variables of interest and others were used to measure other variables that affect the relationships between these variables of interest. In these questions, different scaling techniques were built in, to measure these variables. However, the focus was on the scales that help in providing more information about the variables. The following points illustrate the variables of interest together with the measuring procedures and the scaling techniques that have been used to measure them:

1. The number of shutdown maintenance activities (scope of work of shutdown maintenance):

This variable and its change represent the focal point of the investigation process survey since the aim of this process is to study the effects of this variable on the dependent variables of interest. This variable was measured by one direct question. This question was about measuring the magnitude of the change in the number of shutdown maintenance activities (the measured variable) at the point of time when the change on this number occurred. The way that was used to measure this magnitude was by seeking the percentage of the increase or the decrease in the number of these activities after the change. The scale that was used in this question was the ratio scale since it provides, as it has been mentioned by Czaja and Blair (1996), Fink (1995b), Sekaran (1992), and Sudman and Bradburn (1982), more precise quantifying data, greater flexibility in using more powerful statistical tests and more detailed information about the variable of interest than any other scale which in turn satisfied the purpose of this question. In addition, the use of this scale was also helpful to measure the magnitude and the proportion of the differences among the participating plants in the amount of change in the number of shutdown maintenance activities. In this question, the zero percent of change in the number of shutdown maintenance activities was not accepted as an answer because the change in this number represents the focal point of the survey and because this question as well as the other questions in the questionnaire were to be asked when the change in this number already occurred. An illustration of this question is shown as a part of the questionnaire in Appendix 4.

2. The time length, the frequency and the cost of each shutdown maintenance activity:

These variables were measured by four questions. These questions were organised in a tabulated (grid) form since they shared the same selection of answer categories. In addition, these questions measured the changes in these variables by comparing the values of the average cost of shutdown maintenance activities, the shortest frequency among the frequencies of shutdown maintenance activities, the average time length of the shutdown maintenance activities on the critical path and the average time length of shutdown maintenance activities that are not on the critical path before and after the occurrence of the change in the number of shutdown maintenance activities. In these questions, the participant was asked to write the results of the comparison in the cells that are provided in front of each variable in the table (grid) as a percentage of increase; unchanged or decrease in the value of these variables. The reason behind this was to unify the comparison unit in order to ease the analysis process. Again, the type of scale that was used in all these questions was the ratio scale since, as has been mentioned in the previous point, the ability of this scale to obtain precise quantifying data that increases the flexibility in using more powerful statistical tests which in turn provides more detailed information about all of the above variables coincided with the purpose of these questions. In addition, the use of this scale was also helpful to measure the magnitude and the proportion of the differences among the participating plants in the amount of change in these variables. The ratio scale in these questions had also a neutral point, which is a zero percent of change in the values of these variables. The purpose of this point was to represent the situation when there is no change in these variables after the change in the number of shutdown maintenance activities has occurred. Appendix 4 illustrates all of these questions.

3. Shutdown maintenance direct, overhead and overall costs:

Three direct questions were used to measure these variables. These questions were also organised in a tabulated (grid) form. They measured the changes in the shutdown maintenance direct cost, overhead cost and overall cost by comparing their values before and after the occurrence of the change in the number of shutdown maintenance activities. Same as in the point above, in these questions, the participant was also asked to write the results of the comparison in the cells that are provided in front of each variable in the table (grid) as a percentage of increase, unchanged or decrease in the value of these variables in order to unify the comparison unit. The type of scale that was used in all of these questions was the ratio scale. The reasons of using this scale were similar to the reasons that were mentioned in the previous points. Again, in these questions, a neutral point in the ratio scale was used and it was represented by a zero percent of change in the values of these variables. The purpose of using this point was to represent the situation when there is no effect of the change in the number of shutdown maintenance activities on these variables. Appendix 4 illustrates all of these questions.

4. The unavailability of shutdown maintenance resources, the inaccuracy of scheduling shutdown maintenance activities and the shutdown maintenance duration:

These variables were measured by three direct questions that were organised in a tabulated (grid) form. One of these questions was used to measure the change in the duration of shutdown maintenance by comparing the value of this variable before and after the occurrence of the change in the number of shutdown maintenance activities. The other two questions were used to measure the changes in the unavailability of shutdown maintenance resources and in the inaccuracy of scheduling shutdown maintenance activities. The way that was used to measure the changes in these variables was by comparing the number of times the plant experiences unavailability of maintenance resources on time during the shutdown maintenance and the number of problems associated with scheduling shutdown maintenance activities before and after the occurrence of the change in the number of shutdown maintenance activities. The scale that was used in these questions was again the ratio scale. The purpose of using this scale was exactly similar to the purpose of using it in the previous points. In addition, this scale had a neutral point, which is a zero percent change in the values of these variables. This point was used to represent the situation when there is no change in these variables after the change in the number of shutdown maintenance activities has occurred. In these questions, the participant also was asked to write the results of the comparison in the cells that are provided in front of each variable in the table (grid) as percentage of increase, unchanged or decrease in the value of these variables. The reason for using this way of writing the results was exactly the same as the reason that has been mentioned in the previous points. An illustration of these questions is shown as a part of the questionnaire in Appendix 4.

5. Timing of shutdown maintenance and the loss in production that is caused by shutdown maintenance:

Two questions were used to measure the change in the values of these variables. All of these questions were direct questions that were organised in a tabulated (grid) form together with the variables in the previous point. These questions measured the changes in these variables by comparing their values before and after the change in the number of shutdown maintenance activities. Since the required form of the data out of these questions was the same as the form of the data out of the questions in the previous point, the instructions that were given to the participant in order to respond to these questions were exactly the same as those that were given to respond to the questions in the previous point. In addition, the scale that was used in these questions and the reasons for using this scale were also similar to those that were used in the questions in the previous point. Again, a neutral point in the scale (zero percent change in the values of these variables) was used in these questions in order to represent the situation when there is no change in these variables after the change in the number of shutdown maintenance activities has occurred. These questions are illustrated as a part of the questionnaire in Appendix 4.

6. Shutdown maintenance frequency and the problems that are associated with the change in the number of shutdown maintenance activities:

These variables were measured by four direct questions that were organised in a tabulated (grid) form. One of these questions was used to measure the change in the frequency of shutdown maintenance by comparing the value of this variable before and after the occurrence of the change in the number of shutdown maintenance activities. The other three questions were used to measure the changes in the safety, operational and economic problems that are associated with the change in the number of shutdown maintenance activities. The way that was used to measure these variables was by comparing their numbers before and after the change in the number of shutdown maintenance activities. In these questions, and for the same reason as in the other questions, the participant was also asked to write the results of the comparison in the cells that are provided in front of each variable in the table (grid) as a percentage of increase, unchanged or decrease in the value of these variables. The scale that was used in these questions was also the ratio scale since the purpose of these questions is to obtain precise quantifying data that increases the flexibility in using more powerful statistical tests and which in turn provides more detailed information about all of the above variables. In addition, the use of this scale was helpful to know the magnitude of the difference among the participating plants in the amount of change in these variables. A neutral point of a zero percent change in the values of these variables was used in this scale in order to represent the situation when there is no effect of the change in the number of shutdown maintenance activities on these variables. These questions are illustrated as a part of the questionnaire in Appendix 4.

7. Demographic characteristics of the participating plants:

Four questions measured the demographic characteristics of the participating plant. These questions were about the age, the type of products, the location and the number of machines and equipment that each plant has. Each one of the questions was used to measure one of these characteristics. The purpose of these questions was to describe the sample characteristics in order to make sure that they coincide with the characteristics of the population. Two types of scales were built into these questions in order to measure these characteristics. These scales were the ratio and the nominal scales. Appendix 4 illustrates these questions.

5.5.2 The Type, The Wording, and The Sequencing of Questionnaire Questions:

In addition to the measurement of the variables of interest and the scaling techniques that have been used to facilitate this measurement, three other important design issues were considered in the design of the questionnaire questions of this thesis. The reason behind considering these three issues was to minimise biases in the collected data as it has been suggested in the literature by Czaja and Blair (1996), Fink (1995b), Sekaran (1992), and Sudman and Bradburn (1982).

The first issue among these three issues was the type of the questionnaire questions which refers, as it has been mentioned in the literature, to whether the questions are open-ended or closed-ended (Bourque and fielder, 1995; Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982). Each one of these types of questions has its own characteristics. Open-ended questions allow participants to answer them by using their own words and in any way they choose whereas the closed-ended questions ask the participants to choose among a set of pre-selected alternative answers (Bourque and fielder, 1995; Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982). In the mail questionnaire of this part of this thesis, both of these types of questionnaire questions were used. The closed-ended type of questions with exhaustive and mutually exclusive responses was used to ask about the changes in the variables of interest by comparing their values before and after the occurrence of the change in the number of shutdown maintenance activities. In addition, it was used to reveal the demographic characteristics (the general information) of the participating plant. The open-ended type of questions, on the other hand, was used to invite the participant to comment on the questionnaire in general and on topics that may not have been covered or might have been insufficiently covered in the questionnaire. In other words, most of the questions in this questionnaire were closed-ended except one, which was open-ended and that was about the participants comments on the questionnaire and this question was located at the end of the questionnaire as illustrated in Appendix 4. The reason behind using these types of questions in this way was because open-ended questions as it has been mentioned in the literature are more difficult to answer, code and analyse than the closed-ended ones (Bourque and fielder, 1995; Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982).

In addition to the type of the questionnaire questions, the second issue that was considered in the design of the questionnaire questions of this thesis was the wording of these questions. This issue refers to how the questions are worded and the level of sophistication of the used language in these questions (Bourque and fielder, 1995; Czaja and Blair, 1996; Fink, 1995b; Sekaran, 1992; Sudman and Bradburn, 1982). In this respect, the efforts were made in the questionnaire of this thesis to keep questions as concrete, specific, short and simple as possible in order to quickly draw the attention of the participant to their subject and in turn to make them easy for the participant to understand. Therefore, double-barrelled and ambiguous questions such as those that mention two or more issues at the same time or those that confuse the participants about their meaning were avoided. Also, leading and loaded questions such as those that suggest to the participant that one answer is preferable to another or those that are phrased in an emotionally charged manner were avoided as well. In addition to all of this, the language that was used in the questions of this thesis questionnaire was the English language with some maintenance technical terms. This language and these terms were used since they are appropriate to the level of understanding of the participants (maintenance department's planners) who use them in their every day work.

The last issue that was considered in the design of the questionnaire questions of this thesis was the sequence of these questions. This issue was obtained by placing general and easy questions that are related to the topic of the questionnaire at the beginning of the questionnaire questions list followed by more specific and complex questions such as those about the variables of interest and ending with placing easy-to-answer demographic questions at the end. The reason behind using this sequence of the questionnaire questions was to achieve several important objectives. These objectives are maintaining participant interest, making responding easy and minimising inadequate responses due to participant fatigue by placing easy-to-answer demographic questions at the end of the list of the questionnaire questions.

5.5.3 General Appearance of The Questionnaire Questions List:

This area of the questionnaire questions design includes issues such as the design of a good introduction for the questionnaire questions list, the design of well-organised instructions, and the design of a well-arrayed set of questions and response alternatives (Bourque and fielder, 1995; Czaja and Blair, 1996; Sekaran, 1992). It also includes the format and the general arrangement of the questionnaire (Bourque and fielder, 1995; Czaja and Blair, 1996; Sekaran, 1992).

In the questionnaire of this thesis, the introduction of the questionnaire was written in a form of a cover letter as it has been discussed in the beginning of this section (section 5.5). In this letter, the purpose of the study was identified and several sentences were written to establish rapport with participants and motivate them to respond to the questions. In addition, general instructions were given in this letter about when and how to return the questionnaire and about the realistic estimate of the time required for completing the questionnaire. At the end of this letter, sentences were written to thank the respondent for his time and co-operation and to assure him that all provided information will be dealt with in a complete confidentiality. A copy of this cover letter is illustrated in Appendix 3.

Furthermore, the questions in this questionnaire were logically and neatly organised into six sections according to their relation to the topics of these sections. The arrangement of these sections and the transition statements (in form of sections titles) that were used to facilitate this arrangement were made in such a way that makes each section consistent with previous and subsequent sections. These sections and their order in the questionnaire were summarised in the following:

1. Section one was about the change in the shutdown maintenance activities. This section explains the magnitude of the change in the number, cost, frequency and the time length of shutdown maintenance activities after the occurrence of the change in the number of these activities (scope of work of shutdown maintenance).
2. Section two was about the change in the shutdown maintenance cost and the variables that are related to it. This section reveals the change in the values of the shutdown maintenance direct and overhead costs and the shutdown maintenance cost, after the occurrence of the change in the number of shutdown maintenance activities (scope of work of shutdown maintenance).
3. Section three was about the change in the loss of production and the variables that are related to it. This section describes the change in the duration of shutdown maintenance, the inaccuracy of scheduling shutdown maintenance activities, the unavailability of shutdown maintenance resources, the timing of shutdown maintenance and the loss in production, after the occurrence of the change in the number of shutdown maintenance activities (scope of work of shutdown maintenance).
4. Section four was about the change in the frequency of shutdown maintenance and the problems that are associated with the change in the number of shutdown maintenance activities. This section explains the change in the shutdown maintenance frequency and the safety, operational and economic problems that are associated with the change in the number of shutdown maintenance activities, after the occurrence of the change in this number (scope of work of shutdown maintenance).
5. Section five was the general information section, which was about the demographic characteristics of the participating plant.
6. Section six was the comments section, which was about the participants' comments on the questionnaire.

In each one of these sections, questions were arranged from general to specific in a manner that makes sense to the participants and keeps their focus on the subject of the questionnaire. Also, breaking these questions between pages was avoided in order to prevent the participants from paging back and forth. Moreover, the instructions on how to answer these questions and the definitions that were used to illustrate the meaning of some important terms were also provided in these sections to help the participants to answer the questions. These instructions and definitions were written in bold face inside rectangular box to distinguish them from the questions. In addition to all of this, grids were used in these sections with the questions that use the same selection of answer categories in order to save space on the questionnaire. Also, vertical format with codes assigned to response categories was used in other questions such as the demographic questions in order to differentiates the question from the response categories and differentiates the response categories from each other and to make data entry much easier and more error free. This process of grouping the questionnaire questions into sections allows the participants to recognise the relationships among these questions. In addition, it minimises their responding fatigue. A sample of this thesis questionnaire that shows all of these general appearance design issues is illustrated in Appendix 4.

5.6 THE PRE-TESTING AND THE PILOT STUDY OF THE DEVELOPED DATA COLLECTION METHOD:

Pre-testing and the pilot study are necessary and important steps in the process of data collection method development (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995). They provide useful information about how the data collection method acts in the field (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995). Although they require extra time and energy, the pre-testing and the pilot study are critical steps in assessing the practical application of the data collection method parts and the administrative procedures that are used to apply this method (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995).

In the case of a questionnaire, the pre-testing and the pilot study are used to refine its design and to identify errors, especially those, which are related to the questionnaire's form and presentation (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995). These errors and design problems range from confusing typographical mistakes to overlapping response sets to ambiguous instructions (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995).

In addition, pre-testing and the pilot study allow time and opportunity to redesign problematic parts of the questionnaire and a chance to correct these errors before the questionnaire is mass produced or used on a wider scope to gather real data (Czaja and Blair, 1996; Litwin, 1995). They also predict difficulties in the questionnaire and its administrative procedures that may arise during subsequent data collection that might otherwise have gone unnoticed (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995). At these two steps of the development process of the questionnaire, most of the problems are still correctable (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995).

Since they involve trying the questionnaire out on small sample population, the pre-testing and the pilot study are the most inexpensive tools that could be used to ensure the success of the questionnaire, the survey and the overall research project (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995).

In this thesis, pre-testing and pilot study were used as the cheapest tools to refine the design of the questionnaire that has been constructed in this part of this thesis and the questionnaire administrative procedures before the questionnaire was actually used. In addition, they were conducted prior to the final distribution of the questionnaire to allow the chance of correcting the errors in the questionnaire.

This section discusses the pre-testing and the pilot study of the questionnaire of this part of this thesis. This discussion is organised into several subsections. It is mainly about the ways that have been used to perform the pre-testing and the pilot study, their results, the assessment of the validity and the reliability of the questionnaire questions, the response rate of the pilot study, the follow up strategies that were used in the pilot study to increase the response rate and how these strategies influenced the overall response rate.

5.6.1 The Pre-Testing of The Developed Data Collection Method:

Pre-testing is a set of procedures that are used to overcome the design problems of all parts of the data collection method and to identify and correct the errors in them in such a way that satisfy the purpose of developing them (Czaja and Blair, 1996; Litwin, 1995). It is a confirmation process of the first draft of the data collection method which is based on the researcher judgement about the participants knowledge, their understanding of the used words and terms, the sorts of information they can provide, and the response they can perform (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995).

The aim of using the pre-testing as step in the developing process of the questionnaire in this part of the thesis was to refine the design of all parts of the questionnaire such as the advance letter, the cover letter and the questionnaire questions and to confirm that the constructed questionnaire is appropriate for the understanding and the knowledge of the targeted participants. In particular, the aim was to test the following important aspects of the questionnaire parts in order to make sure that these parts were designed in such a way that satisfy the purpose of designing them:

1. The simplicity and the clearness of the words and the phrases that were used in the advance and the cover letters.
2. The clearness and comprehensiveness of the advance and the cover letters ideas and instructions.
3. The smoothness of the flow of the advance and the cover letters format.
4. The quality of the advance and the cover letters layout.
5. The appropriateness of the content of the questionnaire questions for the variables to be measured.
6. The simplicity and clearness of the words and phrases of the questionnaire questions.
7. The appropriateness of the vocabulary and the language used in these questions for the level of the understanding of the participants.
8. The simplicity and clearness of the questionnaire questions format.
9. The appropriateness of the scales and scaling techniques used to measure the variables of interest for the level of the required information.
10. The simplicity and clearness of the instructions in the list of the questionnaire questions.
11. The accuracy and adequacy of these instructions.
12. The clearness and comprehensiveness of the response categories that are related to the closed-ended questions in the questionnaire.
13. The accuracy and the clearness of the definitions of the technical maintenance terms that have been used in the list of the questionnaire questions.
14. The smoothness of the questions flow.
15. The appropriateness of the order of these questions for the level needed to reflect the focus of the survey and for the necessary need to reduce participants' fatigue.

16. The quality of grouping these questions into sections.
17. The appropriateness of the order of the sections in the list of the questionnaire questions for the necessary support needed to reflect the focus of the survey and to reduce the participants' fatigue.
18. Other important questionnaire aspects.

The following sub-sections explain how the process of pre-testing the questionnaire that has been constructed in this part of this thesis was performed. In addition, they discuss the results of this process.

5.6.1.1 The Way of Performing The Pre-Testing of The Developed Data Collection Method:

Two ways were used to perform the pre-testing of the questionnaire in this part of the thesis. The first one was informal in which informal pre-test of the constructed questionnaire was conducted. This way consisted of one phase. In this phase, a copy of the cover letter and the questionnaire questions were sent or given to doctoral students and non-doctoral students. Some of these students were in the maintenance field and the others were not. The purpose of this phase and in turn this way was to review the simplicity and clearness of the questionnaire questions and the cover letter in addition to the general appearance of the whole questionnaire.

The second way was more formal where a copy of the revised cover letter and the questionnaire questions from the first way in addition to the advance letter were sent to survey professionals and shutdown maintenance experts in order to get their comments on the design of these parts of the questionnaire and their suggestions on the best way to improve them. In addition, a discussion was held with each one of these professionals and experts after receiving their comments and suggestions in order to reveal the best correction actions.

This way was used because it is very effective and efficient in identifying participants' problems with the questionnaire (Bourque and fielder, 1995; Czaja and Blaire, 1996). In addition, it was used because it also leads to recommendations that stem from these experts and professionals experience and knowledge of questionnaires and subject matter rather than from the reactions of pre-test respondents (Bourque and fielder, 1995; Czaja and Blaire, 1996).

The number of phases or pre-tests that were performed by using this way was two phases. The first phase or pre-test was a process of collecting the comments and the suggestions on the design of the parts of this thesis questionnaire. In addition, it was also a process of performing the necessary correction actions for improving these parts. The second phase was, on the other hand, a process of conforming that the correction actions and comments that were suggested in the first phase were performed as intended.

For both of these phases (pre-tests), one group of survey professionals and shutdown maintenance experts were invited to participate. This group consisted of two survey professionals and three shutdown maintenance experts from the industry and three shutdown maintenance experts from the academic environment. These numbers of professionals and experts were used in order to reduce the cost and the time of these pre-tests. In addition, the total of these numbers was within the range that has been suggested in the literature of three to eight professionals and experts (Czaja and Blaire, 1996).

5.6.1.2 The Results of Pre-testing of The Developed Data Collection Method:

The results of the above three phases of pre-testing the questionnaire of this thesis were a group of useful and important comments and suggestions. These comments and suggestions were implemented by taking the necessary correction actions in order to improve the design of all the parts of this questionnaire. In particular, they were implemented in order to improve the design of the advance letter, the cover letter and the constructed questionnaire questions. The following tables illustrate these comments and suggestions, in addition to, the correction actions that were taken to implement them:

Introductory Letter	Comments and Suggestions	Actions Taken
The Advance Letter	• It is preferred to change the following statement "...please ask the planner to fill it out and return it to..." to "...please ask the planner or any person you think that he has the required information to fill it and return it to..."	• It has been changed
The cover Letter	No comments or suggestions	No action has been taken.

Table 5.1 The Results of Pre-testing The Advance and The Cover Letters

Section in The Questionnaire Questions List	Comments and Suggestions	Actions Taken
Section one: Changes in The Shutdown Maintenance Activities	• It is preferred to change the following part of the instruction that explains the way for answering the questions in the table of this section from: "... please note, if there is no change in the value of a variable in the following table, tick the cell that labelled unchanged in front of that variable. Otherwise, state the amount of change. ..." to: "...Then write the results of the comparison in the cells that are provided in front of each variable in the table. The results should be written in the form of either: 1. A percentage of increase in the % of increase cell if the results indicate an increase in the value. 2. A percentage of decrease in the % of decrease cell if the results indicate a decrease in the value. 3. A tick in the unchanged cell if the results indicate an unchanged in the value". • It is good to add question (4.1) from section four that is related to the change in the shortest frequency to the table in this section since this question is related to the changes in the shutdown maintenance activities.	• It has been Changed. • It has been added.
Section Two: Changes in The Shutdown Maintenance Cost and The Variables That are Related to It	• It is preferred to change the following part of the instruction that explains the way for answering the questions in this section from: "... please note, if there is no change in the value of a variable in the following table, tick the cell that labelled unchanged in front of that variable. Otherwise, state the amount of change. ..." to exactly the same sentences of instructions that have been suggested before in section one.	• It has been changed.
Section Three: Changes in The Loss of Production and The Variables That are Related to It	• It is preferred to change the following part of the instruction that explains the way for answering the questions in this section from: "... please note, if there is no change in the value of a variable in the following table, tick the cell that labelled unchanged in front of that variable. Otherwise, state the amount of change. ..." to exactly the same sentences of instructions that have been suggested before in section one and two.	• It has been changed.

Continued in the next page

Section in The Questionnaire Questions List	Comments and Suggestions	Actions Taken
Section Four: Changes in The Frequency of Shutdown Maintenance and The Variables That are Related to It	• It is preferred to cancel this section and move its questions to sections 1 and 5. In particular, question (4.1) to section 1 and question (4.2) to section 5. This helps to enhance the flow of the questions in such a way that make sense to the participants. • It is useful to define the frequency of shutdown maintenance exactly in the same that was used to define the duration of shutdown maintenance in section three.	• The section has been cancelled and the questions have been moved. • It has been defined.
Section Five: Changes in The Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities	• It is good to add item (4.2) that is related to the change in the frequency of shutdown maintenance to this section. • It is preferred to change the following part of the instruction that explains the way for answering the questions in this section from: "... please note, if there is no change in the value of a variable in the following table, tick the cell that labelled unchanged in front of that variable. Otherwise, state the amount of change. ..." to exactly the same sentences of instructions that have been suggested before in section one, two and three.	• It has been added. • It has been Changed.
Section Six: General Information	• It is good to add codes to the response categories of the questions in this section.	It has been added.
Section Seven: Comments	No comments or suggestions	No action has been taken.

Table 5.2 The Results of Pre-testing The List of The Questionnaire Questions

5.6.2 The Pilot Test of The Developed Data Collection Method:

In the literature, it has been found that after refining the design of the data collection method and correcting the errors that are associated with it in the pre-testing process, the data collection method is ready for the pilot test (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995). The purpose of the pilot test is to determine whether the data collection method works in a manner that satisfies the purpose of the survey (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995). Therefore, in the pilot test not only the design of all parts of the data collection method are tested but also the administrative procedures that are used to carry out the method (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995). In other words, in a pilot test, the data collection method is carried out using the same procedures that are planned to be used in the main survey in order to identify and correct the problems that are related to these procedures and to all parts of the data collection method before conducting the main survey (Bourque and fielder, 1995; Czaja and Blair, 1996; Litwin, 1995).

In this thesis, the pilot test was conducted on the revised questionnaire and by using the same procedures that will be used in the main survey. The purpose of conducting this pilot test was to reveal important issues such as the response rate, the appropriate follow-up strategy and the validity and the reliability of the measures that have been used to measure the variables of interest. In addition, it was conducted as further testing of the simplicity and clearness of the advance letter, the cover letter, the questionnaire questions, the instructions, the definitions and the response categories, in addition to the general appearance of the whole questionnaire. The following sub-sections explain how this pilot test was conducted and the results that were generated from this test.

5.6.2.1 The Way of Performing The Pilot Test of The Developed Data Collection Method:

The way of performing the pilot test of the revised questionnaire in this thesis was similar to what will be used to perform the main survey. It was started by drawing a sample of 40 plants from the 368 continuous process plants in Saudi Arabia (the target population) through the use of simple random sample design which is the same design that will be used in the main survey. The reason of using this design and the 40 plants as a sample was to give each element of the population equal chance to be in the sample and to reduce the cost and the time of the pilot test without affecting its benefits. The sampling frame that has been used in this sampling process was the updated list (dated October, 1999) of the continuous process plants in Saudi Arabia that has been provided through the home page of the Saudi chambers of commerce and industry which is also the same list that will be used in the main survey.

After drawing the sample of this pilot test and exactly in the same way as in the main survey, the participating plants were represented by the planners in these plants maintenance departments. These maintenance planners (participants) were provided with copies of the revised questionnaire that had been sent to them by the mail. In addition, they were also provided with self-addressed and stamped return envelopes in order to encourage them to respond.

5.6.2.2 The Follow-up Strategy and The Response Rate:

All of the 40 questionnaires that were used in the pilot test were prepared and sent together to the participants. After two weeks of sending these questionnaires, 14 of them were returned completed which represents 35% of the total that has been sent. Since this response rate was an unexpectedly low response rate, it has been decided that a good solution to increase it was by conducting a follow-up strategy. Therefore, the literature was reviewed to consolidate this decision.

In the literature, it has been found that several follow-up strategies were suggested as useful strategies for increasing the overall response rate (Bourque and fielder, 1995; Fox, Robinson and Boardley, 1998). These strategies were the postcard reminders, the second mailing of the questionnaire, the telephone reminders and the Dillman's multiple follow-up strategy which is the combination of all three strategies (Fox, Robinson and Boardley, 1998). However, it has been shown that if the telephone numbers are available, there will be no significant difference between response rates of the telephone reminders strategy and the best strategy among the other three follow-up strategies (Fox, Robinson and Boardley, 1998).

Since the telephone numbers of all participating plants in this study were available through the use of the updated list of these plants that had been provided through the home page of the Saudi chambers of commerce and industry, the telephone reminders strategy was used as the main follow-up strategy for this pilot test and for the main survey. In addition, fax reminders which is similar to the telephone reminders in its nature were used as a back up strategy because the fax numbers of all participating plants were also available and because this strategy is cheap. Also, e-mail reminders were used as well if they were available because of the same reasons.

Thus, a total of 26 phone calls, faxes and e-mails were executed in order to contact the remaining 26 non-respondents. The result was that 23 completed questionnaires were returned which increased the total number of returned questionnaires to reach 37 completed questionnaires out of the 40 that have been sent and the total response rate to 92.5%. Table 5.3 illustrates the influence of the telephone, fax and e-mail reminders on the response rate of the pilot test.

Source	Total of Questionnaires Sent	Number of Returned Questionnaires	Response Rate
Questionnaire Batch	40	14	35%
Follow-up (Telephone calls, Faxes and e-mails)	–	23	57.5%
Total	40	37	92.5%

Table 5.3 The Influence of The Telephone, Fax and e-mail Reminders on The Pilot Test Response Rate

5.6.2.3 The Results of The Pilot Test of The Developed Data Collection Method:

Most of the comments from the participants in the pilot test on the revised questionnaire stated that the questions in the questionnaire were easy to understand and answer and they did not involve a lot of thinking. In addition, they were directly related to the subject matter.

However, the representatives of 10 of the participating plants out of the total of 40 mentioned that questions 1.1 and 1.3 in section one contains too many phrases which made the meaning of these questions unclear. This problem was solved through rephrasing these two questions and then contacting five of these representatives to confirm this change.

5.6.3 The Assessment of the Validity and Reliability of The Variables' Measures (Questionnaire Questions):

The assessment of the validity and reliability of the measures of the variables of interest is very important issue in the process of refining the data collection method (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992). In particular, it is important for testing the goodness of these measures (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992). The assessment of validity is concerned with making sure that measuring instruments measure the variables that they intend to measure and that participants interpret the measuring instruments as intended (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992). In other words, it is concerned with making sure whether the right variables are being measured (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992). The assessment of reliability, on the other hand, is concerned with making sure that these measuring instruments are stable and consistent in measuring the variables that they intend to measure (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992).

In this part of the thesis and during the pilot test and the pre-test of the questionnaire, two types of validity assessment approaches were used to validate the measures of the variables of interest of this thesis (questionnaire questions). The first approach was the face validity, which indicates that a measure that is supposed to gauge a variable does on the face of it look like it is gauging the intended variable (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992). This validity approach was performed during the pre-testing process by simply asking doctoral students and non-doctoral students in the maintenance field to review the questionnaire questions and assess their appropriateness to the variables that they intend to measure.

The second approach that has been used was the content validity approach which ensures that a measure is adequate and representative of the variable that it is supposed to gauge through reviewing this measure by the people who have the knowledge on the subject matter of this variable (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992). It usually involves an organised review of the data collection method contents to ensure that it includes everything it should and does not include anything it should not (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995d; Litwin, 1995; Sekaran, 1992). This approach was started in the pre-testing process when the questionnaire was reviewed by the experts in the shutdown maintenance field. Then, it has been completed in the pilot test. In this approach, the experts and the representatives of the 40 participating plants who participated in the pilot test were asked to rate each question and scale for its appropriateness and relevance to the variable that is intended to be measured. In addition, they were asked to list any areas that are pertinent to the subject matter but not covered in the questions.

These two approaches of the validity assessment were used in this part of the thesis because they were the least time consuming approaches that could be used to assess the validity of these questions. Moreover, they were the cheapest. The result of these two approaches was that the questionnaire questions, which have been used to gauge this thesis's variables of interest, were valid in their face and content.

In addition to the assessment of the validity of the questionnaire questions of this thesis, the reliability of these questions was assessed. The way that has been used to asses the reliability of these questions was based on sending alternate but equivalent form of the questionnaire questions to 20 of the participants who participated in the pilot test and asking them to answer these questions. Then, their answers to this list of questions were compared with their answers in the pilot test and the coefficients of correlation, which showed the magnitude of the correlation between the two sets of answers, were calculated in order to measure the reliability of these questions. The alternate list of the questionnaire questions that was used in this way of assessing the reliability was different from the original list in the order of the questions inside the grids and in the wording of the response item (unchanged 0%) in each grid which has been changed to (the same 0%).

This way (alternate-form reliability or parallel-form reliability) of assessing the reliability of these questions was used in this part of the thesis because it was the cheapest and the least time consuming way that could be used to measure the reliability of these questions. In addition, it was the best way to avoid what is called the practice effect which is the familiarity of the participants with the items that makes them simply answer these items again based on their memory of what they answered last time.

The result of this way was a set of correlation coefficients with values exceeding the value of 0.8 (in particular, between 0.81 and 0.85) which indicated according to the literature (Litwin, 1995; Sekaran, 1992) that the interviewing questions in this part of the thesis were reliable.

5.7 IMPLEMENTATION OF THE MAIN SURVEY:

The implementation process of the main survey started by mailing a total of 208 questionnaires to the participating plants. It began with sending 153 questionnaires followed by 55 questionnaires after one week from sending the first batch. This unplanned division in the mailing process was because of the problem that occurs in printing the address tags of the participating plants. For each of the participating plants, a package was sent which included a covering letter that illustrates the purpose of the study, a questionnaire and a pre-stamped addressed envelope.

After two weeks from starting the implementation process, 64 questionnaires were returned from both batches, which represents 30.8% of the total that has been sent. As a result of this unexpected low response rate, the decision was made to launch telephone, fax and e-mail reminders.

5.7.1 Main Survey Follow-up Strategy:

As a second step of the implementation process of the main survey, the follow-up strategy, which consists of the telephone, fax and e-mail reminders, was launched. The priority in this strategy was given to the telephone reminders since they represent the main type of follow-up reminders that has been selected in sub-section (5.6.2.2) for the main survey of this thesis.

Therefore, 83 telephone reminders, 42 fax reminders and 19 e-mail reminders were sent to the 144 participating plants, which they did not respond to, the main mailed survey. The result of this step was 103 questionnaires were returned which represents 71.5% of those plants, which did not respond to the main mailed survey. Table 5.4 illustrates the influence of the main survey's follow-up strategy on the response rate.

Type of Remainder	Total of Reminders Sent	Number of Returned Questionnaires	Response Rate
Telephone Remainders	83	59	71.1%
Fax Remainders	42	30	71.4%
E-mail Reminders	19	14	73.7%
Total	144	103	71.5%

Table 5.4 The Influence of The Main Survey Follow-up Strategy on The Response Rate

5.7.2 The Main Survey and The Overall Response Rate:

After conducting the follow-up strategy, the total number of questionnaires that have been returned increases to reach 167 completed questionnaires. This figure was a result of adding the 64 returned questionnaires from the main mailed survey and 103 returned questionnaires as a result of the telephone, fax and e-mail reminders. In addition, this figure represents 80.3% of the total questionnaires that have been sent to the participating plants.

Moreover, the 37 questionnaires that have been returned as a result of conducting the pilot study were added to the above responses. The reason for this was because there were no major changes that were suggested in the pilot study in the content or the sequence of the questions in these questionnaires. Also, the questionnaires in both the main survey and the pilot study were basically the same. As a result, the total number of questionnaires that have been sent increased to 248 of which 204 questionnaires were returned back completed. This means that the overall response rate achieved is 82.3% which is reasonable response rate according to Gillham (2000) and Remenyi, Williams, Money and Swartz (1998) who say that a response rate of 30% is considered to be fairly satisfactory and more than 50% is exemplary. Table 5.5 shows the breakdown of the overall responses.

Source	Total Mailed	Total Responses	Response Rate
Pilot	40	37	92.5%
Main Survey	208	167	80.3%
Total	248	204	82.3%

Table 5.5 Overall Response Rate

5.8 SUMMARY:

In this chapter, the design of all parts of the investigation process survey as well as the design of all parts of the data collection method, which is in this thesis a mail questionnaire were discussed. In addition, the pre-testing process and the pilot test that were used to test the selected data collection method (mail questionnaire) in order to refine all of its parts and administrative procedures before they were implemented in the field were discussed as well. This chapter also discussed the implementation of the main survey and the resultant overall response rate.

The next chapter will discuss the descriptive and the inferential statistical analysis of the data that has been collected by the refined questionnaire. In addition, it will discuss the results of this analysis (the description of the variables of interest of this thesis and the evaluation of the relationships between them) and the relation of these results to this thesis's objectives.

CHAPTER 6

THE INVESTIGATION PROCESS: DATA ANALYSIS AND THE RESULTS OF THE INVESTIGATION PROCESS

6

6.1 INTRODUCTION:

After the process of developing and refining the questionnaire and the process of designing and implementing the investigation process survey, the data that has been collected from the field was ready for the analysis process. The purpose of the analysis process was to answer the first stage and the research questions. Specifically, the purpose of the analysis process was to describe and to evaluate the following important relationships in order to reveal how important the number of shutdown maintenance is to the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production:

1. The relationship between the number of shutdown maintenance activities (the scope of work of shutdown maintenance) and the shutdown maintenance cost.
2. The relationship between the number of shutdown maintenance activities (the scope of work of shutdown maintenance) and the loss in the production that occurs as a result of performing shutdown maintenance activities.
3. The relationship between the number of shutdown maintenance activities (the scope of work of shutdown maintenance) and the frequency of shutdown maintenance.

The way that has been used to facilitate the achievement of this purpose was by setting clear analysis objectives, as it has been suggested in the literature by Diamantopoulos and Schlegelmilch (1997). These analysis objectives were used for directing and guiding the analysis process. In particular, the roles of these objectives as it has been mentioned in the literature were to (Diamantopoulos and Schlegelmilch, 1997):

1. Help in ensuring that only relevant analysis is undertaken. This means that any analysis performed should contribute directly to answering the research questions of interest.

2. Provide a check on the comprehensiveness of the analysis, which means making full use of the information potential in the data.
3. Help in avoiding redundancy in the analysis, which means to avoid getting the same information from different analyses.

A good-starting point for setting these analysis objectives is to derive them from the overall research objectives (Diamantopoulos and Schlegelmilch, 1997). In other words, an excellent point of departure for developing analysis objectives is through a careful re-examination of the overall aims of the research (Diamantopoulos and Schlegelmilch, 1997).

In this thesis, these objectives were derived from the aim of the first stage of the research methodology, which is represented by the above purpose of the data analysis process. The reason behind this was because the data analysis process represents an important (the final) part of this stage. Therefore, the analysis objectives of this thesis which were derived from the above aim were basically the following:

1. Understand the nature and the characteristics of the participating plants' responses as they are represented by the distribution of the values of each variable in the relationships of interest.
2. Describe the changes in the variables of interest and other variables that intervene in or moderate the relationships of interest.
3. Provide measures of the typical participating plants' responses and measures of the extent of variation in these responses for all variables.
4. Study and evaluate the relationships of interest.

The achievement of these objectives and in turn the purpose of the analysis process was based, as it has been recommended in the literature, on analysing the collected data by the use of two types of statistical analysis (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). These types were the descriptive and the inferential statistical analysis (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992).

In this chapter, the discussion will be on the analysis process that has been used in this thesis. Particularly, it will be on how the descriptive and the inferential statistical analyses were used to achieve the above mentioned analysis objectives. In addition, it will be on the results of these statistical analyses and the relation of these results to the overall research objectives.

6.2 THE DESCRIPTIVE STATISTICAL ANALYSIS OF THE COLLECTED DATA:

Descriptive analysis of the data is a very important source of information for answering research questions. It provides a very useful initial examination of the data even when the concern of the research is inferential in nature (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). It is also used to describe and summarise the data that has been collected (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). More precisely, it describes the phenomena of interest by knowing how frequently this phenomena occurs and reveals the central tendency when a set of figures are involved as well as the extent of variability in the set (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Sekaran, 1992). Moreover, it gives a good idea of how the respondents reacted to the items in the questionnaire (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Sekaran, 1992).

In addition, descriptive analysis is important for detecting the errors in coding and entering of data as well as the appropriateness of the scales (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Sekaran, 1992). The results of this type of analysis indicate how respondents perceive the variables that are assessed and how clustered or dispersed these perceptions appear to be (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Sekaran, 1992). In summary, descriptive analysis is used to (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Sekaran, 1992):

1. Provide better understanding of the nature of the responses obtained as it is reflected in the distribution of the values for each variable under study.
2. Provide summary measures of the central tendency of responses as well as the extent of variation in these responses for a given variable.
3. Help in detecting errors in the coding and the entering process.
4. Provide good means for presenting the data in a digestible manner, by using tables and graphs.

In this stage of the thesis, the descriptive statistical analysis was used to understand the nature and the characteristics of the participating plants' responses regarding the changes in the variables of interest and in the other variables that intervene or moderate the relationships of interest. Also, it was used to describe the sample demographic characteristics and compare these characteristics with their counterpart characteristics of the population in order to reveal how well the sample represents the population. In addition, it was used to check for possible data entry errors and to ascertain whether there are outliers. The following subsections, which explain the demographic characteristics and the changes in the variables that constitute the relationships of interest, will discuss the descriptive statistical analysis of the data that has been collected by the mail questionnaire of this thesis.

6.2.1 The Description of The Demographic Characteristics: The Age of The Participating Plants:

There is no published statistics that categorises the continuous process plants in Saudi Arabia according to their age. However, it has been found from the Saudi industrial directory-Ministry of Industry and Electricity (1999) that the oldest continuous process plant is 55 years old. This figure is reasonable since the age of the Kingdom of Saudi Arabia as a recognised country is not more than 68 years old (The Saudi Arabian Information Resource, 1999). Also, from the same source, it has been found that there was a few number of continuous process plants at the beginning of Saudi Arabia industrial era then this number was boosted to reach its peak in the period from the early to the mid of the 1980's. After this period, the increase in the number of this type of plants started to slow down because of the reduction in the oil prices in the world market.

The analysis of data that has been collected by this thesis mail questionnaire and that is related to the age variable shows almost the same results. Table 6.1 which illustrates the frequency distribution for the age of the participating plants in this survey shows that the highest frequency is related to the category of the participating plants which their ages ranging from 16 to 20 years old. This means that the highest frequency is related to those plants that were established in the period from the early to mid 1980's which is similar to the findings from the Saudi industrial directory-Ministry of Industry and Electricity (1999). This category of the participating plants represents 29.4% of the sample. Also, this table shows that the fluctuation in the number of participating plants between the different age categories is almost the same fluctuation that has been found in the Saudi industrial directory (1999). This means that the random sample, which has been chosen to answer the questions of the first stage of this thesis, covers a wide range of these plants' ages.

Age Category	Frequency	Percentage
Under 5	35	17.2
6-10	42	20.6
11-15	36	17.6
16-20	60	29.4
21-25	20	9.8
26-30	6	2.9
Over 31	5	2.5
Total	**204**	**100.0**

Table 6.1 Grouped Frequency Distribution for The Ages of The Participating Plants

6.2.2 The Description of The Demographic Characteristics: The Industrial Sectors of The Participating Plants:

It has been found in the Saudi Arabian Information Resource (1999) that there are different types of industrial sectors to which different continuous process plants in Saudi Arabia are related and belong. These industrial sectors were classified into refined petroleum products, petrochemicals, chemicals, rubber and plastics, industrial gases, and other small sectors (The Saudi Arabian Information Resource, 1999; U.S. Department of Commerce-National Trade Data Bank, 1999). However, there is no published statistics that illustrate how many plants there are in each sector. The only published information could be found in the Saudi Industrial Directory-Ministry of Industry and Electricity (1999) which reveals that the highest number of these plants belong to the rubber and plastics sector followed by chemicals, petrochemicals, refined petroleum products, industrial gases and other different sectors respectively. Similar findings to these were also reached through the results of the analysis of the data that has been gathered by the mail questionnaire and that is related to the industrial sector variable. These results were summarised in table 6.2 as follows:

1. The highest frequency is related to the number of participating plants from the rubber and plastics sector. The plants from this sector represents 30.4% of the participating plants in the sample.
2. Following the plants from this sector, the participating plants from the chemicals and the petrochemicals sectors come in the second and the third place in terms of

their frequencies. They represent 25.5% and 14.2% of the participating plants in the sample respectively.

3. The lowest frequency in this table is associated with the plants from the other sectors with a percentage score of 7.8%. These plants are proceeded in terms of the magnitude of the frequency by the plants from the industrial gases and petroleum products sectors. The plants in these two sectors represent 11.8%, and 10.3% of the participating plants in the sample respectively.

All of these results imply that the study sample covers a wide range of the industrial sectors.

Industrial Sector	Frequency	Percentage
Petroleum	24	11.8
Petrochemicals	29	14.2
Chemicals	52	25.5
Plastics/Rubber	62	30.4
Industrial Gases	21	10.3
Others	16	7.8
Total	**204**	**100.0**

Table 6.2 Grouped Frequency Distribution for The Industrial Sectors of The Participating Plants

6.2.3 The Description of The Demographic Characteristics: Provinces Where The Participating Plants Are Located:

It has been found in the Saudi Industrial Directory-Ministry of Industry and Electricity (1999) and the Saudi Arabian Information Resource (1999) that the province in Saudi Arabia, which has the highest number of the continuous process plants on its land, is the central province. Following this province is the eastern province, which has also a high number of this type of plants located on its land (Ministry of Industry and Electricity, 1999; The Saudi Arabian Information Resource, 1999). The lowest number of these plants, according to the same sources, is in the northern and southern provinces because the infrastructures in these provinces have not been completed yet. In addition, the western province of Saudi Arabia has a high number of these plants but it is not as high as the number of plants in the central and eastern provinces (Ministry of Industry and Electricity, 1999; The Saudi Arabian Information Resource, 1999).

The analysis of the data that has been collected by the mail questionnaire and related to this issue reveals the same results. Table 6.3, which summarised these results, shows that most of the participating plants in the sample are located in the central province. The plants in this province represent 30.4% of the plants in the sample. In addition, table 6.3 shows that the next two provinces that come after the central province in terms of the number of continuous process plants are the eastern and western provinces. The plants in these provinces represent 28.4% and 27.9% of the plants in the sample respectively. Lastly, the table reveals that the lowest number of the participating plants is the one, which is associated with the northern and the southern provinces. The percentage of the plants representing these provinces in the sample is 7.4% and 5.9% respectively.

Province	Frequency	Percentage
Central	62	30.4
Eastern	58	28.4
Western	57	27.9
Northern	15	7.4
Southern	12	5.9
Total	**204**	**100.0**

Table 6.3 Grouped Frequency Distribution for The Provinces Where The Participating Plants Are Located

6.2.4 The Description of The Demographic Characteristics: The Size of The Participating Plants:

According to the findings from the interviews in chapter four, the number of machines in each plant was chosen as the classification measure for the size of the continuous process plants in this study. As a result, the participating plants in the sample of the mail questionnaire were asked to provide the necessary data on this number. The provided data on this number was then classified in to different groups in order to ease the analysis. Table 6.4 illustrates these groups and the differences between them.

Total Number of Machines	Frequency	Percentage
Less Than 250	17	8.3
251-500	25	12.3
501-750	41	20.1
751-1000	51	25.0
1001-1250	33	16.2
1251-1500	21	10.3
1501-Over	16	7.8
Total	**204**	**100.0**

Table 6.4 Grouped Frequency Distribution for The Number of Machines in The Participating Plants

As represented in this table, the highest frequency is associated with the group of plants that have a number of machines ranging from 751 to 1000 machines. These plants represent 25% of the participating plants in the sample. Following this group is the group of plants that have a number of machines ranging from 501 to 750 machines. The plants in this group represent 20.1% of the plants that participated in the survey. On the other hand, the lowest frequency is related to those plants that have more than 1501 machines. The percentage of this group of plants in the sample is 7.8%. In addition to these results, the average number of machines in the participating plants is 807 machines with a dispersion from this mean of 553 machines measured by the standard deviation.

From all of these results, it has been recognised that their trend is similar to that observed in the analysis of the interviews. Moreover, they imply that the sample of the participating plants covers a wide range of plants with a different number of machines.

6.2.5 The Description of The Change in The Number of Shutdown Maintenance Activities:

In chapter five, it has been mentioned that the focal point of the investigation process (the first stage of this thesis) and in turn the data analysis is the change in number of shutdown maintenance activities. The reason behind this is because the number of shutdown maintenance activities is the independent variable in the relationships of interest which the understanding of its effects on the dependent variables of interest represents the aim of the investigation process. Therefore, the participants who represented the participating plants in the survey were asked to provide the rate of change in the dependent variables of interest and the rates of change in the other independent variables that affect the variables of interest at the point of time when the change in this number occurred naturally. In addition, they were asked to provide the rate of change in the number of shutdown maintenance activities in order to measure the magnitude of change in this number.

The different rates of the change in the number of shutdown maintenance activities that were collected from the different participating plants are shown in table 6.5. The description of these rates and the change in the number of shutdown maintenance activities in general is summarised in the following points:

1. The group of rates of change in the number of shutdown maintenance activities with the highest frequency is the one in which the rates are in the range from 8.01% to 12%. This group of rates represent 21.6% of the rates of change in this number that have been provided by the participating plants in the sample.
2. Following this group of rates is the group of rates of change in the number of shutdown maintenance activities that are ranged from 12.01% to 16%. The figure that represents the percentage of these rates among the rates of change in this number in the sample is 19.1%.
3. The group of rates of change in the number of shutdown maintenance activities that has the lowest frequency is the one, in which the rates are in the range from 20.01% to 24%. The rates in this group represent 4.4% of the rates that have been provided by the participating plants in the sample.
4. The average rate of the change in the number of shutdown maintenance activities is 9.97% (median = 10%) with a dispersion from this mean of 8.14% measured by the standard deviation.

The Rate of Change in The Number of Shutdown Maintenance Activities	Frequency	Percentage
Less Than -4.00%	16	7.8
-3.99% to 0.00%	12	5.9
0.01% to 4.00%	20	9.8
4.01% to 8.00%	32	15.7
8.01% to 12.00%	44	21.6
12.01% to 16.00%	39	19.1
16.01% to 20.00%	20	9.8
20.01% to 24.00%	9	4.4
24.01% and Over	12	5.9
Total	**204**	**100.0**

Table 6.5 Grouped Frequency Distribution for The Change in The Number of Shutdown Maintenance Activities

6.2.6 The Description of The Change in Other Characteristics of Shutdown Maintenance Activities:

The other characteristics of shutdown maintenance activities that represent important variables in the relationships of interest are the cost, the time length and the frequency of each shutdown maintenance activity. The change in these characteristics together with the change in the number of the shutdown maintenance activities and the change in other variables describe the variation in the dependent variables of interest.

The description of the change in these characteristics that has been detected by the analysis of the collected data is discussed in the following points:

1. **The description of the change in the cost of each shutdown maintenance activity:**

The change in this variable that has been revealed by the analysis of the collected data is shown in table 6.6. In this table, the highest frequency is associated with the rates of change in this variable that are ranged from -0.09% to 1%. These rates represent 28.4% of the rates of change in this variable that were collected from the participating plants in the sample. The next highest frequency in this table is related to the group of rates, which are in the range from -1.19% to -0.1%. The figure that represents these rates in the sample is 27.5%.

The Rate of Change in The Cost of Each Shutdown Maintenance Activity	Frequency	Percentage
Less Than -3.40%	4	2.0
-3.39% to -2.30%	13	6.4
-2.29% to -1.20%	21	10.3
-1.19% to -0.10%	56	27.5
-0.09% to 1.00%	58	28.4
1.01% to 2.10%	35	17.1
2.11% to 3.20%	12	5.9
3.21% and Over	5	2.4
Total	**204**	**100.0**

Table 6.6 Grouped Frequency Distribution for The Change in The Cost of Each Shutdown Maintenance Activity

Also, in this table, the lowest frequency is related to the rates of change in this variable that are less than or equal to -3.4%. These rates represent 2% of the rates of change in this variable that have been collected from the participating plants in the sample. In addition to all these results, the mean rate of change in this variable is 0.01% (median = 0%) with a dispersion from this mean of 1.48% measured by the standard deviation.

2. The description of the change in the time length of each shutdown maintenance activity on the critical path:

The description of the change in the time length of each shutdown maintenance activity on the critical path of the maintenance schedule was summarised in table 6.7. In this table, the highest frequency is related to the group of rates of change in the time length of each shutdown maintenance activity on the critical path, which are ranged from 5.01% to 10%. These rates represent 30.4% of the rates of change in the time length of these activities. The lowest frequency in this table, on the other hand, is the one, which is related to the rates of change in the time length of these activities that are less than or equal to -5% and greater than or equal to 20.01%. The figure that represents the percentage of each of these two groups of rates in the sample is 2%. In addition, the average rate of change in the time length of these activities and the standard deviation are 8.52% (median = 8.8%) and 6.44% respectively.

The Rate of Change in The Time Length of Each Shutdown Maintenance Activity on The Critical Path	Frequency	Percentage
Less Than -5.00%	4	2.0
-4.99% to 0.00%	20	9.8
0.01% to 5.00%	38	18.6
5.01% to 10.00%	62	30.4
10.01% to 15.00%	44	21.5
15.01% to 20.00%	32	15.7
20.01% and Over	4	2.0
Total	**204**	**100.0**

Table 6.7 Grouped Frequency Distribution for The Change in The Time Length of Each Shutdown Maintenance Activity on The Critical Path

3. The description of the change in the time length of each shutdown maintenance activity that is not on the critical path:

The description of the change in this variable was shown in table 6.8, which was constructed to facilitate this description. In this table, the rates of change in the time length of these activities were different and they were classified into groups. The group of rates that has the highest frequency is the one in which the rates of change in the time length of these activities are in the range from 6.01% to 11%. The rates in this group represent 27.5% of the rates of change in the time length of these activities. On the other hand, the lowest frequency is related to the group of rates of change in the time length of these activities that are less than or equal to -4%. The percentage figure that represents this group of rates in the sample is 2%. In addition, the average rate of change in the time length of these activities is 8.52% (median = 8.8%) and the standard deviation is 6.5%.

The Rate of Change in The Time Length of Each Shutdown Maintenance Activity That Is Not on The Critical Path	Frequency	Percentage
Less Than -4.00%	4	2.0
-3.99% to 1.00%	24	11.7
1.01% to 6.00%	49	24.0
6.01% to 11.00%	56	27.5
11.01% to 16.00%	43	21.1
16.01% to 21.00%	23	11.3
21.01% and Over	5	2.4
Total	**204**	**100.0**

Table 6.8 Grouped Frequency Distribution for The Change in The Time Length of Each Shutdown Maintenance Activity That Is Not on The Critical Path

4. The description of the change in the Frequency of each shutdown maintenance activity:

The change in this variable that has been revealed by the analysis of the collected data is shown in table 6.9. As represented in this table, the highest frequency is related to the rates of change in this variable that are in the range from -9.99% to 15% with a percentage representing this group of rates in the sample of 33.8%. Also, in this table, the lowest frequency is related to the rates of change in this variable that are less than or equal to -60%. The percentage of this group of rates among the other groups of rates of change in this variable that have been provided by the participating plants in the sample is 1%.

In addition to this table, the change in this variable was also described by calculating the mean rate of change in this variable and the dispersion from this mean that has been measured by the standard deviation. The figures that represent these two measures are -0.082% (median = 0%) and 29.29% respectively.

The Rate of Change in The Frequency of Each Shutdown Maintenance Activity	Frequency	Percentage
Less Than -60.00%	2	1.0
-59.99% to -35.00%	19	9.3
-34.99% to -10.00%	46	22.5
-9.99% to 15.00%	69	33.8
15.01% to 40.00%	45	22.1
40.01% to 65.00%	18	8.8
65.01% and Over	5	2.5
Total	**204**	**100.0**

Table 6.9 Grouped Frequency Distribution for The Change in The Frequency of Each Shutdown Maintenance Activity

6.2.7 The Description of The Change in The Direct, The Overhead and The Overall Costs of Shutdown Maintenance:

In the literature (chapter one) and from the findings of the interviews (chapter four), the shutdown maintenance cost is defined as combination of the direct cost of shutdown maintenance and the overhead cost of shutdown maintenance. Also, from the findings of the interviews and the theoretical framework in chapter four, it has been found that shutdown maintenance direct cost and shutdown maintenance overhead cost represent important variables in the relationship between the number of shutdown maintenance activities and the cost of shutdown maintenance. Therefore, the participating plants in the survey were asked to provide the rates of change in these two cost variables, in addition to, the rates of change in the overall shutdown maintenance cost at the point of time when the change in the number of shutdown maintenance activities occurred naturally.

The provided rates of change in all of these variables by the participating plants in the survey are shown in separate tables in the points below. In addition to these tables, the description of these rates of change is discussed and summarised as well.

1. The description of the change in the shutdown maintenance direct cost:

The change in this variable was described by the rates of change that are related to this variable and that have been collected from the participating plants in the sample. These rates of change in this variable were classified into different groups in order to simplify their analysis. These groups were then organised in table 6.10.

In this table, the two highest frequencies are related to two groups of rates of change in the direct cost of shutdown maintenance. The first group among these two groups is the one in which the rates of change are in the range from 4.51% to 8.5%. The percentage of this group of rates among the rates of change in this variable that have been provided is 33.8%. The second group among these two groups of rates of change in this variable is the one in which the rates are ranged from 0.51% to 4.5%. The percentage figure that represents this group of rates in the sample is 27.5%. Also, in this table, the lowest frequency is related to the rates of change in this variable that are less than or equal to -3.5%. These rates represent 2% of the rates of change in this variable that have been collected from the participating plants in the sample.

In addition to all these results, the average rate of change in this variable is 5.65% (median = 5.6%) with a dispersion from this average of 5.08% measured by the standard deviation.

The Rate of Change in The Direct Cost of Shutdown Maintenance	Frequency	Percentage
Less Than -3.50%	4	2.0
-3.49% to 0.50%	24	11.7
0.51% to 4.50%	56	27.5
4.51% to 8.50%	69	33.8
8.51% to 12.50%	33	16.2
12.51% to 16.50%	13	6.4
16.51% and Over	5	2.4
Total	**204**	**100.0**

Table 6.10 Grouped Frequency Distribution for The Change in The Direct Cost of Shutdown Maintenance

2. The description of the change in the shutdown maintenance overhead cost:

The change in this variable was also described by the rates of change that are related to this variable and that have been collected from the participating plants in the sample. These rates of change were also classified into groups as represented in table 6.11 below. In this table, most of the rates of change in this variable are clustered in the group that has rates of change ranged from 0.71% to 1.35%. These rates represent 21.1% of the rates of change in this variable that have been provided by the participating plants in the sample. Also, in this table, the smallest number of the rates of change in this variable is found in the group of rates that are less than or equal to -1.25%. The percentage figure that represents this group of rates in the sample is 2.5%. In addition to all of this, the mean rate of change in the overhead cost of shutdown maintenance is 1.16% (median = 1.2%). Also, the standard deviation that measures the dispersion from this mean is 1.19%.

The Rate of Change in The Overhead Cost of Shutdown Maintenance	Frequency	Percentage
Less Than -1.25%	5	2.5
-1.24% to -0.60%	15	7.4
-0.59% to 0.05%	18	8.8
0.06% to 0.70%	36	17.6
0.71% to 1.35%	43	21.1
1.36% to 2.00%	40	19.6
2.01% to 2.65%	25	12.3
2.66% to 3.30%	16	7.8
3.31% and Over	6	2.9
Total	**204**	**100.0**

Table 6.11 Grouped Frequency Distribution for The Change in The Overhead Cost of Shutdown Maintenance

3. The description of the change in the shutdown maintenance cost:

The shutdown maintenance cost is one of the variables of interest since it represents the dependent variable in one of the relationships of interest that needs to be studied in this stage. In the analysis of the data that has been collected by the mail questionnaire and that is related to this variable, the rate of change in this variable was different from one participating plant to another. This difference in the rate of change in this variable among the participating plants was described by the results of this analysis and it is summarised in table 6.12.

As represented in this table, the group of rates of change in this variable with the highest frequency is the one in which the rates are in the range from 5.01% to 8%. This group of rates represent 25.5% of the rates of change in this variable that have been provided by the participating plants in the sample. Following this group is the group of rates of change in this variable in which the rates are ranged from 8.01% to 11%. The rates in this group represent 18.1% of the rates of change in this variable that have been provided. Moreover, the lowest frequency in this table is related to the group of rates of change in this variable that are in the range from -4% and less. The percentage of these rates among the other provided rates of change in this variable is 2%.

In addition, and as a completion step to the description of the change in this variable, the average rate of change in this variable is 6.64% and the median is 6.7%. Also, the dispersion from this average, which is measured by the standard deviation, is 5.39%.

The Rate of Change in The Cost of Shutdown Maintenance	Frequency	Percentage
Less Than -4.00%	4	2.0
-3.99% to -1.00%	20	9.8
-0.99% to 2.00%	16	7.8
2.01% to 5.00%	32	15.7
5.01% to 8.00%	52	25.5
8.01% to 11.00%	37	18.1
11.01% to 14.00%	23	11.3
14.01% to 17.00%	12	5.9
17.01% and Over	8	3.9
Total	**204**	**100.0**

Table 6.12 Grouped Frequency Distribution for The Change in The Cost of Shutdown Maintenance

6.2.8 The Description of The Change in The Unavailability of Shutdown Maintenance Resources, The Inaccuracy of Scheduling Shutdown Maintenance Activities and The Timing of Shutdown Maintenance Programme:

As it has been discussed in chapter four, all of these variables represent some of the important independent variables that affect the dependent variables of interest. In particular, they are some of the important independent variables that affect either the loss in production that occurs as a result of performing shutdown maintenance activities, the shutdown maintenance cost or both. Therefore, the change in these variables together with the change in other independent variables is very important for describing the variation in the loss of production that occurs as a result of performing shutdown maintenance and in the cost of shutdown maintenance.

The way that has been used to collect the data about the change in these variables was described in chapter five and it was represented by collecting this data in the natural environment and at the point of time when the change in the number of shutdown maintenance activities occurred. The description of the change in these variables that has been detected by the analysis of the collected data is discussed in the following points:

1. The description of the change in the unavailability of shutdown maintenance resources:

The change in this variable was revealed by the description of the rates of change that are related to this variable and that have been provided by the participating plants in the sample. These rates of the change in this variable were classified into different groups in order to simplify the analysis and they are shown in table 6.13. The description of these rates and the description of the change in the unavailability of shutdown maintenance resources in general were summarised in the following points:

1. The average rate of the change in the unavailability of shutdown maintenance resources is -2.01% and the median is -2.1%.
2. The dispersion from this mean that is measured by the standard deviation is 2.37%.
3. The rates of change in the unavailability of shutdown maintenance resources with the highest frequency are those which are in the range from -3.09% to -1.1%.

These rates, as shown in table 6.13, represent 33.3% of the rates of change in this variable that have been provided by the participating plants in the sample.

4. Following these rates are the rates of change in the unavailability of shutdown maintenance resources that are ranged from -1.09% to 0.9%. The figure in table 6.13 that represents the percentage of these rates among the rates of change in this variable is 20.1%.
5. The group of rates of change in the unavailability of shutdown maintenance resources that has the lowest frequency is the one, in which the rates are in the range from -7.01% and less. The rates in this group, as shown in table 6.13, represent 1% of the rates that have been provided by the participating plants in the sample.

The Rate of Change in The Unavailability of Shutdown Maintenance Resources	Frequency	Percentage
Less Than -7.10%	2	1.0
-7.09% to -5.10%	25	12.3
-5.09% to -3.10%	38	18.6
-3.09% to -1.10%	68	33.3
-1.09% to 0.90%	41	20.1
0.91% to 2.90%	25	12.3
2.91% and Over	5	2.4
Total	**204**	**100.0**

Table 6.13 Grouped Frequency Distribution for The Change in The Unavailability of Shutdown Maintenance Resources

2. **The description of the change in the inaccuracy of scheduling shutdown maintenance activities:**

The change in this variable was revealed by the analysis of the collected data from the participating plants in the sample that are related to this variable and it is shown in table 6.14. In this table, the different rates of change in this variable were also classified into groups in order to ease the description of these rates. The group of these rates that has the highest frequency in this table is the one in which the rates of change in this variable are in the range from 0.51% to 1.5%. This group of rates represents 28.4% of the rates of change in this variable. Following this group is the group of rates of change in this variable in which the rates are ranged from 1.51% to 2.5%. The rates in this group represent 16.7% of the rates of change in this variable that have been provided. Also, in this table, the lowest frequency is related to the rates of change in this variable that are less than or equal to -2.5% and greater than or equal to 4.51%. The percentage figure that represents each one of these two groups of rates in the sample is 2%. In addition to all these results, the mean rate of change in this variable is 1.06% (median = 1.1%) with a dispersion from this mean of 1.77% measured by the standard deviation.

The Rate of Change in The Inaccuracy of Scheduling Shutdown Maintenance Activities	Frequency	Percentage
Less Than -2.50%	4	2.0
-2.49% to -1.50%	11	5.4
-1.49% to -0.50%	29	14.2
-0.49% to 0.50%	27	13.2
0.51% to 1.50%	58	28.4
1.51% to 2.50%	34	16.7
2.51% to 3.50%	20	9.8
3.51% to 4.50%	17	8.3
4.51% and Over	4	2.0
Total	**204**	**100.0**

Table 6.14 Grouped Frequency Distribution for The Change in The Inaccuracy of Scheduling Shutdown Maintenance Activities

3. The description of the change in the timing of shutdown maintenance:

The change in this variable that has been revealed by the analysis of the collected data is shown in table 6.15. As represented in this table, the rate of change in this variable (measured by the level of the demand of the production process) is different from one participating plant to another. However, the average rate of change in this variable is -0.05% (median = 0%) with a dispersion from this average of 3.06% measured by the standard deviation. In addition, the highest frequency is related to the rates of change in this variable that are in the range from -1.49% to 1% with a percentage representing this group of rates in the sample of 30.4%. Moreover, the lowest frequency is related to the rates of change in this variable that are less than or equal to -6.5% and greater than or equal to 6.01%. The percentage of these rates among the other rates of change in this variable that have been provided by the participating plants in the sample is 1.5%.

The Rate of Change in The Timing of Shutdown Maintenance	Frequency	Percentage
Less Than -6.50%	3	1.5
-6.49% to -4.00%	19	9.3
-3.99% to -1.50%	40	19.6
-1.49% to 1.00%	62	30.4
1.01% to 3.50%	52	25.5
3.51% to 6.00%	25	12.2
6.01% and Over	3	1.5
Total	**204**	**100.0**

Table 6.15 Grouped Frequency Distribution for The Change in The Timing of Shutdown Maintenance

6.2.9 The Description of The Change in The Duration of Shutdown Maintenance:

The duration of shutdown maintenance is an important intervening variable that affects the relationship between the number of shutdown maintenance activities and the loss in production that occurs as a result of performing these activities, in addition to, the relationship between the number of shutdown maintenance activities and the shutdown maintenance cost. Therefore, it was very important to ask the participating plants in the sample of the survey to provide the rate of change in this variable. As a result, the participating plants which represent a mixture of continuous process plants provided different rates of change in this variable. These different rates of change were then organised in table 6.16 in a grouped frequency distribution form.

The description of these rates as presented in this table shows that the highest frequency is related to the plants that have rates of change in this variable ranging from 5.01% to 10%. These plants represent 25% of the plants that participated in the survey. Also, in this table, the next group of plants, which has the second highest frequency, is the one in which the rates of change in this variable are ranging from 10.01% to 15%. The percentage of this group of plants in the sample is 23.5%. In addition, the lowest frequency is associated with those plants that their rates of change in this variable are less than or equal to -5.0%. The plants in this group represent 2% of the participating plants in the sample. Moreover, the average rate of change in this variable is almost 7.9% with dispersion from this average of 6.67% measured by the standard deviation.

The Rate of Change in The Duration of Shutdown Maintenance	Frequency	Percentage
Less Than -5.00%	4	2.0
-4.99% to 0.00%	24	11.8
0.01% to 5.00%	45	22.1
5.01% to 10.00%	51	25.0
10.01% to 15.00%	48	23.5
15.01% to 20.00%	26	12.7
20.01% and Over	6	2.9
Total	**204**	**100.0**

Table 6.16 Grouped Frequency Distribution for The Change in The Duration of Shutdown Maintenance

6.2.10 The Description of The Change in The Frequency of Shutdown Maintenance:

The frequency of shutdown maintenance is one of the important dependent variables in the relationships of interest in this stage. In the survey of this study, the mean rate of change in this variable was -16.67% and the dispersion from this mean is 23.86% measured by the standard deviation. In addition, the survey shows that the rate of change in this variable was different from one participating plant to another. This difference between the participating plants in their rates of change in this variable has been revealed in table 6.17.

In this table, most of the participating plants have their rates of change in this variable in the range between -25.99% and -9%. The percentage figure that represents these plants in the sample is 27%. These plants were then followed by the group of plants that have their rate of change in this variable in the range between -8.99% and 8%. The percentage of this group of plants in the sample is 22.1%. Finally, in this table, the smallest number of the participating plants in the sample is found in the group of rates that are in the range from 25.01% and over. These plants represent 2% of the participating plants in the sample.

The Rate of Change in The Frequency of Shutdown Maintenance	Frequency	Percentage
Less Than -60.00%	5	2.4
-59.99% to -43.00%	21	10.3
-42.99% to -26.00%	35	17.1
-25.99% to -9.00%	55	27.0
-8.99% to 8.00%	45	22.1
8.01% to 25.00%	39	19.1
25.01% and Over	4	2.0
Total	**204**	**100.0**

Table 6.17 Grouped Frequency Distribution for The Change in The Frequency of Shutdown Maintenance

6.2.11 The Description of The Change in The Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities:

From the findings of the interviews (chapter four) and the theoretical framework in chapter four, all of the problems that are associated with the change in the number of shutdown maintenance activities represent important dependent variables in the relationships of interest. In other words, these problems that were classified into safety, operational and economic problems in chapter four make with the number of shutdown maintenance activities three different relationships that need to be evaluated. Therefore, the participating plants in the survey were asked to provide the rates of change in the number of these problems after the occurrence of the change in the number of the shutdown maintenance activities.

The provided rates of change in the number of all of these types of problems by the participating plants in the survey are shown in separate tables in the points below. In addition to these tables, the description of these rates of change is discussed and summarised as well.

1. **The description of the change in the number of the safety problems that are associated with the change in the number of shutdown maintenance activities:**

The change in the number of this type of problems was described by the rates of change that are related to this number and that have been collected from the participating plants in the sample. These rates of change were classified into different groups in order to simplify their analysis and then these groups were organised in table 6.18.

In this table, the highest frequency is related to the group of rates of change in the number of these problems that are in the range from -11.79% to -7.8%. The percentage of this group of rates among the rates of change in the number of these problems is 27%. The next group of rates of change in the number of these problems in terms of the highest frequency is the one in which the rates are ranged from -7.79% to 3.8%. The percentage figure that represents this group of rates in the sample is 21.1%. Also, in this table, the lowest frequency is related to the rates of change in the number of this type of problems that are in the range from -19.8% and less. These rates represent 1.5% of the rates of change in the number of these problems that have been collected from the participating plants in the sample. In addition to all of these results, the average rate of change in the number of this type of problems is –7.87% (median = -7.8%) and the dispersion from this average is 6.29% measured by the standard deviation.

The Rate of Change in The Safety Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities	Frequency	Percentage
Less Than -19.80%	3	1.5
-19.79% to -15.80%	24	11.7
-15.79% to -11.80%	21	10.3
-11.79% to -7.80%	55	27.0
-7.79% to -3.80%	43	21.1
-3.79% to 0.20%	30	14.7
0.21% to 4.20%	24	11.7
4.21% and Over	4	2.0
Total	**204**	**100.0**

Table 6.18 Grouped Frequency Distribution for The Change in The Number of Safety Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities

2. The description of the change in the number of the operational problems that are associated with the change in the number of shutdown maintenance activities:

The change in the number of these problems was also described by the rates of change that have been collected from the participating plants in the sample and that are related to this number. These rates of change were also classified into groups as represented in table 6.19 below. In this table most of the rates of change in the number of this type of problems are clustered in the group that has rates of change ranged from -9.49% to -5%. These rates represent 27.9% of the rates of change in the number of this type of problems that have been provided by the participating plants in the sample. Also, in this table, the smallest number of rates of change in the number of these problems is found in the group of rates that are ranged from 4.01% and over. The rates in this group represent 2% of the rates that have been provided by the participating plants in the sample.

In addition to all of these information, the average rate of change in the number of this type of problems is -8.81% (median = -8.8%). Also, the dispersion from this average is 6.69% measured by the standard deviation.

The Rate of Change in The Operational Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities	Frequency	Percentage
Less Than -23.00%	5	2.5
-22.99% to -18.50%	16	7.8
-18.49% to -14.00%	24	11.8
-13.99% to -9.50%	46	22.5
-9.49% to -5.00%	57	27.9
-4.99% to -0.50%	28	13.7
-0.49% to 4.00%	24	11.8
4.01% and Over	4	2.0
Total	**204**	**100.0**

Table 6.19 Grouped Frequency Distribution for The Change in The Number of Operational Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities

3. The description of the change in the number of the economic problems that are associated with the change in the number of shutdown maintenance activities:

In the analysis of the data that has been collected by the mail questionnaire and that is related to the number of this type of problems, the rate of change in the number of these problems was different from one participating plants to another. This difference in the rate of change in the number of this type of problems, which was described by the results of this analysis, is summarised in table 6.20.

As represented in this table, the group of rates of change in the number of these problems with the highest frequency is the one in which the rates are in the range from -9.49% to -5%. This group of rates represents 26.5% of the rates of change in the number of this type of problems that have been provided by the participating plants in the sample. Following this group is the group of rates of change in the number of this type of problems in which the rates are ranged from -13.99% to -9.5%. The percentage figure that represents this group of rates in the sample is 24.5%. Moreover, the lowest frequency in this table is related to the group of rates of change in the number of this type of problems that are in the range from 4.01% and over. These rates represent 2% of the rates of change in the number of this type of problems that have been provided by the participating plants in the sample.

In addition to all these results and as a completion step to the description of the change in the number of this type of problems, the mean rate of change in this number is -8.8% and the median is -8.8%. Also, the dispersion from the mean, which is measured by the standard deviation, is 6.71%.

The Rate of Change in The Economic Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities	Frequency	Percentage
Less Than -23.00%	5	2.4
-22.99% to -18.50%	16	7.8
-18.49% to -14.00%	22	10.8
-13.99% to -9.50%	50	24.5
-9.49% to -5.00%	54	26.5
-4.99% to -0.50%	29	14.2
-0.49% to 4.00%	24	11.8
4.01% and Over	4	2.0
Total	204	100.0

Table 6.20 Grouped Frequency Distribution for The Change in The Number of Economic Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities

6.2.12 The Description of The Change in The Loss of Production That Occurs as a Result of Performing Shutdown Maintenance:

The importance of this variable as the dependent variable in one of the relationship of interest in the investigation process makes the description of its change important.

Therefore, the analysis of the data that is related to the rates of change in this variable and that has been collected by the mail questionnaire of this thesis at the point in time when the change in the main independent variable in these relationships (the number of shutdown maintenance activities) occurred, was the way to satisfy this description. The results of this analysis are shown in table 6.21 and they are summarised in the following points:

1. The average rate of change in this variable is 5.7% and the dispersion from this average is 5.39% measured by the standard deviation.
2. The rates of change in this variable with the highest frequency are those which are in the range from 3.51% to 6.5%. These rates, as shown in table 6.21, represent 27.5% of the rates of change in this variable that have been provided by the participating plants in the sample.
3. Following these rates are the rates of change in this variable that are ranged from 0.51% to 3.5%. The figure in table 6.21 that represents the percentage of these rates among the rates of change in this variable is 18.6%.
4. The group of rates of change in this variable that has the lowest frequency is the one, in which the rates are in the range from 15.51% and over. The rates in this group represent 1.5% of the rates that have been provided by the participating plants in the sample.

The Rate of Change in The Loss of Production	Frequency	Percentage
Less Than -5.50%	4	2.0
-5.49% to -2.50%	16	7.8
-2.49% to 0.50%	8	3.9
0.51% to 3.50%	38	18.6
3.51% to 6.50%	56	27.5
6.51% to 9.50%	31	15.2
9.51% to 12.50%	26	12.7
12.51% to 15.50%	22	10.8
15.51% and Over	3	1.5
Total	**204**	**100.0**

Table 6.21 Grouped Frequency Distribution for The Change in The Loss of Production That is Caused by Shutdown Maintenance

6.3 THE INFERENTIAL STATISTICAL ANALYSIS OF THE COLLECTED DATA:

Inferential statistical analysis of the collected data is the other source of information for answering research questions. It provides useful information about the relationships between the variables of interest, the differences among different groups of objects on a given variable, the differences among different variables of the same group, and so on (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). In addition, it helps to understand certain phenomena of interest and gives a good idea of how the survey participants perceive the relationships between the variables and the importance of these variables in their surrounding environment (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). More precisely, inferential statistical analysis provides statistical results that help to draw inferences about the population (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992).

In this stage of the thesis, the inferential statistical analysis was used to evaluate the relationships of interest in this thesis. In particular, it was used to investigate how the percentage of change in the number of shutdown maintenance activities and other independent variables of interest explain the variation in the percentage of change in the shutdown maintenance cost, frequency and the loss of production that occurs as a result of performing shutdown maintenance. In other words, it was used to investigate how the variation in the number of shutdown maintenance activities and all other independent variables explain the variation in the shutdown maintenance cost, frequency and the loss of production that occurs as a result of performing shutdown maintenance (the dependent variables).

The way in which this type of statistical analysis was used at this stage of the thesis to evaluate the relationships of interest is explained in the following subsections. However, before starting this explanation, the types of the inferential statistical analysis methods and the methods that were used to carry out the analysis of the collected data of the survey of this thesis is discussed in the next subsection.

6.3.1 The Types of The Inferential Statistical Analysis Methods:

The inferential statistical analysis has several methods that are used to carry out the analysis of the collected data. These methods can be categorised into two categories (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). The first category is the parametric statistical methods, which are used when the data are collected on an interval or a ratio scale (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). The use of these statistical methods is based on the assumption that the population from which the sample is drawn is normally distributed (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992). The second category is the non-parametric statistical methods, which make no explicit assumption regarding the normality of distribution in the population, and they are used when the data are collected on a nominal or ordinal scale (Diamantopoulos and Schlegelmilch, 1997; Fink, 1995c; Foster, 1998; Sekaran, 1992).

In this thesis, the inferential statistical analysis methods that were selected were a group of parametric methods that are used to investigate the relationships between different variables. The reason behind the selection of these methods was because the aim of the inferential statistical analysis in this thesis is to examine the relations and the associations between the variables that constitute the relationships of interest and because the data related to these variables were collected on a ratio scale.

The selection of these methods was the first step toward the inferential statistical analysis of the data that has been collected by the investigation process survey and as a completion step several assumptions related to the successful application of these methods were investigated to make sure that they are satisfied in order to apply these methods successfully. The first two assumptions among these important assumptions are the assumption of the normality of the distributions of the variables that constitute the relationships of interest and the assumption of the non-existence of outlier cases (outlier is the case with score that is a very different from the rest or it is the extreme case that has score that is more than three standard deviations away from the mean). These two assumptions were investigated by testing the data that are related to these variables and that have been collected in the investigation process survey. The ways that were used to test the collected data in order to investigate these two assumptions were the box-plot, the normal probability plot, the skewness and kurtosis, the

Kolmogorov-Smirnov statistic with a Lilliefors significance test, and the Mahalanobis distance. The results of these tests are summarised in the following points:

1. The box-plots that were used to test the collected data of the variables of interest showed that the median in each one of these box-plots is positioned in the centre of the box that is bounded between the 25th and the 75th percentiles. This according to Bryman and Cramer (1999), Coakes and Steed (1999) and Diamantopoulos and Schlegelmilch (1997) indicates that the normality assumption is satisfied since in the case of perfect normality, the median in the box-plot is positioned exactly in the centre of the box. An example of the box-plots that were used to test the normality of the collected data of the variables of interest is shown in figure 6.1.
2. The same box-plots also showed that there were no extreme scores recorded between 1.5 and 3 box length from the upper or the lower edge of the box in each one of these plots. This according to Bryman and Cramer (1999), Coakes and Steed (1999), Diamantopoulos and Schlegelmilch (1997) was also an indication of satisfying the assumption that is related to the non-existence of outliers cases.
3. The normal probability plots that were used to test the normality of the collected data of the variables of interest showed that the observed values of the data and the expected values from the normal distribution form almost a straight line. This was an indication of satisfying the normality assumption since in the case of perfect normality, the observed values of the cases and the expected values from the normal distribution fall in almost a straight line in the normal probability plot (Bryman and Cramer, 1999; Coakes and steed, 1999; Diamantopoulos and Schlegelmilch, 1997). An example of the normal probability plots that were used to test the normality of the collected data of the variables of interest is shown in figure 6.2.
4. The calculated values of the kurtosis and skewness of the data that are related to each variable of interest were almost zero and the values of the median and the mean were almost equal. These results also indicated that the normality assumption is satisfied since in the case of perfect normality, the values of the median and the mean should be same and the values of the kurtosis and skewness should be zero (Bryman and Cramer, 1999; Coakes and steed, 1999; Diamantopoulos and Schlegelmilch, 1997; Kline, 1998). Table 6.22 shows an

example of the values of these important indexes that were used to test the normality of the collected data.

5. Lilliefors significance levels of the Kolmogorov-Smirnov statistics that were related to the data of the variables of interest were grater than 0.05. This according to Bryman and Cramer (1999), Coakes and Steed (1999) and Diamantopoulos and Schlegelmilch (1997) indicates that the normality assumption is satisfied since in the case of perfect normality, the Lilliefors significance level of the Kolmogorov-Smirnov statistic should be greater than 0.05. Table 6.22 shows an example of the Lilliefors significance levels of the Kolmogorov-Smirnov statistics that have been used to test the normality of the collected data.
6. The Mahalanobis distances that were calculated during the analysis of the relationships of interest also showed that their values were not greater than the critical values of the chi-square (χ^2) at the significant level of 0.001. This according to Coakes and Steed (1999) and Kline (1998) was also an indication of satisfying the assumption that is related to the non-existence of outliers cases, since in the case of the existence of outliers, some or all of the Mahalanobis distances will exceed the critical values of the (χ^2) at the significant level of 0.001.

As it has been shown in these points, the results of these tests were positive. This means that the assumptions of normality and the non-existence of outliers are satisfied.

The other two assumptions that were investigated to make sure that they are satisfied in order to apply the selected methods successfully are the assumptions of linearity and homoscedasticity of the relationships between the variables of interest. These assumptions were investigated by testing the relationships between the variables of interest through the inspection of the scatter diagrams, which illustrate these relationships. The results of the inspection of these diagrams showed that the points on each diagram form almost a straight line and the variability in the scores for the independent variable in each diagram is roughly the same at all values of the dependent variables. This according to Bryman and Cramer (1999) and Coakes and Steed (1999) and Kline (1998) indicates that the assumptions of linearity and homoscedasticity of the relationships between the variables of interest are satisfied. In particular, it indicates that these relationships are linear and homoscedastic. An example of the scatter diagrams that were used to test the linearity and homoscedasticity of the relationships between the variables of interest is shown in figure 6.3.

The final assumption that was investigated and that needs to be satisfied in order to apply these methods successfully is the assumption of the non-existence of multicollinearity or the non-existence of high correlations among the independent variables. For testing this assumption, correlation matrix, which shows the correlations between the independent variables of interest and the tolerances which detects multicolinearity on a multivariate level by subtracting 1 from the squared multiple correlation between each independent variable and all the rest of the other independent variables were examined. The results of the examination were the following:

1. The absolute values of the correlations in the correlation matrix were between 0.001 and 0.64. This according to Bryman and Cramer (1999) and Coakes and Steed (1999) and Kline (1998) means that the assumption of the non-existence of the bivariate multicolinearity is satisfied since in the case of multicolinearity, the absolute value of correlation between the variables of interest will exceed 0.8.
2. The tolerances that were calculated during the analysis of the relationships of interest were between 0.47 and 0.96. This according to Bryman and Cramer (1999) and Coakes and Steed (1999) and Kline (1998) also means that the assumption of the non-existence of the multicolinearity is satisfied since in the case of multicolinearity, the tolerance of a given variable will be less than 0.1.

All of these results and the results of examining the other assumptions showed that these important assumptions were satisfied which facilitate the application of the selected methods mentioned at the beginning of this section as methods for carrying out the inferential statistical analysis of the data that has been collected by the investigation process survey. In the following subsections, the way in which these methods were used and their results will be discussed.

Measure	Statistics	Df	Significance Level
Mean	9.98	-	-
Median	10.00	-	-
Skewness	-0.009	-	-
Kurtosis	-0.269	-	-
Kolmogorov-Smirnov (Lilliefors)	0.056	204	0.200

Table 6.22 Statistical Measures for The Normality Test of The Data Related to The Number of Shutdown Maintenance Activities

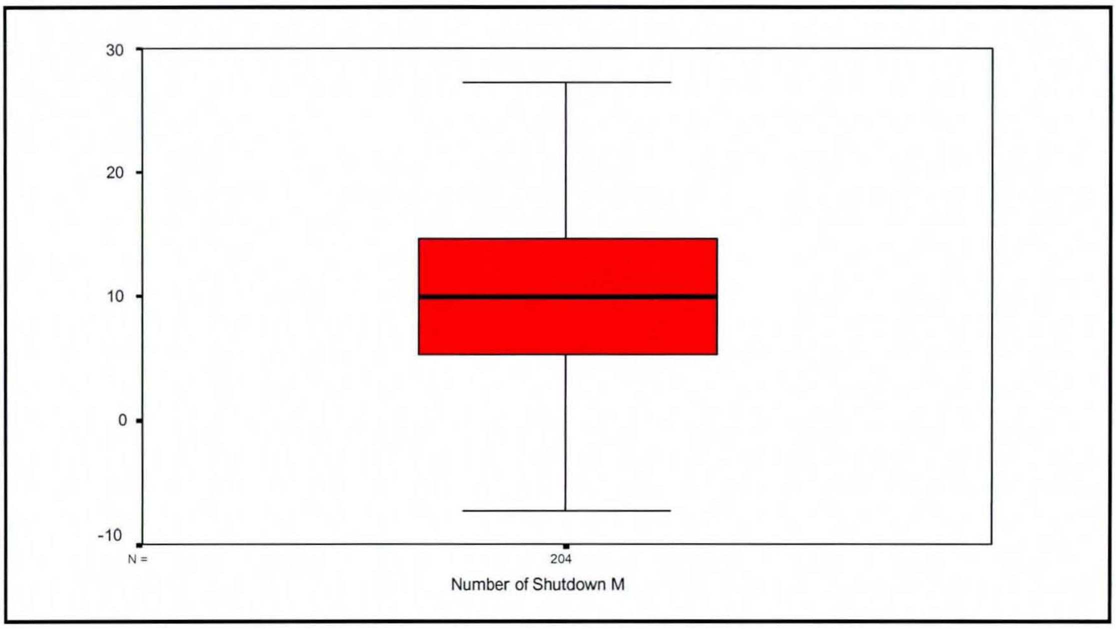

Figure 6.1 The Box-Plot for The Data Related to The Number of Shutdown Maintenance Activities

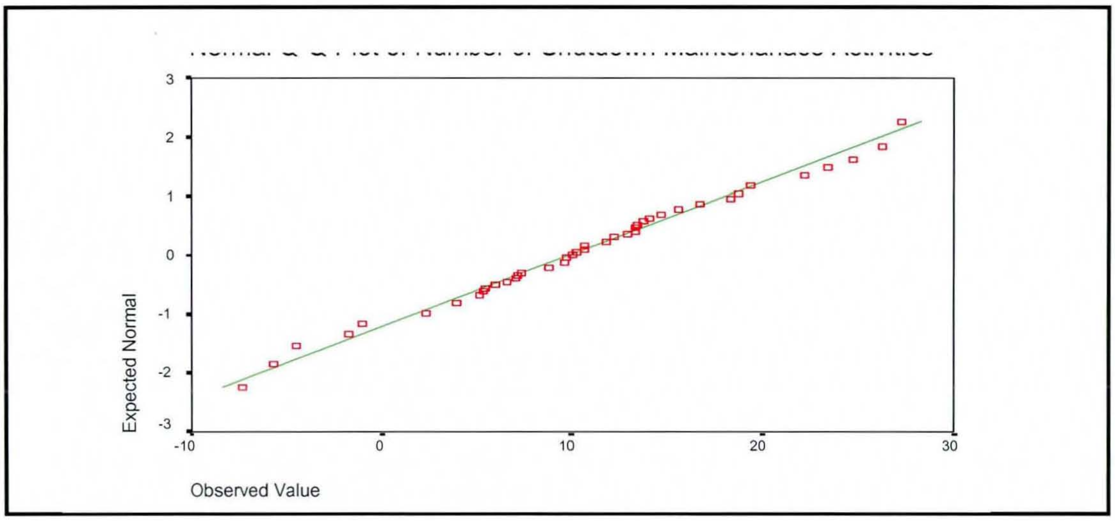

Figure 6.2 The Normality Plot for The Data Related to The Number of Shutdown Maintenance Activities

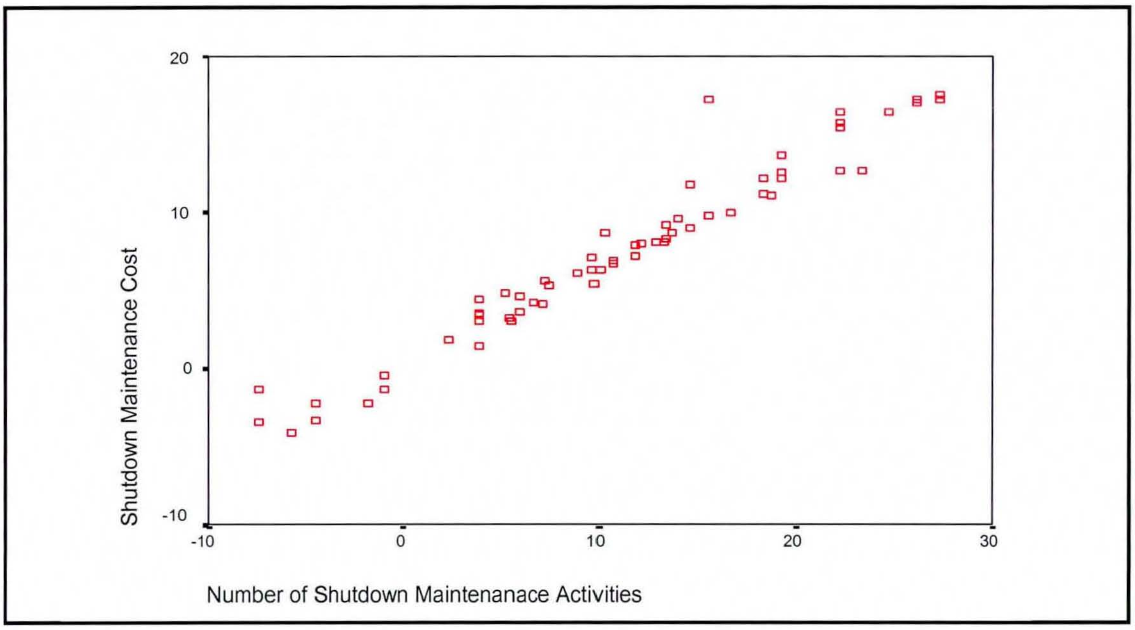

Figure 6.3 The Scatter-Plot of The Relation Between The Number of Shutdown Maintenance Activities and The Shutdown Maintenance Cost

6.3.2 The Analysis of The Relationship Between The Number of Shutdown Maintenance Activities and The Cost of Shutdown Maintenance:

In the theoretical framework of this stage of the thesis which has been discussed in chapter four, the effects of the number of shutdown maintenance activities and other independent variables on the shutdown maintenance cost were illustrated. In particular, they were illustrated in figure 4.1 of that chapter which is repeated in this chapter in figure 6.4 below.

In this figure, it has been shown that several independent variables (predictors or exogenous variables) have direct and indirect effects on several dependent variables (criterions or endogenous variables). In addition, it has been shown that the relationships between these variables, which represent these effects, have been postulated. All of this information that has been extracted from this figure was the important group of factors that affected the selection of the analysis method that was used to analyse the model of the relationships between the variables in this figure. In particular, it was the group of factors that made the selected analysis method to be one of the structural equation modelling methods (Hair et al., 1995; Kline, 1998).

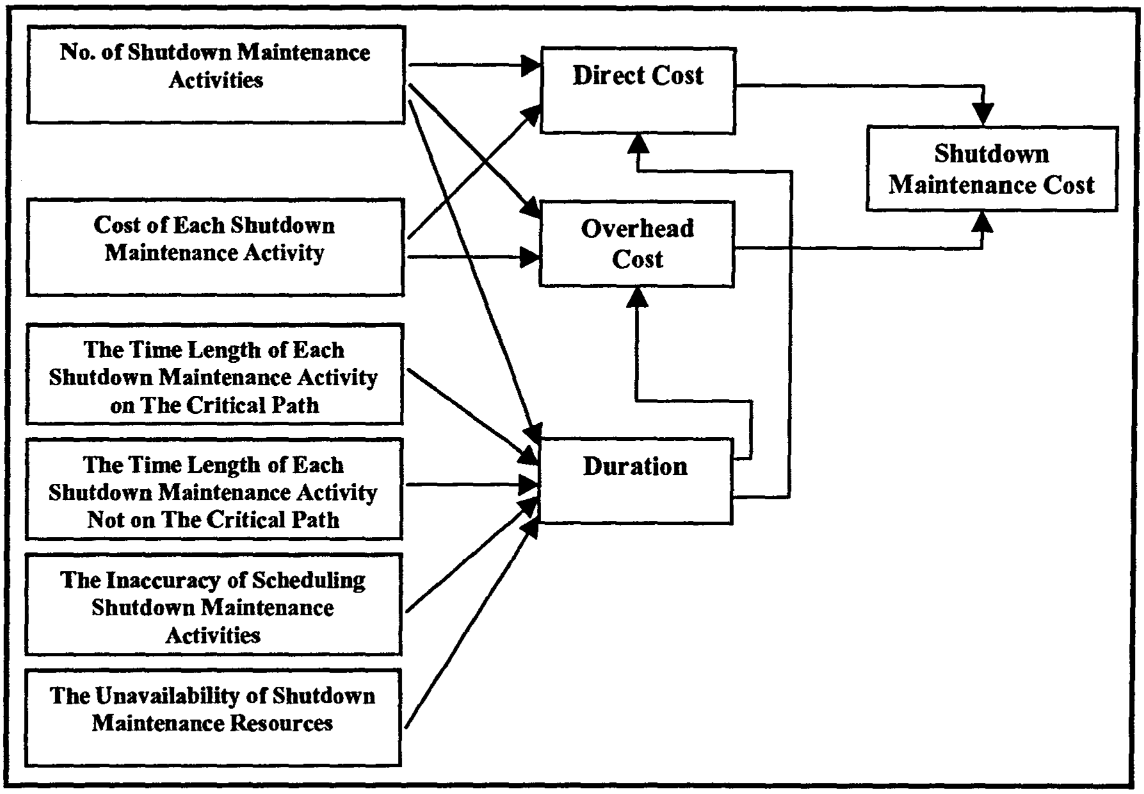

Figure 6.4 The Effects of The Number of Shutdown Maintenance Activities and The Other Variables on The Shutdown Maintenance Cost

In addition to this information, the figure also shows that there are no latent variables (hypothetical construct that consists of a set of effect indicators for assessing its domain (Kline, 1998)) and the relationships between the variables in this figure are unidirectional relationships. This additional information also narrowed down the selection of the analysis method toward one of very important structural equation modelling methods, which is the path analysis method for recursive models (Hair et al., 1995; Kline, 1998). However, there was a very important assumption that needed to be satisfied in order to use this method in the analysis of the model of the relationships in figure 6.4. This assumption was the non-existence of correlated disturbances, in other words, the non-existence of correlated residuals of the endogenous variables (Dillon and Goldstein, 1984; Kline, 1998). The test that was used to examine this assumption was the Durbin-Watson "d" test (Dillon and Goldstein, 1984), which showed that the value of the related statistic was 1.96. This result indicated that the residuals were not correlated among themselves since the Durbin-Watson statistic is closer to 2 (in particular it is in the acceptance region of

1.86 and 2.14) which according to Dillon and Goldstein (1984) is a firmer evidence that there was no autocorrelation present in the residuals.

The technique that was used as a part of the path analysis to carry out the estimation of the effects in the model of figure 6.4 was the multiple regression technique. The reason behind using the multiple regression technique was because in the case of recursive model such as the one in figure 6.4, the multiple regression technique yields almost identical estimates to those that are yielded by the other techniques that are used for the same purpose (Hair et al., 1995; Kline, 1998). In addition to this, the multiple regression technique is widely available in many computer programs and packages such as the SPSS package which makes it less expensive to use (Kline, 1998). The following points summarise the way in which the path analysis method was used to analyse the model in figure 6.4 and the results of this method:

1. The calculation of the direct effects on the endogenous variables by other variables in the number of shutdown maintenance activities and shutdown maintenance cost model:

In figure 6.4, there are four endogenous variables (three intervening variables and one dependent variable) that are directly affected by several other variables. Each one of these endogenous variables form with the variables that directly affect them different groups of related variables. For each group, a multiple regression analysis was conducted (by the use of the SPSS package) in order to generate estimates of the direct effects and the disturbance variances. The results of the multiple regression analysis of each group of variables are summarised in table 6.23 and figure 6.5 and they include the standardised regression coefficients, the multiple coefficients of determination (R^2s), the proportion of unexplained variance for each endogenous variable ($1-R^2$), and the results of the significance tests.

According to these results, one of the endogenous variables, which is the direct cost of shutdown maintenance was found to be significantly and directly affected by three variables (two independent variables and one intervening variable). These variables which significantly explained 91.6% of the variance in the shutdown maintenance direct cost were the number of shutdown maintenance activities, the cost of each shutdown maintenance activity and the shutdown maintenance duration. Among these three variables, the number of shutdown maintenance activities has a large positive and significant direct effect on the direct cost of shutdown maintenance (Standardised regression coefficient = 0.658 with resultant significant level (p-value) = 0.000 which indicates large effect since according to Kline (1998), standardised regression coefficient with absolute values less than 0.1 indicate small effect; values between 0.1 and 0.5 indicate medium effect and those greater than 0.5 indicate large effect). Whereas, each one of the shutdown maintenance duration and the cost of each shutdown maintenance activity have a medium positive and significant direct effect represented by the standardised regression coefficients of 0.329 and 0.139 respectively and with p-value =0.000 for both.

Also these results showed that another endogenous variable, which is the overhead cost of shutdown maintenance, was significantly and directly affected by the same three variables that affected the direct cost of shutdown maintenance. In particular, it has been found that each one of these three variables have a significant and positive direct effect on the overhead cost of shutdown maintenance and they significantly explained 81.3% of the variance in this variable. However, the large positive and significant direct effect on the overhead cost of shutdown maintenance was associated with the number of shutdown maintenance activities (Standardised regression coefficient = 0.573 with p-value = 0.000). Whereas, each one of the other two variables which are the shutdown maintenance duration and the cost of each shutdown maintenance activity have a medium positive and significant direct effect (Standardised regression coefficients = 0.295 and 0.256 respectively with p-value = 0.000 for both).

In addition to all of this information, the results showed that the duration of shutdown maintenance, which represents the third endogenous variable, was found to be significantly and directly affected by five variables (all of them are independent variables). These variables which significantly explained 85.4% of the variance in the duration of the shutdown maintenance were the number of shutdown maintenance activities, the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, the unavailability of shutdown maintenance resources, and the inaccuracy of scheduling shutdown maintenance activities. The effects of these variables on the duration of shutdown maintenance were classified into three groups according to their magnitudes. The first group was represented by the large positive and significant direct effect of the number of shutdown maintenance activities on the duration of shutdown maintenance. The magnitude of this effect was measured by the standardised regression coefficient of 0.821 (p-value = 0.000). The second group of these effects was the medium positive and significant direct effects of the time length of each shutdown maintenance activity on the critical path and the unavailability of shutdown maintenance resources which were represented by the standardised regression coefficients of 0.109 (p-value = 0.007) and 0.131 (p-value = 0.000) respectively. Finally, the third and the last group of these effects were the small positive and significant direct effects of the time length of each shutdown maintenance activity not on the critical path and the inaccuracy of scheduling shutdown maintenance activities. These effects were represented by the standardised regression coefficients of 0.075 (p-value = 0.026) and 0.067 (p-value = 0.033) respectively.

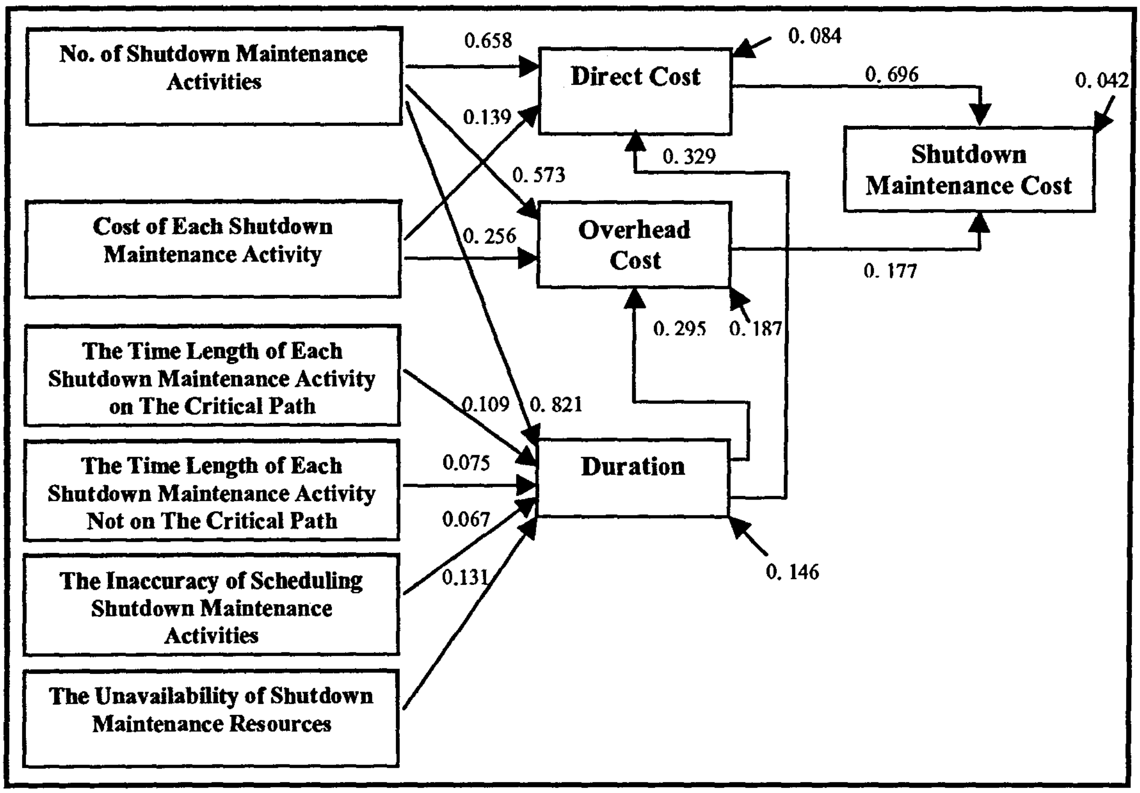

Figure 6.5 The Significant Direct Effects of The Number of Shutdown Maintenance Activities and The Other Variables on The Intervening variables and The Shutdown Maintenance Cost

The results of the multiple regression analysis also showed that the fourth endogenous variable (the dependent variable), which is the cost of shutdown maintenance, was significantly and directly affected by two variables (both of them are intervening variables). These two variables were the direct cost of shutdown maintenance which has a large positive and significant direct effect on the cost of shutdown maintenance (Standardised regression coefficient = 0.696 with p-value = 0.000) and the overhead cost of shutdown maintenance which has a medium positive and significant direct effect (Standardised regression coefficient = 0.177 p-value = 0.000). Both of these two variables were found to significantly explain 95.8% of the variance in the shutdown maintenance cost.

All of the above results show how they were consistent with the hypothesises that were theoretically suggested in the theoretical framework in chapter four especially those that were related to the magnitude of the relationships between the variables in the model of figure 6.4 that were predicted theoretically to be not significant (no relationship) and which were included in the model to be tested.

Criterion	Predictors	Standardised Regression Coefficients	R^2	$(1-R^2)$
Direct Cost of Shutdown Maintenance	Number of shutdown maintenance activities	0.658*	0.916	0.084
	Cost of each shutdown maintenance activity	0.139*		
	Duration of shutdown maintenance	0.329*		
	Time length of each shutdown maintenance activity on the critical path	0.029		
	Time length of each shutdown maintenance activity not on the critical path	0.026		
	The unavailability of shutdown maintenance resources	0.048		
	The inaccuracy of scheduling shutdown maintenance activities	0.033		
Overhead Cost of Shutdown Maintenance	Number of shutdown maintenance activities	0.573*	0.813	0.187
	Cost of each shutdown maintenance activity	0.256*		
	Duration of shutdown maintenance	0.295*		
	Time length of each shutdown maintenance activity on the critical path	0.020		
	Time length of each shutdown maintenance activity not on the critical path	0.035		
	The unavailability of shutdown maintenance resources	0.015		
	The inaccuracy of scheduling shutdown maintenance activities	0.046		

Continued in the next page

Criterion	Predictors	Standardised Regression Coefficients	R^2	$(1-R^2)$
Duration of Shutdown Maintenance	Number of shutdown maintenance activities	0.821*	0.854	0.146
	Time length of each shutdown maintenance activity on the critical path	0.109*		
	Time length of each shutdown maintenance activity not on the critical path	0.075*		
	The unavailability of shutdown maintenance resources	0.131*		
	The inaccuracy of scheduling shutdown maintenance activities	0.067*		
Shutdown Maintenance Cost	Direct cost of shutdown maintenance	0.696*	0.958	0.042
	Overhead cost of shutdown maintenance	0.177*		
	Number of shutdown maintenance activities	0.047		
	Cost of each shutdown maintenance activity	0.008		
	Duration of shutdown maintenance	0.071		
	Time length of each shutdown maintenance activity on the critical path	0.020		
	Time length of each shutdown maintenance activity not on the critical path	0.011		
	The unavailability of shutdown maintenance resources	0.007		
	The inaccuracy of scheduling shutdown maintenance activities	0.003		

Note: (*) means the effect is significant and the significant level is $P < 0.05$

Table 6.23 The Results of The Multiple Regression Analysis of Each Group of Related Variables (The Direct Effects of The Predictive Variables on Shutdown Maintenance Direct Cost, Overhead Cost, Duration and The Overall Cost)

2. The calculation of the indirect effects of the exogenous variables on the endogenous variables of the number of shutdown maintenance activities and shutdown maintenance cost model:

By indirect effect, it was meant, in this analysis, the effect of the exogenous variable on the endogenous variable through other variables (Bryman and Cramer, 1999; Kline, 1998). This type of effect was estimated statistically as the products of the direct effects of the related variables (Bryman and Cramer, 1999; Kline, 1998).

Among the four endogenous variables (the three intervening variables and the dependent variable) in the model of figure 6.4, there were three variables that were found to be significantly and indirectly affected by other variables. One of these three variables was the direct cost of shutdown maintenance, which was significantly and indirectly affected by five variables. These variables were the number of shutdown maintenance activities (Standardised indirect effect = 0.270), the time length of each shutdown maintenance activity on the critical path (Standardised indirect effect = 0.036), the time length of each shutdown maintenance activity not on the critical path (Standardised indirect effect = 0.025), the unavailability of shutdown maintenance resources (Standardised indirect effect = 0.043), and the inaccuracy of scheduling shutdown maintenance activities (Standardised indirect effect = 0.022). Each one of these variables has a significant and positive indirect effect on the direct cost of shutdown maintenance. The largest positive and significant indirect effect among the effects of these variables on the direct cost of shutdown maintenance was the effect of the number of shutdown maintenance activities while the smallest positive and significant indirect effect was the effect of the inaccuracy of scheduling shutdown maintenance activities.

The other variable that was significantly and indirectly affected by other variables in figure 6.4 was the overhead cost of shutdown maintenance. This variable was significantly and indirectly affected by the same five variables that indirectly affected the direct cost of shutdown maintenance. The effects of these five variables were ranged from medium positive and significant indirect effect to small positive and significant indirect effect. However, the largest positive and significant indirect effect among these effects was the effect of the number of shutdown maintenance activities (Standardised indirect effect = 0.242), followed by the effect of the unavailability of shutdown maintenance resources (Standardised indirect effect = 0.039), the effect of the time length of each shutdown maintenance activity on the critical path (Standardised indirect effect = 0.032), the effect of the time length of each shutdown maintenance activity not on the critical path (Standardised indirect effect = 0.022), and the effect of the inaccuracy of scheduling shutdown maintenance activities (Standardised indirect effect = 0.02) respectively.

In addition to these two endogenous variables, the last endogenous variable that was significantly and indirectly affected by other variables was the shutdown maintenance cost. This variable was significantly and indirectly affected by six variables. One of these variables was the number of shutdown maintenance activities, which has four positive and significant indirect effects on the shutdown maintenance cost. These effects influenced the shutdown maintenance cost through the direct cost of shutdown maintenance (Standardised indirect effect = 0.458), the overhead cost of shutdown maintenance (Standardised indirect effect = 0.101), the duration and then the direct cost of shutdown maintenance (Standardised indirect effect = 0.188) and the duration and then the overhead of shutdown maintenance (Standardised indirect effect = 0.043). All of these effects represent the largest indirect significant effects on the shutdown maintenance cost.

In addition to this variable, the other variable that has significant and indirect effects on the shutdown maintenance cost was the cost of each shutdown maintenance activity. This variable has two positive and significant indirect effects on the shutdown maintenance cost. One of these effects was through the direct cost of shutdown maintenance (Standardised indirect effect = 0.097) while the other was through the overhead cost of shutdown maintenance (Standardised indirect effect = 0.045). These effects, as shown in table 6.24, represent the next largest indirect significant effects on the shutdown maintenance cost after the indirect effects of the number of shutdown maintenance activities.

The other four variables that have significant and indirect effects on the shutdown maintenance cost were the time length of each shutdown maintenance activity on the critical path (Standardised indirect effects = 0.025 and 0.006), the time length of each shutdown maintenance activity not on the critical path (Standardised indirect effects = 0.017 and 0.004), the unavailability of shutdown maintenance resources (Standardised indirect effects = 0.03 and 0.007), and the inaccuracy of scheduling shutdown maintenance activities (Standardised indirect effects = 0.015 and 0.004). Each one of these variables has two positive and significant indirect effects on the shutdown maintenance cost (as it has been represented between the parentheses above). One of these effects (the first one in each parentheses above) was through the duration and the direct cost of shutdown maintenance whereas the other effect (the second one in each parentheses above) was through the duration and the overhead cost of shutdown maintenance. These effects as shown in table 6.24 represent the smallest indirect effect on the shutdown maintenance cost.

Exogenous Variable	Effect Type	Shutdown Maintenance Cost
Number of Shutdown Maintenance Activities	Indirect Effect Via Direct Cost	0.458
	Indirect Effect Via Overhead Cost	0.101
	Indirect Effect Via Duration and Direct Cost	0.188
	Indirect Effect Via Duration and Overhead Cost	0.043
	Total Effect	**0.790**
Cost of Each Shutdown Maintenance Activity	Indirect Effect Via Direct Cost	0.097
	Indirect Effect Via Overhead Cost	0.045
	Total Effect	**0.142**
Time Length of Each Shutdown Maintenance Activity on The Critical Path	Indirect Effect Via Duration and Direct Cost	0.025
	Indirect Effect Via Duration and Overhead Cost	0.006
	Total Effect	**0.031**
Time Length of Each Shutdown Maintenance Activity not on The Critical Path	Indirect Effect Via Duration and Direct Cost	0.017
	Indirect Effect Via Duration and Overhead Cost	0.004
	Total Effect	**0.021**
The Unavailability of Shutdown Maintenance Resources	Indirect Effect Via Duration and Direct Cost	0.030
	Indirect Effect Via Duration and Overhead Cost	0.007
	Total Effect	**0.037**
The Inaccuracy of Scheduling Shutdown Maintenance Activities	Indirect Effect Via Duration and Direct Cost	0.015
	Indirect Effect Via Duration and Overhead Cost	0.004
	Total Effect	**0.019**

Table 6.24 The Significant Indirect and Total Effects of The Exogenous Variables on The Shutdown Maintenance Cost

3. The calculation of the total effect of each exogenous variable on the shutdown maintenance cost:

The calculation of the total effect of each exogenous variable on the shutdown maintenance cost was the final and the most important step in this analysis. The reason behind this was because it revealed the magnitudes of the relationships between these variables and the shutdown maintenance cost especially the magnitude of the relationship between the shutdown maintenance cost and the number of shutdown maintenance activities. The way that was used to calculate the effects of this type was the same as that recommended in the literature for calculating such effects which is the sum of the direct and the indirect effects of each exogenous variable on the endogenous variable of interest (shutdown maintenance cost) (Bryman and Cramer, 1999; Kline, 1998).

The results of this way were different positive and significant total effects that are summarised in table 6.24. Among these effects, the largest positive and significant total effect was the total effect of the number of shutdown maintenance activities on the shutdown maintenance cost. The magnitude of this effect was 0.79, which was the sum of the magnitudes of the positive and significant indirect effects of 0.458, 0.101, 0.188 and 0.043. Following this effect were the positive and significant total effects of the cost of each shutdown maintenance activity (total effect = 0.142), the unavailability of shutdown maintenance resources (total effect = 0.037), the time length of each shutdown maintenance activity on the critical path (total effect = 0.031) and the time length of each shutdown maintenance activity not on the critical path (total effect = 0.021). These total effects were calculated by adding the positive and significant indirect effects of these variables on the shutdown maintenance cost as illustrated in table 6.24.

In addition to all of these effects, the smallest positive and significant total effect in table 6.24 was related to the inaccuracy of scheduling shutdown maintenance activities, which has a magnitude of 0.019. This magnitude was calculated by adding the positive and significant indirect effects of 0.015 and 0.004.

6.3.3 The Analysis of The Relationship Between The Number of Shutdown Maintenance Activities and The Loss of Production that Occurs as a Result of Performing Shutdown Maintenance:

In the theoretical framework of this stage of the thesis that has been discussed in chapter four, the effects of the number of shutdown maintenance activities and other variables on the loss of production that occurs as a result of performing shutdown maintenance were also illustrated. In particular, they were illustrated in figure 4.4 of that chapter which is also repeated in this chapter in figure 6.6 below.

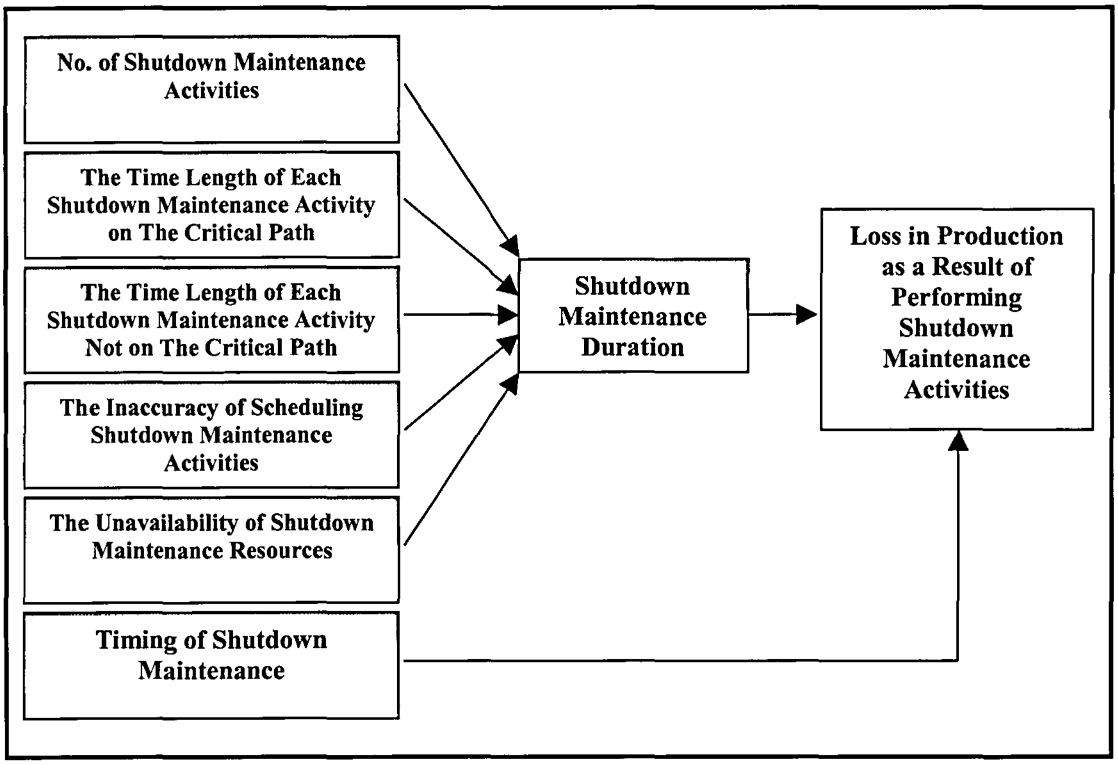

Figure 6.6 The Effects of The Number of Shutdown Maintenance Activities and The Other Variables on The Loss of Production That Occurs as a Result of Performing Shutdown Maintenance

In this figure as in figure 6.4, it has been shown that several independent variables (predictors or exogenous variables) have direct and indirect effects on several dependent variables (criterions or endogenous variables). Also, it has been shown that the directions of the relationships between these variables are determined. In addition, the figure also shows that there are no latent variables and the relationships between the variables in this figure are unidirectional relationships. All of these points that have been extracted from this figure represent the important factors that led to the selection of the analysis method that was used to analyse the model of the relationships between the variables in this figure. In particular, they represent the group of factors that led to the selection of one of very important structural equation modelling methods, which is the path analysis method for recursive models (Hair et al., 1995; Kline, 1998).

However, the selection of this method as a method for the analysis of the model of the relationships in figure 6.6 and the useful application of it were found to be related to the satisfaction of a very important assumption. This assumption as it has been mentioned in the previous subsection was the non-existence of correlated disturbances, in other words, the non-existence of correlated residuals of the endogenous variables (Dillon and Goldstein, 1984; Kline, 1998). The test that was used to examine this assumption was the Durbin-Watson "d" test (Dillon and Goldstein, 1984), which showed that the value of the related statistic in this case was 1.87. This result indicated that the residuals were not correlated amongst themselves since the Durbin-Watson statistic is closer to 2 (in particular it is in the acceptance region of 1.84 and 2.16) which according to Dillon and Goldstein (1984) is a firmer evidence that there was no autocorrelation present in the residuals.

In addition to all of this, the technique that was used as a part of the path analysis to carry out the estimation of the effects in the model of figure 6.6 was the multiple regression technique which was the same technique that was used in the previous subsection. The reason for using this technique was because in the case of recursive model such as the one in figure 6.6, there is no difference between the multiple regression technique and the other techniques that are used for the same purpose in the produced estimates (Hair et al., 1995; Kline, 1998). In addition, the multiple regression technique as mentioned in the previous subsection is widely available in many computer programs and packages such as the SPSS package which makes it less expensive to use (Kline, 1998). In the following points the way in which the path analysis method was used to analyse the model in figure 6.6 and the results of this method are summarised:

1. The calculation of the direct effects on the endogenous variables by other variables in the number of shutdown maintenance activities and the loss of production model:

In figure 6.6, there are two endogenous variables (one intervening variable and one dependent variable) that are directly affected by several other variables. For each one of these endogenous variables and the variables that directly affect them, a multiple regression analysis was conducted (by the use of the SPSS package) in order to generate estimates of the direct effects on the endogenous variables and the disturbance variances. The results of the multiple regression analysis of each group of variables are summarised in table 6.25 and figure 6.7 and they include the standardised regression coefficients, the multiple coefficients of determination (R^2s), the proportion of unexplained variance for each endogenous variable ($1-R^2$), and the results of the significance tests.

According to these results, one of the endogenous variables, which is the duration of shutdown maintenance was found to be significantly and directly affected by five variables (all of them were independent variables). These variables which significantly explained 85.4% of the variance in the shutdown maintenance duration were the number of shutdown maintenance activities, the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, the unavailability of shutdown maintenance resources, and the inaccuracy of scheduling shutdown maintenance activities. The effects of these variables on the duration of shutdown maintenance were classified into three groups according to their magnitudes. One of these groups was represented by the large positive and significant direct effect of the number of shutdown maintenance activities on the duration of shutdown maintenance. The magnitude of this effect was measured by the standardised regression coefficient of 0.821 (p-value = 0.000). The other group of these effects was the group of the medium positive and significant direct effects of the time length of each shutdown maintenance activity on the critical path and the unavailability of shutdown maintenance resources. The magnitudes of the effects in this group were also measured by the standardised regression coefficients of 0.109 (p-value = 0.007) and 0.131 (p-value = 0.000) respectively. Finally, the third and the last group of these effects was the group of the small positive and significant direct effects of the time length of each shutdown maintenance activity not on the critical path and the inaccuracy of scheduling shutdown maintenance activities. The magnitude of the effects in this group were represented by the standardised regression coefficients of 0.075 (p-value = 0.026) and 0.067 (p-value = 0.033) respectively.

In addition to the duration of shutdown maintenance, the results of the multiple regression analysis also showed that the second endogenous variable (the dependent variable), which is the loss of production that occurs as a result of performing shutdown maintenance, was significantly and directly affected by two variables (one intervening variable and one independent variable). These two variables were the duration of shutdown maintenance which has a large positive and significant direct effect on the loss of production that occurs as a result of performing shutdown maintenance (Standardised regression coefficient = 0.459 with p-value = 0.000) and the timing of shutdown maintenance which has a medium positive and significant direct effect (Standardised regression coefficient = 0.343 with p-value = 0.000). Both of these two variables were found to significantly explain 66.4% of the variance in the loss of production that occurs as a result of performing shutdown maintenance.

In addition to all of these results, the relationships between the variables in the model shown in figure 6.6 that were predicted theoretically to be not significant and which were included in the model to be tested were found in the analysis to be not significant as well. This indicates that this result and the other results that have been discussed in this point were consistent with the hypothesises that were theoretically suggested in the theoretical framework in chapter four and in turn they support the predictions that are related to these hypotheses.

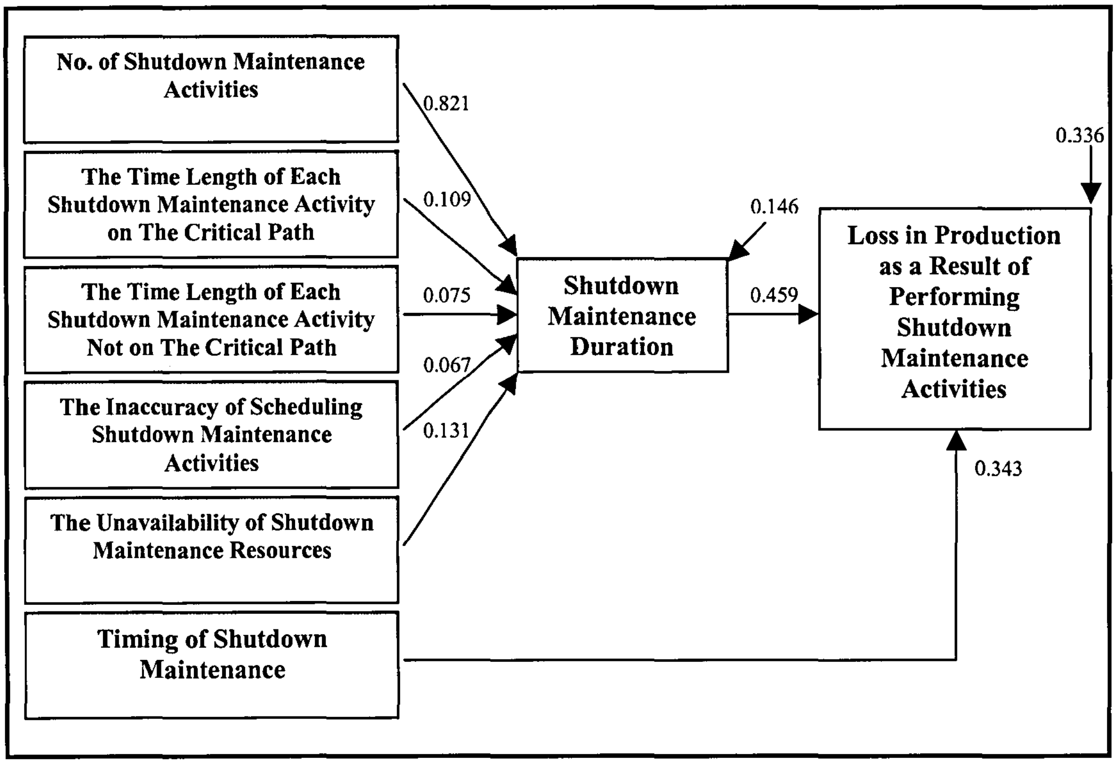

Figure 6.7 The Significant Direct Effects of The Number of Shutdown Maintenance Activities and The Other Variables on The Shutdown Maintenance Duration and The Loss of Production That Occurs as a Result of Shutdown Maintenance

Criterion	Predictors	Standardised Regression Coefficients	R^2	$(1-R^2)$
Shutdown Maintenance Duration	Number of shutdown maintenance activities	0.821*	0.854	0.146
	Time length of each shutdown maintenance activity on the critical path	0.109*		
	Time length of each shutdown maintenance activity not on the critical path	0.075*		
	The unavailability of shutdown maintenance resources	0.131*		
	The inaccuracy of scheduling shutdown maintenance activities	0.067*		
The Loss of Production as a Result of Performing Shutdown maintenance	Number of shutdown maintenance activities	0.136	0.664	0.336
	Time length of each shutdown maintenance activity on the critical path	0.040		
	Time length of each shutdown maintenance activity not on the critical path	0.057		
	The unavailability of shutdown maintenance resources	0.010		
	The inaccuracy of scheduling shutdown maintenance activities	0.088		
	Duration of shutdown maintenance	0.459*		
	Timing of shutdown maintenance	0.343*		

Note: (*) means the effect is significant and the significant level is $P < 0.05$

Table 6.25 The Results of The Multiple Regression Analysis of Each Group of Related Variables (The Direct Effects of The Predictive Variables on The Shutdown Maintenance Duration and The Loss of Production as a Result of Performing Shutdown Maintenance)

2. The calculation of the indirect effects of the exogenous variables on the endogenous variables of the number of shutdown maintenance activities and the loss of production model:

Among the two endogenous variables (the intervening variable and the dependent variable) shown in the model of figure 6.6, only the loss of production that occurs as a result of performing shutdown maintenance was found to be significantly and indirectly affected by other variables. In particular, this variable was found to be significantly and indirectly affected by five variables as it is shown in table 6.26.

These five variables were the number of shutdown maintenance activities (Standardised indirect effect = 0.377), the time length of each shutdown maintenance activity on the critical path (Standardised indirect effect = 0.050), the time length of each shutdown maintenance activity not on the critical path (Standardised indirect effect = 0.034), the unavailability of shutdown maintenance resources (Standardised indirect effect = 0.060), and the inaccuracy of scheduling shutdown maintenance activities (Standardised indirect effect = 0.031). Each one of these variables has a significant and positive indirect effect on the loss of production that occurs as a result of performing shutdown maintenance through the duration of shutdown maintenance. The largest positive and significant indirect effect among these effects was the effect of the number of shutdown maintenance activities while the smallest positive and significant indirect effect among these effects was the effect of the inaccuracy of scheduling shutdown maintenance activities.

Exogenous Variable	Effect Type	The Loss of Production as a Result of Shutdown Maintenance
Number of Shutdown Maintenance Activities	Indirect Effect Via Shutdown Maintenance Duration	0.377
	Total Effect	**0.377**
Time Length of Each Shutdown Maintenance Activity on The Critical Path	Indirect Effect Via Shutdown Maintenance Duration	0.050
	Total Effect	**0.050**
Time Length of Each Shutdown Maintenance Activity not on The Critical Path	Indirect Effect Via Shutdown Maintenance Duration	0.034
	Total Effect	**0.034**
The Unavailability of Shutdown Maintenance Resources	Indirect Effect Via Shutdown Maintenance Duration	0.060
	Total Effect	**0.060**
The Inaccuracy of Scheduling Shutdown Maintenance Activities	Indirect Effect Via Shutdown Maintenance Duration	0.031
	Total Effect	**0.031**
Timing of Shutdown Maintenance	Direct Effect	0.343
	Total Effect	**0.343**

Table 6.26 The Significant Indirect and Total Effects of The Exogenous Variables on The Loss of Production That Occurs as a Result of Performing Shutdown Maintenance

3. The calculation of the total effect of each exogenous variable on the loss of production that occurs as a result of performing shutdown maintenance:

As mentioned in the last subsection, the calculation of the total effect of each exogenous variable on the endogenous variable of interest is the most important step in this type of analysis (Hair et al., 1995; Kline, 1998). The reason behind this is because the calculation of the total effects of the exogenous variables reveals the magnitudes of the relationships between these exogenous variables and the endogenous variable of interest (Hair et al., 1995; Kline, 1998).

In the model of figure 6.6, six variables were found to have significant and positive total effects on the endogenous variable of interest in this model which is the loss of production that occurs as a result of performing shutdown maintenance. One of these variables was the number of shutdown maintenance activities which has the largest positive and significant total effect on the loss of production that occurs as a result of performing shutdown maintenance. The magnitude of its effect was 0.377, which was the same as its indirect effect on this endogenous variable. The other variable that has a significant total effect on the loss of production that occurs as a result of performing shutdown maintenance, was the timing of shutdown maintenance. This variable as shown in table 6.26 has the second largest positive and significant total effect on the loss of production that occurs as a result of performing shutdown maintenance. The magnitude of its effect was 0.343.

In addition to these two variables, the other four variables that were found to have significant total effects on the loss of production that occurs as a result of performing shutdown maintenance were the unavailability of shutdown maintenance resources (total effect = 0.060), the time length of each shutdown maintenance activity on the critical path (total effect = 0.050), the time length of each shutdown maintenance activity not on the critical path (total effect = 0.034) and the inaccuracy of scheduling shutdown maintenance activities (total effect = 0.031). Each one of these variables has a small positive and significant total effect on the loss of production that occurs as a result of performing shutdown maintenance as illustrated in table 6.26.

6.3.4 The Analysis of The Relationship Between The Number of Shutdown Maintenance Activities and The Frequency of Shutdown Maintenance:

The effect of the number of shutdown maintenance activities on the frequency of shutdown maintenance was discussed in the theoretical framework of this stage in chapter four of this thesis. In particular, this effect was discussed together with the effect of the frequency of each shutdown maintenance activity on the shutdown maintenance frequency in that chapter and they were illustrated in figure 4.5, which is repeated in this chapter in figure 6.8.

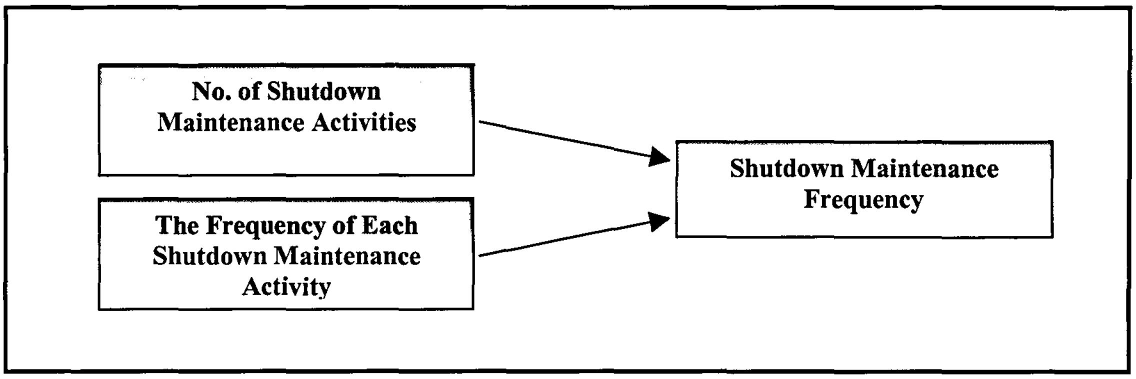

Figure 6.8 The Effects of The Number of Shutdown Maintenance Activities and The Frequency of Each Shutdown Maintenance Activity on The Shutdown Maintenance Frequency

As discussed in the theoretical framework in chapter four, the model in this figure consists of two independent variables or predictors (the number of shutdown maintenance activities and the frequency of each shutdown maintenance activity) that have effects on one dependent variable or criterion (Shutdown maintenance frequency) and all these variables were measured by the ratio scale (metric). This important information about the model led to the selection of the analysis method that was used to analyse the relationships between the variables in this model. In particular, it led to the use of one of the multivariate dependence methods (Hair et al., 1995; Kline, 1998). This method was the multiple regression analysis (Hair et al., 1995; Kline, 1998).

However, the selection of this method as a method for the analysis of the model of the relationships in figure 6.8 and the useful application of it were found to requires the satisfaction of several important assumptions (Hair et al., 1995; Kline, 1998). All of these assumptions which were the normality of the distributions of the variables that constitute the relationships of interest, the non-existence of outlier cases, the linearity and homoscedasticity of the relationships between the variables of interest and the non-existence of multicollinearity or the non-existence of high correlations among the independent variables were satisfied in subsection 6.3.1 of this chapter.

The way in which the multiple regression analysis method was used to estimate both of the effects on the dependent variable of the model in figure 6.8 (shutdown maintenance frequency) and the disturbance variance of this variable was by the use of the multiple regression function in the SPSS computer package. The results of this way were summarised in table 6.27 and figure 6.9 and they were discussed in the following points:

1. All of the independent variables collectively (the number of shutdown maintenance activities and the frequency of each shutdown maintenance activity) have large positive and significant correlation with the dependent variable (the shutdown maintenance frequency) of 0.941 (p-value =0.000).
2. Among the two independent variables in figure 6.8, the frequency of each shutdown maintenance activity (measured in terms of rate of change in time) has a large positive and significant effect on the shutdown maintenance frequency (measured in terms of rate of change in the time between successive shutdown maintenance programs). In other words, an increase in the frequency of each shutdown maintenance activity (number of times of performing each activity in a certain period of time) contributes largely to the increase in the shutdown maintenance frequency (number of the times of performing shutdown maintenance program in a certain period of time). The magnitude of this effect was 0.521 with a p-value = 0.000.
3. The other independent variable, which is the number of shutdown maintenance activities, has almost a large negative and significant effect on the shutdown maintenance frequency (measured by the rate of change in the time between successive shutdown maintenance programs) of -0.475 (p-value =0.000). In other words, an increase in the number of shutdown maintenance activities contributes almost largely to the increase in the shutdown maintenance frequency (number of

the times of performing shutdown maintenance program in a certain period of time).

4. Both of these independent variables (the number of shutdown maintenance activities and the frequency of shutdown maintenance activity) significantly explained 88.5% of the variance in the shutdown maintenance frequency.

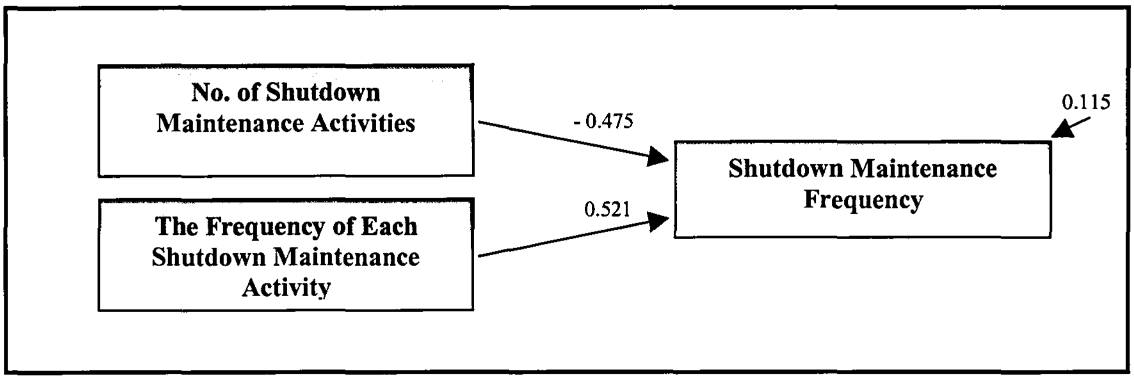

Figure 6.9 The Significant Effects of The Number of Shutdown Maintenance Activities and The Frequency of Each Shutdown Maintenance Activity on The Shutdown Maintenance Frequency

Criterion	Predictors	Standardised Regression Coefficients	R^2	$(1-R^2)$
Shutdown Maintenance Frequency	Number of shutdown maintenance activities	-0.475*	0.885	0.115
	The frequency of each shutdown maintenance activity	0.521*		

Note: (*) means the effect is significant and the significant level is $P < 0.05$

Table 6.27 The Results of The Multiple Regression Analysis of The Model of The Relationships Between The Predictive Variables and The Shutdown Maintenance Frequency (The Effects of The Predictive Variables on The Shutdown Maintenance Frequency)

6.3.5 The Analysis of The Relationships Between The Number of Shutdown Maintenance Activities and The Problems That Are Associated With The Change in This Number:

The relationships between the number of shutdown maintenance activities and the problems that are associated with the change in this number were discussed in the theoretical framework of this stage in chapter four of this thesis and they were shown in several figures in that chapter. The discussion and the figures in chapter four showed that the number of shutdown maintenance activities has an effect on each type of these problems. In particular, they showed that the number of shutdown maintenance activities has an effect on the safety problems, the economic problems and the operational problems that are associated with the change in this number on a one to a one basis.

In addition to this and in chapter five, it was also mentioned that all the variables that constitute these relationships were measured by the use of the ratio scale. In other words, they were metric variables.

All of these important points of information about these relationships represent the factors that led to the selection of the analysis method that was used to analyse these relationships. In particular, they represent the factors that led to the selection of the bivariate correlation and the regression techniques as the method to analyse these relationships since these techniques provide valuable information about the strength and the direction (in terms of positive or negative relationship) of these relationships, the estimation of the effect of the independent variable on the dependent variable, and the proportion of the variation in the dependent variable that is explained by the independent variable (Bryman and Cramer, 1999; Kline, 1998).

However, the selection of these two techniques as a method for the analysis of these relationships and the useful application of them were found to require the satisfaction of four important assumptions (Bryman and Cramer, 1999; Kline, 1998). All of these assumptions which were the normality of the distributions of the variables that constitute the relationships of interest, the non-existence of outlier cases and the linearity and homoscedasticity of the relationships between the variables of interest were satisfied in subsection 6.3.1 of this chapter.

The way that was used to carry out these two techniques for analysing these relationships was through the use of the SPSS bivariate correlation and regression functions. The interpretation of the results of these two functions depends on three important measures (Bryman and Cramer, 1999; Diamantopoulos and Schlegelmilch, 1997; Kline, 1998). One of these measures is the correlation coefficient (r), which measures the strength and the direction of the relationship between the variables (Bryman and Cramer, 1999; Diamantopoulos and Schlegelmilch, 1997). The values of this measure are ranged between 0 and ±1, with 0 indicating no relationship between the variables and 1 indicating a perfect relationship (Bryman and Cramer, 1999; Diamantopoulos and Schlegelmilch, 1997). The (+) or (-) sign in this measure indicates the direction of the relationship (Bryman and Cramer, 1999; Diamantopoulos and Schlegelmilch, 1997). According to Diamantopoulos and Schlegelmilch (1997), a relationship regardless of its direction is considered to be strong if its correlation coefficient is greater than 0.8, moderate if this measure is between 0.4 and 0.8, and weak if this measure is less than 0.4. The other two measures that help in the interpretation of the results of these two techniques are the coefficient of determination (r^2) and the standardised regression coefficient (Bryman and Cramer, 1999; Kline, 1998). The first measure among these two measures is concerned with measuring the proportion of the variation in the dependent variable that is explained by the variation in the independent variable whereas the second measure is concerned with measuring the effect of the independent variable on the dependent variable (Bryman and Cramer, 1999; Kline, 1998). In addition to all of this, these three measures are always accompanied with the result of the significance test, which indicates whether the association between the variables, the effect of the independent variable on the dependent variable, and the proportion of the variation in the dependent variable that is explained by the independent variable in the population are significant (their values significantly different from zero) (Bryman and Cramer, 1999; Diamantopoulos and Schlegelmilch, 1997; Kline, 1998).

In the following points, the results of these two techniques that were used to analyse the relationships of interest in this subsection and the values of these measures were discussed and they were also summarised in tables 6.28 and 6.29 below:

1. The relationships between the number of shutdown maintenance activities and the safety problems, the economic problems and the operational problems were found to be strong negative and significant relationships of $r = -0.858$, $r = -0.890$ and $r = -0.899$ (p-value =0.000 for all) respectively.

2. The number of shutdown maintenance activities has a large negative and significant effect on the safety problems that are associated with the change in this number of –0.858 (p-value=0.000). This means that an increase in the number of shutdown maintenance activities contributes largely to the decrease in the safety problems that are associated with the change in this number during normal operation. In addition, the number of shutdown maintenance activities was found to significantly explain 73.7% (r^2= 0.737) of the variance in this type of problems.
3. The number of shutdown maintenance activities has also a large negative and significant effect on the operational problems that are associated with the change in this number of –0.899 (p-value=0.000). In particular, the number of shutdown maintenance activities significantly explained 80.8% (r^2= 0.808) of the variance in this type of problems. All of this means that an increase in the number of shutdown maintenance activities contributes largely to the decrease in the operational problems that are associated with the change in this number during normal operation.
4. The number of shutdown maintenance activities has a large negative and significant effect on the economic problems that are associated with the change in this number as well. The magnitude of this effect was –0.890 (measured by the standardised regression coefficient with p-value=0.000). This means that an increase in the number of shutdown maintenance activities also contributes largely to the decrease in the economic problems that are associated with the change in this number during normal operation. In addition, it was found that the number of shutdown maintenance activities significantly explained 79.2% (r^2= 0.792) of the variance in this type of problems.

The Relationship	Correlation Coefficient (Pearson's (r))	Result of The Significance Test (One-Tailed P-Value)
The Number of Shutdown Maintenance Activities – The Safety Problems That Are Associated With The Change in This Number	-0.858	0.000
The Number of Shutdown Maintenance Activities – The Operational Problems That Are Associated With The Change in This Number	-0.899	0.000
The Number of Shutdown Maintenance Activities – The Economical Problems That Are Associated With The Change in This Number	-0.890	0.000

Table 6.28 The Correlation Coefficients and The Results of The Significant Tests of The Relationships Between The Number of Shutdown Maintenance Activities and The Problems That Are Associated With The Change in This Number

Criterion	Predictors	Standardised Regression Coefficients	R^2	$(1-R^2)$
Safety Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities	Number of Shutdown Maintenance Activities	-0.858*	0.737	0.263
Operational Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities	Number of Shutdown Maintenance Activities	-0.899*	0.808	0.192
Economical Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities	Number of Shutdown Maintenance Activities	-0.890*	0.792	0.208

Note: (*) means the effect is significant and the significant level is $P < 0.05$

Table 6.29 The Results of The Regression Analysis of The Relationships Between The Number of Shutdown Maintenance Activities and The Problems That Are Associated With The Change in This Number

6.4 THE GENERAL DISCUSSION OF THE DATA ANLYSIS RESULTS:

The results of the data analysis of this stage (the investigation process) can be divided into two categories according to the information revealed about the relationships of interest and the variables that constitute these relationships. The first category among these two types is the results of the descriptive statistical analysis, which revealed information about the sample demographic characteristics and the changes in the variables that constitute the relationships of interest. This category showed how well the investigation process survey sample represents the population. In particular, they showed that the sample of this study has covered a wide range of continuous process plants in Saudi Arabia. This has been shown by the frequencies of different groups of plants that have different sizes, ages, and locations and that are belonged to different industrial sectors.

In addition, this category showed and described the changes in the variables that constitute the relationships of interest. In this matter, they showed that these changes in these variables are indicators of the efforts that have been done by the plants to improve the way of dealing with these variables which in turn improve these plants performance of carrying out the shutdown maintenance programme. This has been shown by the mean scores of the rates of change in these variables. Also, these results showed how the variation in the rates of change of these variables describe the variation in the maintenance management efforts to control these variables and obtain the improvement in the performance of carrying out the shutdown maintenance programme. In particular, they showed how similar the different maintenance mangers' efforts are when the rates of change of these variables are close to the mean scores and how different these managers' efforts are when the rates of change of these variables are far from the mean scores. This has been shown by the variance scores of the rates of change in these variables.

The second category of the results of the data analysis is the results of inferential statistical analysis, which revealed additional useful and important information. This information is about the relationships of interest and it was revealed by several interesting findings of the analysis process of these relationships. The description of these findings and the important points of information that were extracted from these findings are discussed in the following two subsections.

6.4.1 The Findings of The Analysis of The Relationships of Interest:

From the analysis of the relationships of interest, it has been found that the number of shutdown maintenance activities represents the major variable that affects the shutdown maintenance cost, which is one of the three important dependent variables in these relationships. In particular, it has been found that among the six independent variables that affect the shutdown maintenance cost, the number of shutdown maintenance activities has the largest positive and significant effect.

Also, from the same analysis, it has been found that the loss in the production that occurs as a result of performing shutdown maintenance which is the second variable out of the three important dependent variables in these relationships was affected by the number of shutdown maintenance activities together with five other variables. The effect of each one of these variables on the loss of production that occurs as a result of performing shutdown maintenance was positive and significant effect. However, the largest effect among the effects of these variables on the loss of production was also belonged to the number of shutdown maintenance activities.

In addition to this, the third and the last important dependent variable in these relationships of interest, which is the frequency of shutdown maintenance, was found to be significantly affected by two variables. One of these variables was the number of shutdown maintenance activities, which has almost a large positive and significant effect on the shutdown maintenance frequency (number of the times of performing shutdown maintenance program in a certain period of time).

All of these results show that all of the dependent variables in these relationships of interest were positively and significantly affected by the number of shutdown maintenance activities. In addition, two of these variables were largely affected by the number of shutdown maintenance activities. This means that a decrease (increase) in the number of shutdown maintenance activities decreases (increases) the cost of shutdown maintenance, the frequency of shutdown maintenance and the loss of production that occurs as a result of performing shutdown maintenance. However, and as shown in the analysis, the decrease (increase) in the number of shutdown maintenance activities increases (decreases) the safety, the operational and the economic problems that are associated with the change in the number of shutdown maintenance activities during normal operation since the number of shutdown maintenance activities has a large negative and significant effect on each type of these problems.

6.4.2 The Overall Findings:

In addition to all of the above results and findings, several important points of information were revealed from the analysis process. One of these points was that the effect of the unavailability of the shutdown maintenance resources and the effect of the inaccuracy of scheduling shutdown maintenance activities on the cost of shutdown maintenance and on the loss of production were found to be small positive effects and they were not negligible as it has been found in the results of this thesis interviews in chapter four. Also, the effect of the timing of shutdown maintenance on the loss of production was almost equal to the effect of the number of shutdown maintenance activities, which makes this variable one of the major variables that affect the loss of production.

However, the most important results and findings of the analysis process were those that are related to the relationships between the number of shutdown maintenance activities and the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that occurs as a result of performing shutdown maintenance. These findings and results are similar to the findings that were found in the interviews and the findings that were extracted from the literature review. All of these findings and results show that the reduction (increase) in the number of shutdown maintenance activities strongly contributes to the reduction (increase) of these variables. In particular, they show that the number of shutdown maintenance activities is the major variable that affects the shutdown maintenance cost and frequency and the loss in production that occurs as a result of performing shutdown maintenance. This agreement between all of these sources of information supports the claim of this thesis that has been mentioned in chapter three and which stated that the real reduction of the shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance which makes huge increase in the net savings of the profit is achieved by a systematic reduction of the scope of work of shutdown maintenance (number of shutdown maintenance activities).

In conclusion, what has been found from the results and discussed in this section forms the base for the development of a model to reduce the shutdown maintenance cost and frequency and the loss in production that is caused by shutdown maintenance whilst maintaining the purpose of shutdown maintenance and without creating any operational, safety, or economic problem.

6.5 SUMMARY:

In this chapter, the discussion was based on the analysis of the data that has been collected by the mail questionnaire of the investigation process survey. The aim of this analysis was to evaluate the relationship between the number of shutdown maintenance activities and the shutdown maintenance cost and between the number of shutdown maintenance activities and the frequency of shutdown maintenance, in addition to, the relationship between the number of shutdown maintenance activities and the loss in production. This analysis was carried out through the use of several statistical techniques. The end results of this analysis were a complete evaluation of the above mentioned relationships of interest and a comprehensive description of the variables that constitute these relationships. All of these results were found to be important supports for the aim of investigation process (the first stage of this thesis).

In the next chapter, the development of a model that is based on the results of the investigation process (the results obtained above in this chapter) with the purpose of reducing the shutdown maintenance cost and frequency and the loss in production that occurs as a result of performing shutdown maintenance will be discussed. The discussion in the next chapter will include an explanation of several model development issues, in addition to, the description of the model structure.

CHAPTER 7

THE MODEL OF ASSESSING THE SCOPE OF SHUTDOWN MAINTENANCE WORK

7

7.1 INTRODUCTION:

After the completion of the first stage of this thesis research methodology in which the importance of the scope of work of shutdown maintenance (number of shutdown maintenance activities) as a major variable that affects the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production has been verified, the second stage was ready to be carried out. The purpose of the second stage of the research methodology was to create a model that applies the above mentioned result of the first stage in order to reduce the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by shutdown maintenance without increasing the number of the unplanned shutdowns or creating interruptions to the production line.

The creation process of the proposed model that has been used was based on the reduction of the number of shutdown maintenance activities. The reason for using the reduction in the number of these activities as a base for this model was because the reduction in this variable greatly contributes to the reduction of the shutdown maintenance cost, shutdown maintenance frequency and the loss of production that is caused by shutdown maintenance as shown in the discussion at the end of the first stage of the research methodology.

In this chapter, the discussion will be mainly about this creation process of the proposed model. Discussing in particular subjects that are related to this process such as the type of the proposed model, the modelling method or methods that will be used to develop the structure of proposed model, the description of the structure of the proposed model and the general and specific characteristics of the model.

7.2 GENERAL CHARACTERISTICS OF THE SHUTDOWN MAINTENANCE SCOPE OF WORK ASSESSMENT MODEL (SMWAM):

The determination of the general characteristics of the shutdown maintenance scope of work assessment model is an important step toward the creation of this proposed model. The reason behind this is that the determination of these characteristics will reveal very important model aspects such as the purpose, the type and the use of the model, which helps in building the model structure. However, before starting to describe the general characteristics of the shutdown maintenance scope of work assessment model, a separate subsection will be provided to discuss the general definition of a model in order to illustrates its meaning.

7.2.1 Model Definition:

There are many definitions that illustrate the meaning of model. Some of these definitions are simple such as the one that has been driven by Cooke and Slack (1991) in which they stated that:

> a model is an explicit statement of our image of reality. It is a representation of the relevant aspects of the decision with which we are concerned.

Others are more explicit and have more detail about the function of the model such as the one, which has been derived by Austin and Ghandforoush (1993), in which they define the model as a reflection of the structure of the system to be represented and as:

> a description and explanation of the relationship of the parts of the problem to one another or of the problem to its environment.

These definitions as they appear are simple, however, they ignore very important model issues such as why the model is being built, which part of reality is being represented and for whom the model is being built. These issues have been recognised by some other writers in this field and they added them to their definitions in order to reach a complete definition for a model. One of these writers was Pidd (1996) who define model as:

an external and explicit representation of part of reality as seen by the people who wish to use that model to understand, to change, to manage and to control that part of reality.

In this stage of the thesis, the proposed model will represent the reality of the shutdown maintenance cost, frequency and the loss in production that is caused by the shutdown maintenance in order to better understand, change, manage and control this reality.

7.2.2 The Purpose of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

The purpose of the shutdown maintenance scope of work assessment model (SMWAM) is to reduce the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by shutdown maintenance through proper assessment of the shutdown maintenance scope of work. In addition, the model should maintain or reduce the number of the unplanned shutdowns.

The proposed way to accomplish this purpose is through transferring some activities from the list of shutdown maintenance activities to other maintenance programmes list of activities. The result of doing this way is a reduction in the number of shutdown maintenance activities to be performed which means a reduction in the amount of shutdown maintenance work, cost, frequency and the loss of production that is caused by shutdown maintenance. At the same time, the expected increase in the number of the unplanned shutdowns as a result of leaving out these transferred activities without being performed will be avoided since these activities will be performed through other maintenance programmes.

However, arbitrary selection of those shutdown maintenance activities that will be transferred could cause several problems. These problems are:

1. Increasing the overall maintenance cost because in some cases the cost of performing those transferred activities in another maintenance programme is much higher than the cost of performing them in the shutdown maintenance.
2. Creating safety problems since some of those transferred activities need safety precautions, which can only be applicable, when the plant is in a complete shutdown situation.

3. Creating operation problems because working with some of those transferred activities while the plant is running (not in shutdown situation) could cause full or partial unplanned shutdown or reduce the quality of the final product.

The way to avoid such problems is by performing the selection process of the maintenance activities to be transferred in a systematic way. This means that the selection process should consider the above three types of problems as the important and critical factors that affect the selection of those activities to be transferred. The reason for considering these types of problems in this process was because they are the factors that have been determined by the participants in the interviews and in the main survey of the first stage of this thesis research methodology as the important factors that affect the criticality of these types of maintenance activities.

7.2.3 The Type of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

The way to determine the type of shutdown maintenance scope of work assessment model is by investigating the different classifications of models. The reason behind this is that there is no single and unique classification for models. In other words, the way of determining the type of the SMWAM model is based on the fact that models could be classified in a variety of ways according to different criteria (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994).

One of these ways is the one where models are classified according to their purpose. In this way of classifying models, the consideration of the uses for which models will be built represents the base for the classification process (Austin and Ghandforoush, 1993; Jennings and Wattam, 1994). This means that models could be classified as planning models, forecasting models, training models, behavioural models, or some combination (Austin and Ghandforoush, 1993; Jennings and Wattam, 1994).

Another way of classifying models is when models are classified according to the degree of abstraction (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994). Models classified in this way fall into one of two categories. These categories are the isomorphic models and the homomorphic models (Austin and Ghandforoush, 1993). The isomorphic models are those in which every component in the real world system has a corresponding component in the model (Austin and Ghandforoush, 1993). On the other hand, homomorphic models are those in which each component in the model may represent many components in the real world system (Austin and Ghandforoush, 1993).

In addition to these ways of classification, models could also be classified according to perspective (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994). In this way, models may fall into one of two basic categories. These are the descriptive models category and prescriptive models category (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994). The descriptive models category represents those models that try to describe an existing situation, as it actually is (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994). Prescriptive models, on the other hand, represent those models, which attempt to describe an existing situation, as it ideally should be (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994).

Moreover, classification of models could be performed by considering the model content as the base for the classification process (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994; Taha, 1987). Classifying models in this way creates four categories of models. One of these categories is the mental models (Austin and Ghandforoush, 1993). These models represent the basis for all human behaviour (Austin and Ghandforoush, 1993). However, they are simple and weak, since human mental faculties are limited in such a way that there is a limit to the number of factors, humans can consider simultaneously (Austin and Ghandforoush, 1993). The next category in this classification is the physical models in which the real world system is represented by a three dimensional replica (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994; Taha, 1987). This type of models is being used by scientists, engineers and architects in order to test the characteristics of the real world system (Austin and Ghandforoush, 1993). The third category in this classification is the verbal models (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994). These models describe what the observer perceives and they are well known in the areas of business, economics, sociology, psychology, political science and history (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994). The last category of these four categories is the management science models (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994; Taha, 1987). A management science model is a quantitative representation of the real world system that includes those components relevant to the problem at hand (Austin and

Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994; Taha, 1987). It is a model that encompasses quantitative, mathematical, or graphic forms (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994; Taha, 1987). It has been used to influence, formalise, and concretise the mental model in order to make a better decision aid than using the mental models alone (Austin and Ghandforoush, 1993).

The above investigation of the different classifications of models indicates that the shutdown maintenance scope of work assessment model could be classified in different ways. It could be classified as a planning and a decision making model since its purpose is to reduce the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production through proper assessment of the shutdown maintenance scope of work. In addition, it could be classified as a mental and management science model since it uses quantitative and graphical forms in order to represent the assessment process of the shutdown maintenance scope of work which in turn will help in making mental decisions. Also, it could be classified as a prescriptive model in the sense that it will suggest important additions to the existing technique of shutdown maintenance assessment. At the same time, it will act as a descriptive model since it aims to portray the selection process of the activities to be transferred and the effects of the critical factors, which are related to the safety, operational, and economic issues on this process. Finally, this model could be classified as a sort of homomorphic model in the sense that it includes only those components, which are relevant to the problem.

7.2.4 The Use of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

Models, in general, can be used to aid decisions in many ways and at all stages in the decision process since they form a link between the intuitive and the rational (Cooke and Slack, 1991; Pidd, 1996). They can be of assistance to enhance the better understanding of the problem, to stimulate creativity in the search for possible solutions to the problem and to evaluate alternative courses of action (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994; Pidd, 1996; Taha, 1987). In addition, they can be used as a simplification of certain aspects of the real world in order to clarify those complex areas within the problem at hand

and to ensure a close examination of those parts of the system that may prove contentious, or those parts where an improvement in existing working is required (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Jennings and Wattam, 1994; Pidd, 1996; Taha, 1987).

Models and their users form a system that can help to examine the possible consequences of the proposed options or actions (Jennings and Wattam, 1994; Pidd, 1996). In other words, the compression of a system into model form allows information to be passed, assessed and quantified, so that the ideas and beliefs contained within the model can be altered or modified without exposing the real world system to cost, danger or to consume its valuable time (Jennings and Wattam, 1994; Pidd, 1996). This means that models can also be useful when the replication of the experimentation is needed (Jennings and Wattam, 1994; Pidd, 1996).

In this thesis, the shutdown maintenance scope of work assessment model is used to be of assistance in:

1. Enhancing the understanding of the importance of the reduction of the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production through the proper assessment of the scope of work of shutdown maintenance.
2. Stimulating creativity in the search for possible solutions to assess the proper shutdown maintenance scope of work that would end up with a reduction in the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production that is caused by shutdown maintenance.
3. Evaluating the alternative courses of action that could lead to the proper scope of work of shutdown maintenance that would end up with a reduction in the shutdown maintenance cost, shutdown maintenance frequency and the loss of production that is caused by shutdown maintenance.
4. Simplifying the assessment process of the shutdown maintenance scope of work in such a way that the selection process of those activities to be included in the shutdown maintenance and those to be transferred to other maintenance programmes becomes clear and easy to understand.
5. Examining the possible consequences of the different courses of action without exposing the continuous process plants to cost, danger or to consume their valuable time.

7.3 THE MODELLING METHOD FOR DEVELOPING THE STRUCTURE OF THE SHUTDOWN MAINTENANCE SCOPE OF WORK ASSESSMENT MODEL (SMWAM):

There are several methods for developing model structures. These methods could be classified into two categories. The first category represents the methods, which are based on the soft (interpretative) approach to solve problems. These methods are used when the problem at hand is ill-defined (Jennings and Wattam, 1994; Pidd, 1996). In other words, the definition of the problem is not straightforward because of the complexity of the problem (Jennings and Wattam, 1994; Pidd, 1996). In this case, the definition of the problem emerges through debate and discussion (Jennings and Wattam, 1994; Pidd, 1996). In addition, the solution to the problem will be a process of improvement that allows those involved to share their perceptions and to engage in a debate from which agreed proposals for improvement will emerge and be implemented (Jennings and Wattam, 1994; Pidd, 1996). The aim of these methods is to gain improvement to the system through a multistage process of information gathering, description, analysis, and debate (Jennings and Wattam, 1994; Pidd, 1996).
The other category represents the hard approach methods. These methods are used when the problem is well defined which means that the definition of the problem at hand is straightforward (Jennings and Wattam, 1994; Pidd, 1996). In addition, the solution to the problem in these methods will be a definite product or a set of recommendations that has been achieved through proper representation of that part of the real world which is related to the problem at hand (Jennings and Wattam, 1994; Pidd, 1996). The aim of these methods is to reach this definite product or set of recommendations (Jennings and Wattam, 1994; Pidd, 1996).
Since the problem of this thesis which is the reduction of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in the production through the proper assessment of the scope of work of shutdown maintenance was well defined in previous chapters, one or more of the hard approach methods will be used to build the structure of the model that will solve this problem. The types of these methods and the selected method or methods that will be used to develop the structure of the proposed model will be discussed in the next two subsections.

7.3.1 Types of Modelling Methods:

There are different types of the hard approach modelling methods. These types could be categorised into four main groups according to their analytical characteristics (Andriole, 1989). The first group represents the decision analytic methods (Andriole, 1989). These methods unite subjective judgement with selected models of problem structuring and information processing (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). They summarise the decision problem in a manner that allows systematic identification and evaluation of all decision alternatives of the problem in order to reach the decision by selecting the alternative that is judged to be the best among all available options (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). Also, they involve the identification of alternative choices, the assignment of values for outcomes, and the probabilities of the events leading to them if applicable (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987).

In addition, these methods are used when the problem is unstructured and little verifiable data has been quantified (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). They are intuitively appealing to the users because their models are more compatible with the way many people solve problems. In other words, it is relatively easy to understand the divide-and-conquer decision analytic strategy compared to the mathematics that drives the models (Andriole, 1989; Pidd, 1996). These methods provide a great deal of structure and flexibility since they permit users to not only change the value of input data but to alter the problem-solving logic (Andriole, 1989; Pidd, 1996). In addition, the sensitivity analysis permitted by these methods and techniques is theoretically unbounded by an initial set of conditions (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). In terms of transparency and safety, the results of the decision analysis in these methods are often very easy to trace (Andriole, 1989; Pidd, 1996).

The other group of the hard approach methods represents the operations research methods (Andriole, 1989; Pidd, 1996). These methods are quantitative-empirical and data-based type of methods (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). They solve those kinds of problems that require the specification, measurement and projection of relationships among variables (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). The key distinction between these methods and decision analytic methods lies in the formalisation of the models and the nature of the data used to exercise the models (Andriole, 1989; Pidd, 1996). In other words, the models in the decision analytic methods are graphic and well structured, though not susceptible to easy mathematical conversion while operations research models are highly structured and frequently mathematical (Andriole, 1989; Pidd, 1996). In addition, decision analytic data is frequently subjective whereas the data that drives the operations research models is nearly always quantitative-empirical (Andriole, 1989; Pidd, 1996).

Moreover, these methods are used when large amount of data exists and when the problem at hand lends itself to its application (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). In addition, they are easy to be applied; however, some times their concepts are difficult to be understood by the users because they are based on a mathematical background (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). In terms of structure and flexibility, operations research methods provide a great deal of both because of the same reason that has been mentioned in the discussion about the decision analytic methods (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987). The problem of these methods is that some times the result of their analyses can be difficult to interpret and they do not provide clear audit trails (Andriole, 1989; Pidd, 1996). In addition, these methods cannot be used to model some of those decision problems that usually include important intangible factors which cannot be translated directly in terms of the mathematical model (Andriole, 1989; Austin and Ghandforoush, 1997; Pidd, 1996; Taha, 1987).

The third group in this classification of the hard approach methods represents the artificial intelligence methods (Andriole, 1989; Sauter, 1997). These methods actively interact with and adapt to their users (Andriole, 1989; Sauter, 1997). They solve problems through making inferences and implementing rules of thumb (Andriole, 1989; Sauter, 1997). They do that through storing and applying knowledge to a variety of unspecified problems within selected problem domains (Andriole, 1989; Sauter, 1997). These methods are similar to the decision analytic methods in that they are used when the problem is unstructured and little verifiable data has been quantified (Andriole, 1989; Sauter, 1997). In addition, they are similar to the decision analytic methods in that they are intuitively appealing to users because their models are more compatible with the way many people solve problems (Andriole, 1989;

Sauter, 1997). However, they are at times relatively inflexible since they rely upon sets of specific rules, frames, scripts, or some hybrid knowledge representation technique (Andriole, 1989; Sauter, 1997). In addition, knowledge based sensitivity analysis in these methods is bounded by the initial set of conditions for which knowledge exists (Andriole, 1989; Sauter, 1997). In terms of transparency and safety, these methods provide clear audit trails (Andriole, 1989; Sauter, 1997). In other words, in these methods, it is possible to ask the system for the knowledge used to reach a certain conclusion (Andriole, 1989; Sauter, 1997).

The last main group of the hard approach methods represents the management science methods (Andriole, 1989). These methods include all those methods targeted at projects such as programme scheduling, monitoring, and management (Andriole, 1989). They are similar to the operations research methods in that they are used when a large amount of data exists and when the problem at hand lends itself to its application (Andriole, 1989; Winston and Albright, 1997). They are also like the operations research methods in that their concepts are difficult to understand by users because they are based on mathematical background (Andriole, 1989). In terms of structure and flexibility, the management science methods provide a great deal of both because of the same reason that has been mentioned in the discussion about the decision analytic and the operations research methods (Andriole, 1989; Winston and Albright, 1997). The problem of these methods is that some times the results of their analysis can be difficult to interpret and they do not provide clear audit trails (Andriole, 1989).

Among these groups of methods, the group of methods that will be used in this thesis in order to build the structure of the shutdown maintenance scope of work assessment model is the decision analytic methods. The reason behind this is that the shutdown maintenance scope of work assessment model is based on the subjective judgement by which the selection of the maintenance activities from the shutdown maintenance list that needs to be transferred to other maintenance programmes and those that needs to remain in the list are executed according to critical factors that are related to the safety, the operational and economic issues. In addition, by using these methods a great deal of structure and flexibility will be provided. Moreover, these methods will provide transparency, safety and clear audit trails which means that it will be very easy to trace the results of the decision analysis if it is needed.

7.3.2 The Selected Modelling Method for Developing The Structure of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

As mentioned in the previous subsection, the selected group of methods for developing the structure of the proposed model is the one, which represents the decision analytic (making) methods. However, these methods are classified into different types according to two main approaches.

The first approach is the one, which classifies these methods according to the availability of the information about the problem at hand (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). Classifying these methods by using this approach creates three main types of methods. The first type of these methods represents the decision-making methods under the condition of certainty (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). This type assumes the availability of perfect information about the problem at hand that will be used to formulate and solve the decision model (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). In other words, any variation which is possible will not affect the consequences of choosing a particular option that could solve the problem because only one state of nature is possible for the uncontrollable factors (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). This means that the decision by using these methods is judged to be insensitive to any uncontrollable factors present (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987).

The second type of methods in this classification represents the decision-making methods under the condition of risk (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). The methods of this type assume the availability of partially perfect information about the states of nature of the uncontrollable factors (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). However, they deal with the shortages in this information by expressing the likelihood of the occurrence of these states of nature in terms of a probability density function (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). In other words, the information about the problem at hand that will be used to formulate and solve the decision model in these methods is completed by expressing the states of nature in a probabilistic manner (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). This means that the decision in these methods is sensitive to the changes in the uncontrollable factors (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987).

The last type of these methods in this classification is the decision-making methods under the condition of uncertainty (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). These methods assume imperfect information about the problem at hand which means that not only the consequences of a decision cannot be predicted, but further there is little confidence in the information of either the states of nature that are possible, or the likelihood of their occurrence (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987). In addition to this, it can also mean that there are multiple objectives that must be considered or that a problem is so complex that the hope is only to be able to understand its basic underlying structure (Austin and Ghandforoush, 1993). In other words, there is a complete absence of probabilistic information about the environment (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Taha, 1987).

The other approach of classifying the decision analytic (making) methods is the one, which classifies them according to the number of criteria against which the alternative courses of action are evaluated. The result of classifying these methods by using this approach of classification is two main types of methods. The first type of these methods represents the single criterion decision-making methods (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Goicoechea, Hasen and Ducksten, 1982). These methods are used when the modelling process of a problem is focused on a single objective that is needed to be optimised (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Goicoechea, Hasen and Ducksten, 1982). The other type of methods in this classification represents the multicriterion decision making methods which are used when the number of objectives in the problem that are needed to be focused on is more than one (Austin and Ghandforoush, 1993; Cooke and Slack, 1991; Goicoechea, Hasen and Ducksten, 1982). This type is further classified into two sub-types. These are the continuous and the discrete methods (Goicoechea, Hasen and Ducksten, 1982). The continuous methods are those which are used when a choice situation involves an infinite number of possible alternatives, whereas, the discrete methods are used when there is finite number of alternatives to choose from that has been evaluated on a common set of criteria (Goicoechea, Hasen and Ducksten, 1982).

In this thesis, the type of decision analytic methods that will be used is the discrete multicriterion (multiobjective) decision methods. The reason behind this is that the problem at hand has three main criteria representing the critical factors which are related to the safety, operational and economic issues and it has a finite number of alternatives representing the maintenance activities that are nominated to be performed by the shutdown maintenance programme. Among these methods, the separate preference elimination method (Exclusionary screening) which treats each criterion separately and uses preference scales for each criterion to exclude or eliminate certain options will be selected to develop the structure of the proposed model. The reason behind selecting this method is that it does not depend on the pairwise comparisons between the alternatives and between the criteria and it can easily deal with critical factors. This makes the method suitable for modelling the problem at hand since the criteria and the alternatives in the problem are critical and equally important which means that they are not vulnerable to pairwise comparisons techniques.

In addition to this method, the decision tree which shows the logical progression that occurs over time in terms of decisions and outcomes will be used in the structure of the SMWAM model (Austin and Ghandforoush, 1993; Goodwin and Wright, 1991; Wisniewski, 1997). Using the tree, for visual impact will help the proposed model to structure the problem sequentially by picturing explicitly the precedence relations, which could not easily be shown in tabular form. In other words, the tree will help the model to develop a clear view of the structure of the problem and make it easier to determine the possible scenarios, which can result if a particular course of action is chosen. In addition, it can also help to judge the nature of the information, which needs to be gathered in order to tackle the problem, and, since it is generally easy to understand, the tree can be used in the structure of the model as an excellent medium for communication.

7.4 DEVELOPING THE STRUCTURE OF THE SHUTDOWN MAINTENANCE SCOPE OF WORK ASSESSMENT MODEL (SMWAM):

The way to develop the structure of the SMWAM model is based on using the decision making method selected in the previous section in order to frame the selection process of the shutdown maintenance activities to be transferred from the shutdown maintenance programme to other in-process maintenance programmes and the critical factors that affect this process. In particular, it is based on using the selected method to build a structure for the SMWAM model that is able to carry out the evaluation of the shutdown maintenance activities by which the determination of the activities that will remain in the shutdown maintenance programme and those that will not could easily be achieved. However, before starting to describe the developed structure of the SMWAM model, a separate subsection will be provided to discuss the elements of the SMWAM model and their role in this structure.

7.4.1 Elements of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

Shutdown maintenance scope of work assessment model (SMWAM) has three main elements. These elements are very important and represent the keystones for the selection process of the shutdown maintenance activities to be transferred (the evaluation process of shutdown maintenance activities).

The first element among the SMWAM model elements represents the decision options (alternatives) which are the shutdown maintenance activities between which nothing, one or a set of activities must be chosen to be transferred to other in-process maintenance programme. These alternatives (shutdown maintenance activities) will be evaluated (tested) against the three main factors that affect the selection process and which are related to the safety, operational and economic issues.

The second element of the SMWAM model represents the above-mentioned three main factors. These factors have been identified by the participants (industrial maintenance mangers and the shutdown maintenance planner) of the interviews and the main survey of the first stage of this thesis research methodology as critical factors. This, as it has been mentioned by Austin and Ghandforoush (1993) in the definition and description of the critical factor in the multicriterion decision model, means that if a shutdown maintenance activity does not meet the requirements of any one of these factors, it will be automatically eliminated from further consideration at the very beginning of the evaluation process, regardless of all other conditions that might exist. In particular, it means that failing to satisfy the requirements of any one of these factors during the evaluation of a certain shutdown maintenance activity will indicate that this activity is either a safety, operationally or costly critical which will preclude the selection of it for transition to other in-process maintenance programmes at the very beginning of the evaluation process, regardless of all other conditions that might exist. By safety, operationally or costly critical activity, it has been meant that this activity will create safety, operationally or economically problems if it will be performed by other in-process maintenance programmes.

The result of evaluating the shutdown maintenance activities against the three main critical factors will be a set of consequences, which represent the third element of the SMWAM model. Each one of these consequences could be represented by any one of the following:

1. The evaluated shutdown maintenance activity is a safety critical activity and it should not be transferred to other in-process maintenance programmes since it will cause harm or danger to the outside environment or to the workplace when they are performed by other in-process maintenance programmes.
2. The evaluated shutdown maintenance activity is an operationally critical activity and it should not be transferred to other in-process maintenance programmes since it will cause partial or full unplanned shutdowns or reduce the quality of the final product when they are performed by other in-process maintenance programmes.
3. The evaluated shutdown maintenance activity is a costly critical activity and it should not be transferred to other in-process maintenance programmes since the cost of performing this activity by other in-process maintenance programmes is greater than performing it in the shutdown maintenance which will cause an increase in the overall maintenance cost.
4. The evaluated shutdown maintenance activity is a non-critical activity and it should be transferred to other in-process maintenance programmes since it will not cause any safety or operational problems and will not increase the overall maintenance cost.

7.4.2 The Structure of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

The best way to describe the structure of this model is by means of explaining the following steps, which are illustrated in the logical decision tree in figure 7.1.

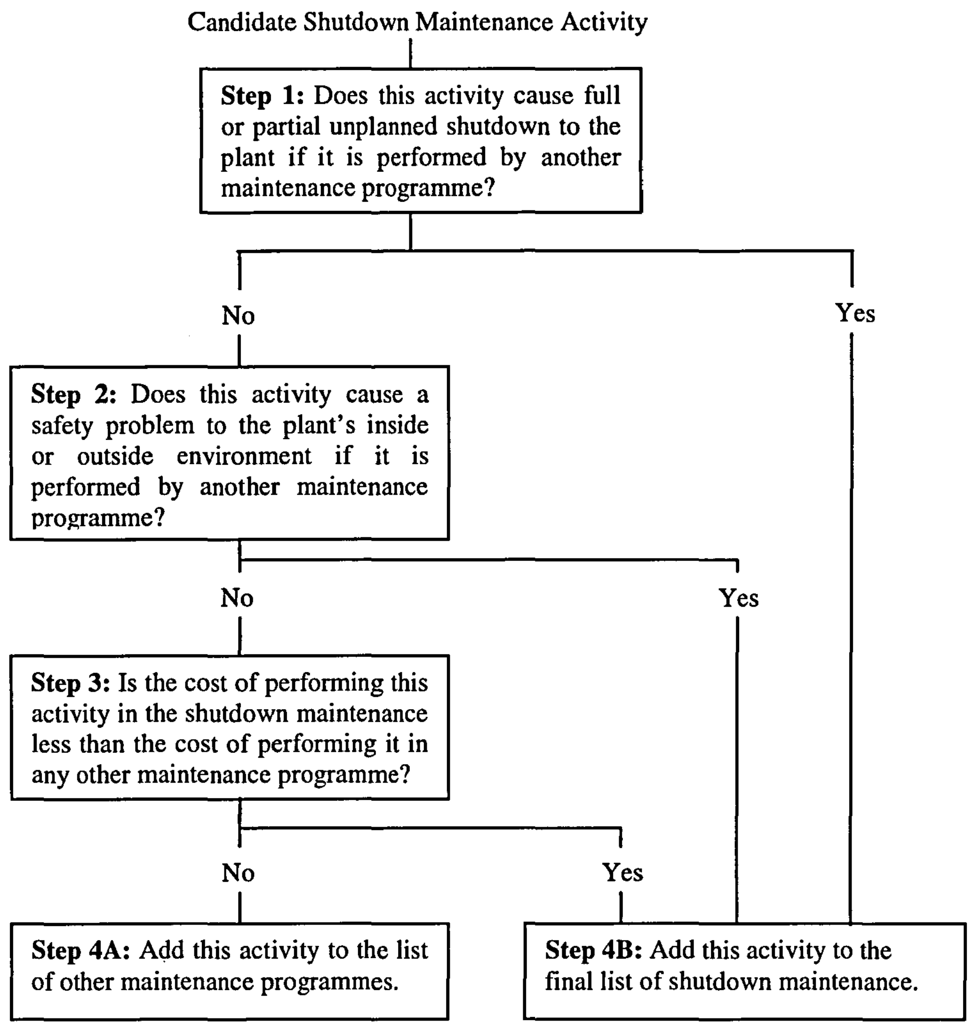

Figure 7.1 The Structure of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM)

Step 1: Evaluating the inclusion of the nominated maintenance activities for shutdown maintenance into the shutdown maintenance list according to the operational issues:

This step of the model starts after receiving the work request forms that are related to the shutdown maintenance from each unit and department and after the completion of the initial candidate list of shutdown maintenance activities. It starts first by making each activity in the above-mentioned list passes through the questions that are related to the operational issues in order to evaluate its inclusion in the list of shutdown maintenance activities. In general, in this step two main questions are asked. These questions are:

1. If this activity is performed by another in-process maintenance programme, does it cause full shutdown to the plant?
2. If this activity is performed by another in-process maintenance programme, does it cause partial shutdown to the plant?

If the answer to any one of these questions is (Yes), then the evaluated activity will be included in the final list of the shutdown maintenance activities. Otherwise, it will be moved to the next step for further evaluation.

These two general questions were used to represent the important issues about the plant operation; however, there could be more than these two issues depending on how the plant operation is defined. In addition, in the second question of this evaluation, there is no specific percentage figure that illustrates the concerned level of the partial shutdown maintenance. This also depends on how the word partial is being defined by the people in the plant where the model is being applied.

The way to perform and facilitate the above evaluation is by using a special table that will summarise the results of the evaluation and which will serve as a documentation tool for these results. A sample of this table is illustrated by table 7.1.

In this special table, there is a space available in the centre for writing questions related to the plant operation issues. In the general case mentioned above, the two questions, which have been mentioned, have filled this space. Below this space, there are three main columns. The first column on the left-hand side is for listing the activities. Following this column is the column that is dedicated to the answers of the questions. This column is further subdivided into several columns according to the number of questions. Each one of these columns will be dedicated to register the answer of each question, which means that the number of these columns should match the number of questions. The last column in this table represents the result column where the results of analysing the answers in the preceding sub-columns are registered.

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)			
Step 1: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the operational issues.		**Date:**	
Plant:		**Plant ID:**	
Analysts:			
List of Issues 1. If the activity is performed by another in-process maintenance programme, does it cause full shutdown maintenance to the plant? 2. If the activity is performed by another in-process maintenance programme, does it cause partial shutdown to the plant?			
Activity	**Answers**		**The Result**
	Question #1	**Question #2**	

Table 7.1 The Evaluation Table For The First Step in The Structure of The SMWAM Model

The analysis process of the answers to the questions will be of two types. The first type is to analyse the answers logically by using the logic expressions such as (OR), (AND) or a combination of both. The second type is the one that analyses the answers arithmetically by using arithmetical operations. The choice of the analysis process type depends on the type of data (quantitative/qualitative (yes/no)) that is related to each issue and the relationship between the issues. In general, the arithmetical analysis is used when all the issues are measured by quantitative data and the logic analysis is used when all the issues are measured by qualitative data (yes/no) or when some of these issues are measured by quantitative data and the other some by qualitative data (yes/no). In the general case of table 7.1 above, the two operational issues are mutually exclusive and the data related to them is qualitative in nature, which facilitate the use of the logic expressions for the analysis of the answers to the questions that are related to these issues. The logic expression used in this case is the logic expression (OR) since at least one of these issues needs to be satisfied in order to include the evaluated maintenance activity in the shutdown maintenance list. This means that if the answer to any one of the questions is (Yes) then the result in the last column (the result column) is (Yes) and the evaluated maintenance activity is included in the shutdown maintenance list of activities. Otherwise, the result in the last column (the result column) is (No) and that particular maintenance activity moves to the next step for further evaluation.

In addition to the above mentioned spaces, the table has several other spaces dedicated to other information such as the analyst (analysts) name, the plant title and ID, the date of the evaluation, and the evaluation step title.

Step 2: Evaluating the inclusion of the remaining maintenance activities from the first step into the shutdown maintenance list according to the safety issues:

In this step, the remaining maintenance activities from the first step that are not included in the final list of the shutdown maintenance activities are evaluated according to the safety issues. This evaluation is carried out by examining each one of these maintenance activities against questions related to the safety issues. In general, the examination of these activities is against the following questions:

1. If this activity is performed by another in-process maintenance programme, does it cause any death or injury to the employees in the plant?

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 2: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the safety issues.	**Date:**
Plant:	**Plant ID:**
Analysts:	

List of Issues

1. If this activity is performed by another in-process maintenance programme, does it cause any death or injury to the employees in the plant?
2. If this activity is performed by another in-process maintenance programme, does it cause any death, injury or harm to the people out side the plant?
3. If this activity is performed by another in-process maintenance programme, does it cause any danger or damage to the physical workplace in the plant?
4. If this activity is performed by another in-process maintenance programme, does it cause any harm to the outside environment?

Activity	**Answers**				**The Result**
	Question #1	**Question #2**	**Question #3**	**Question #4**	

Table 7.2 The Evaluation Table For The Second Step in The Structure of The SMWAM Model

2. If this activity is performed by another in-process maintenance programme, does it cause any death, injury or harm to the people out side the plant?
3. If this activity is performed by another in-process maintenance programme, does it cause any danger or damage to the physical workplace in the plant?
4. If this activity is performed by another in-process maintenance programme, does it cause any harm to the outside environment?

If the answer to any one of these questions is (Yes), then the evaluated maintenance activity will be included in the final list of the shutdown maintenance activities. Otherwise, it will be moved to the next step for further evaluation.

These four questions were used to represent the general safety issues; however, there could be more than these issues depending on how plant safety is defined. In addition, a similar table and a similar analysis process to those that are used in the first step are also used in this step in order to facilitate the above evaluation and to summarise its results.

In the above general case of this step (table 7.2), the table used includes four questions related to safety issues and the answers to these questions are analysed logically by using the logic expression (OR) since at least one of these issues needs to be satisfied in order to include the evaluated maintenance activity in the shutdown maintenance list. This means that if the answer to any one of these questions is (Yes) then the result of the analysis which will be recorded in the last column is (Yes) which in turns means that the evaluated maintenance activity should be included in the shutdown maintenance list of activities. Otherwise, the result of the analysis that will be recorded in the last column is (No) and that particular maintenance activity should move to the next step for further evaluation. A sample of the table used in this step is illustrated by table 7.2.

Step 3: Evaluating the inclusion of the remaining maintenance activities from the Second step into the shutdown maintenance list according to the economic issues:

In this step, the nominated maintenance activities for shutdown maintenance that did not pass the evaluations of the first and second steps and which are not included in the final list of the shutdown maintenance activities will be evaluated according to economic issues. This evaluation will be done for each activity in the list of the remaining nominated maintenance activities by comparing the total cost of performing the activity in the shutdown maintenance programme with the total cost of performing it in any other maintenance programme. In both cases the total cost includes the direct maintenance cost (includes direct cost of materials, spare parts, labour, tools and equipment), the overhead cost (includes indirect cost of materials, spare parts, labour, tools and equipment and other expenses that are used for carrying out maintenance activities), the losses (includes the loss in production, loss of sales, and loss of quality) and any other cost elements. If the result of this comparison shows that the total cost of performing a particular maintenance activity in the shutdown maintenance programme is less than the total cost of performing the same activity in any other maintenance programme, then the evaluated activity will be included in the final list of the shutdown maintenance activities. Otherwise, it will be moved to the list of the maintenance programme where the total cost of performing this activity is less than the total cost of performing it in the shutdown maintenance.

The way to simplify the use of the above evaluation is through the use of a similar table to the one used in the first and second steps. However, each question in this table will be related to the total cost of performing a particular maintenance activity in each possible maintenance programme with one of these questions related to the total cost of performing the same activity in the shutdown maintenance. In addition, the evaluation in this table is based on finding the maximum saving (Yi) in the total cost of performing a maintenance activity (i). The way to achieve (Yi) is through searching for the maximum difference between the total cost of performing a maintenance activity (i) in the shutdown maintenance and the total cost of performing the same activity (k) in each possible maintenance programme (j). The mathematical equation that is used for the calculation of (Yi) is the following:

$$Yi = \max_{\text{all } j} (Xi - Zkj) \qquad i = 1,2,\ldots\ldots,m \quad j = 1,2,\ldots\ldots,n \quad k = 1,2,\ldots\ldots,pj \qquad (8.1)$$

Where:

Yi= The maximum saving in the total cost of performing the ith activity.

n = The total number of the maintenance programmes.

m = The total number of the remaining maintenance activities from the first and second steps.

pj = The total number of maintenance activities in the jth maintenance programme.

Xi= The total cost of performing ith activity in the shutdown maintenance programme.

Zkj= The total cost of performing kth activity in the jth maintenance programme.

The total cost (Xi) in equation (8.1) above includes the maintenance cost (Ci), the losses (Li) that are caused as a result of performing activity (i) in the shutdown maintenance and the other cost elements (OCi) that are associated with performing activity (i) in the shutdown maintenance. In other words, the total cost of performing activity (i) in the shutdown maintenance is equal to:

$$Xi = Ci + Li + OCi \qquad (8.2)$$

The maintenance cost (Ci) in this equation is equal to the summation of the direct maintenance cost (DCi), and the overhead cost (OVCi) that are associated with performing the ith activity in the shutdown maintenance. In particular, this maintenance cost (Ci) is equal to:

$$Ci = DCi + OVCi \qquad (8.3)$$

In addition, the losses (Li) in equation (8.2) represent different types of losses such as the loss of production (LPi), the loss of sales (LSi) and the loss of quality (LQi) that could happen as a result of performing activity (i) in the shutdown maintenance and it is expressed as follows:

$$Li = LPi + LSi + Lqi \qquad (8.4)$$

In addition to the total cost (Xi), the total cost (Zkj) also includes the maintenance cost (Ckj), the losses (Lkj) that are caused as a result of performing the kth activity in the jth maintenance programme and the other cost elements (OCkj) which are associated with performing maintenance activity (k) in maintenance programme (j). In other words, the total cost of performing activity (k) in the maintenance programme (j) is equal to:

$$Zkj = Ckj + Lkj + OCkj \qquad (8.5)$$

The maintenance cost (Ckj) in this equation is equal to the summation of the direct maintenance cost (DCkj), and the overhead cost (OVCkj) that are associated with performing the kth activity in the jth maintenance programme. In particular, this maintenance cost is equal to:

$$Ckj = DCkj + OVCkj \qquad (8.6)$$

In addition, the losses (Lkj) in equation (8.5) represent deferent types of losses such as the loss of production (LPkj), the loss of sales (LSkj) and the loss of quality (LQkj) that could happen as a result of performing the kth activity in the jth maintenance programme and it is expressed as follows:

$$Lkj = LPkj + LSkj + LQkj \qquad (8.7)$$

The result of this searching process (Yi) will be recorded in the last column of the table, which is further subdivided into two columns. One of these columns is dedicated to the result (Yi) and the other is dedicated to recording the best in-process maintenance programme in which the nominated shutdown maintenance activity (i) will be performed. This result (Yi) and its interpretation could be one of the following:

1. The result (Yi) is a negative figure, which means that the particular nominated shutdown maintenance activity, which this figure is belong to, should be included in the shutdown maintenance list of activities.
2. The result (Yi) is zero, which means that the particular nominated shutdown maintenance activity, which this figure is belong to, could be included in either the shutdown maintenance list or in the list of the in-process maintenance programme in which this activity has maintenance cost and loss of production that are similar to their counterpart in the shutdown maintenance.
3. The result (Yi) is positive, which means that the particular nominated shutdown maintenance activity, which this figure is belong to, should be included in the list of the in–process maintenance programme which has the lowest total maintenance cost and loss of production needed to perform this activity. A sample of this table is illustrated by table 7.3.

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 3: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the economic issues.	**Date:**
Plant:	**Plant ID:**
Analysts:	

List of Issues

1. What is the total cost of performing the activity in the shutdown maintenance programme?
2. What is the total cost of performing the activity in the *first alternative* maintenance programme?
3. What is the total cost of performing the activity in the *second alternative* maintenance programme?

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Activity	Answers						The Result	The Type of The Maintenance Programme
	Q #1	Q #2	Q #3	Q #4	....	....		

Table 7.3 The Evaluation Table For The Third Step in The Structure of The Model

Step 4: Preparing the final list of shutdown maintenance activities:

After the completion of the whole evaluation process by performing the last step, two lists of maintenance activities will be available. One of these lists is the final list of shutdown maintenance activities, which includes those maintenance activities that were confirmed to be shutdown maintenance activities and which have been successfully passed the evaluation process. In addition, it also includes the reasons behind the selection of these maintenance activities. These types of information are represented in this list by using a table that has two main columns. The first one of these columns is dedicated to recording those maintenance activities, which were confirmed to be shutdown maintenance activities. The second column is subdivided into three columns, each of which is dedicated to representing one of the following reasons for the inclusion of a particular maintenance activity in the list:

1. The maintenance activity at hand is an operationally critical activity.
2. The maintenance activity at hand is a safety critical activity.
3. The maintenance activity at hand is an economically critical activity.

The other list that will be available after the completion of the above mentioned evaluation process is the list of maintenance activities that are related to the other in-process maintenance programmes. This list includes those maintenance activities, which failed to pass the evaluation process, and which were not included in the list of shutdown maintenance activities. It also includes the suggested in-process maintenance programmes by which these maintenance activities will be performed. The way in which these types of information are represented is by using a table that consists of two columns. The first column is dedicated to recording each maintenance activity in the above mentioned list of activities and the second one is dedicated to recording the type of corresponding in-process maintenance programme to that particular maintenance activity. These two lists are illustrated in tables 7.4 and 7.5 respectively.

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)			
Step 4: The final list of the shutdown maintenance activities.		**Date:**	
Plant:		**Plant ID:**	
Analysts:			
Activity	**Operationally Critical**	**Safety Critical**	**Economically Critical**

Table 7.4 The Final List of Shutdown Maintenance Activities

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 4: The list of other maintenance programmes activities.	**Date:**
Plant:	**Plant ID:**
Analysts:	
Activity	**Recommended Maintenance Programme**

Table 7.5 The List of Other Maintenance Programmes Activities

7.5 THE SHUTDOWN MAINTENANCE SCOPE OF WORK ASSESSMENT MODEL (SMWAM) AND HOW IT IS USED:

7.5.1 How to Use The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

The need for the assessment of the scope of work of shutdown maintenance begins after the preliminary shutdown maintenance objectives and requirements are clearly defined by the management. The definition of these objectives and requirements is based on the work request forms that are received from each unit and department in the plant and which are related to the shutdown maintenance activities. At that time, a model such as the shutdown maintenance scope of work assessment model (SMWAM) is needed to achieve a proper assessment of the shutdown maintenance scope of work that will greatly contribute to the reduction of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by shutdown maintenance and that will maintain or reduce the number of unplanned shutdowns.

The optimum way to use the model starts with forming a shutdown maintenance scope of work assessment team. In this team, a representative from each discipline who can provide information on the plant operational, safety and maintenance economic issues such as the plant maintenance personnel, operations personnel, safety personnel, technical and service personnel, inspection personnel, shutdown maintenance planner and any other related personnel is included. The reason behind including such personal in this team is to gain maximum benefit from their experience in determining the plant operational, safety and maintenance economic issues (criteria), in addition to, the limits of these issues that will be used in the model evaluation process. In addition, the involvement of such people is necessary and recommended in order to gain their buy-in to the model.

In addition to the formation of the team, the members of the team are provided with several sources of information that can help them to carry out the evaluation process and to identify the different operational, safety and maintenance economic issues (criteria) and the limits of these issues. Some of these sources of information are the following:

1. Support financial data records and files which will provide information on the direct, and the overhead cost of the maintenance activities which in turn represents valuable details in the determination of the economic issues and their limits.
2. Shutdown maintenance records and files which will provide information on the time required to perform each shutdown maintenance activity which in turn helps in calculating the loss in production that is caused by performing each activity. In addition, these records and files help in the determination of the non-acceptable level of the partial shutdown maintenance and also in the determination of the economic issues and their limits.
3. Safety records, files and governmental and international safety regulations which will provide information on safety precautions that are needed to perform each maintenance activity and the level of the safety risk that is associated with failure to perform certain maintenance activities. This type of information will help in the determination of the safety issues and their limits.
4. System operation manuals, which provide information on how, the system to which the maintenance activity is related, is intended to function, how it relates to other systems and what operational limits are employed. This information will help in the determination of the operational issues and their limits.
5. Any other source of information; such as piping and instrumentation diagrams, process flow diagrams, the industry operational standards, the work order system, the cross sectional drawings, the equipment list and classification sheet and the rework shutdown maintenance jobs records; which the team identifies as important in the determination of the plant operational, safety and maintenance economic issues.

In general, the members of the team needs to know the following general guidelines in order to determine the plant operational, safety and maintenance economic issues and their limits and to carry out the evaluation process:

1. The definition of the operationally critical maintenance activity (this definition has been mentioned in chapter 1 in subsection 1.24).
2. The minimum acceptable production rate which will contribute in the determination of the acceptable and the non-acceptable levels of the partial shutdown maintenance.

3. The maximum acceptable loss of production which also will contribute to the determination of the acceptable and the non-acceptable levels of the partial shutdown maintenance.
4. The definition of the safety critical maintenance activity (this definition has also been mentioned in chapter 1 in subsection 1.24).
5. The maximum level of safety risk which will not violate the governmental and international safety regulations. This will contribute in the determination of the acceptable limits of the safety issues.
6. The definition of the costly critical maintenance activity (this definition has been mentioned in chapter 1 in subsection 1.24).
7. The direct and overhead costs of performing certain maintenance activity, which will help in determining the total cost of that maintenance activity when it is performed in any maintenance programme.
8. The loss in production as a result of performing certain maintenance activity represented in terms of a monetary figure, which will also help in determining the total cost of that activity when it is performed in any maintenance programme.
9. The plant processes and their inputs and outputs which will help to measure the exact effect of carrying out a maintenance activity on these processes while these processes are part of a running production line.
10. The information on how plant processes are connected which will help to measure the magnitude of the complete effect of carrying out a maintenance activity on these processes while the production line is running.
11. The types and the classifications (main or redundant) of plant machines and equipment which will help in determining the criticality of the maintenance activities that are being performed on them and the best maintenance programme that is used to carry out these activities.
12. The duration of performing each maintenance activities, which will help to measure the effect of carrying out anyone of these activities on the production rate, while the production line is running.
13. The plant production strategy which will help to know the maximum production rate that could be lost.
14. The dangerous points in the area to be maintained and their classification which will help to measure the exact effect of carrying out a maintenance activity while the production line is running on the safety of the maintained area.

15. The information on the maintenance materials and equipment that will be used which will help in determining the type of the required safety precautions and the possibility of applying them.
16. The information on how easy to reach the area to be maintained (equipment or machines) which will help in determining the safety issues.
17. The information on the outside environment safety, which will help to measure the exact effect of carrying out a maintenance activity on the safety of the outside environment while the production line is running.
18. The loss of the quality as a result of performing a maintenance activity represented in terms of a monetary figures which will also help in determining the total cost of that activity when it is performed in any maintenance programme.
19. The demand on the plant products which will help in calculating the loss of sales as a result of carrying out a maintenance activity.

After the completion of performing the shutdown maintenance scope of work assessment model (SMWAM), the final list of shutdown maintenance activities (final scope of shutdown maintenance work) and the final list of those activities which will be performed by other in-process maintenance programmes will be reviewed and approved by the management.

7.5.2 The Comparison Between The Conventional Way of Identifying The Scope of Work of Shutdown Maintenance and The Shutdown Maintenance Scope of Work Assessment Model (SMWAM):

The shutdown maintenance scope of work assessment model (SMWAM) and the present method of assessing the work of shutdown maintenance are similar in their aim since the aim of both of them is to achieve the proper assessment of the shutdown maintenance scope of work. However, there are several differences between these two approaches. These differences are summarised in the following table:

Features	SMWAM	The Conventional Way
The structure	The model has well defined structure, which is represented by four steps.	There is no specific structure. The shutdown maintenance activities are specified through the work request forms from the departments.
Flexibility	The model allows justifiable changes in the number of issues and the limits of these issues.	There is a total flexibility, which is not restricted by any justification.
Documentation	The model is well documented through the use of tables that include all necessary information and justifications regarding the inclusion of certain maintenance activity in the shutdown maintenance list.	The documentation is weak. Some times, it is represented by only a final list of shutdown maintenance activities.
The bases of selection process	The selection process is based on the issues related to the plant operation, safety and maintenance cost.	The base of the selection process is changing which some times causes some non-critical maintenance activities to be included in the shutdown maintenance list and in other times it causes some critical maintenance activities to be excluded from the shutdown maintenance list.

Table 7.6 The Comparison Between The Conventional Way of Identifying The Scope of Work of Shutdown Maintenance and The Shutdown Maintenance Scope of Work Assessment Model (SMWAM)

7.6 SPECIFIC CHARCTERISTICS OF THE SHUTDOWN MAINTENANCE SCOPE OF WORK ASSESSMENT MODEL (SMWAM):

The SMWAM model has several specific characteristics which make the model useful for reassessing the scope of work of shutdown maintenance in order to reduce the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by shutdown maintenance. These characteristics are summarised in the following points:

1. The above mentioned model is complete and simple. It is complete in the sense that it includes the important factors that affect the assessment process as identified by industrial maintenance managers. In addition, it is simple in the sense that it represents these factors in a simple and understandable way.
2. The above model is also easy to control. It has control on the number of the issues that represent each factor affecting the selection process of the shutdown maintenance activities. In addition, this control some times could be exceeded to include the control of specific limits of some issues such as the percentage that illustrates the concerned level of the partial shutdown maintenance.
3. The model is an adaptive and flexible model. It is so in the sense that it has two forms of analysis to choose from in order to analyse the data that are related to the factors at hand. These are the logical and the arithmetical forms. In addition, the ability to increase the number of issues that represent each factor affecting the selection process under this model is possible.
4. The model is easy to communicate. It is so in the sense that the data required by the model is in the same terms as those with which the manager is familiar. In addition, the output from the model has been represented in a tabulation form and lists which make important information such as the date of the evaluation, the analyst (analysts) name, the results of the evaluation and the evaluation steps to be easily followed and communicated by the related personnel.

7.7 SUMMARY:

In this chapter, the creation process of a model to reduce the number of shutdown maintenance activities without increasing the number of the unplanned shutdowns through the proper assessment of the scope of work of shutdown maintenance has been discussed. This process was based on the reduction of the number of shutdown maintenance activities which greatly contributes to the reduction in each of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that is caused by the shutdown maintenance as it has been verified in the first stage of the research methodology.

The discussion in this chapter started with a section about the general characteristics of the proposed model which included several subjects such as the proposed model type, purpose and use. Then, the discussion covered important subjects such as the modelling method that was used to develop the structure of the proposed model, the description of the structure of the proposed model and the specific characteristics of the model.

In the next chapter, the validation and verification processes of this model will be discussed. The discussion in that chapter will take the form of explaining the results of testing all parts of the developed model.

CHAPTER 8

THE TEST OF THE SHUTDOWN MAINTENANCE SCOPE OF WORK ASSESSMENT MODEL (SMWAM)

8

8.1 INTRODUCTION:

After the completion of the creation process of the shutdown maintenance scope of work assessment model (SMWAM), the developed model is ready to be tested. The purpose of testing the created model is to ensure that the model is implemented in accordance with what the model should intend to do and to ensure that all parts of the model such as the operational issues, safety issues, economic issues, and the general guidelines are compatible (complete and enough) with the real system of the continuous process industries. In other words, the purpose of testing the model is to reach the final version of the model that satisfies the objectives of building it.

The way to satisfy the above purpose is through carrying out the testing process of the created SMWAM model. This process which represents the third and final stage of this thesis research methodology uses data from the real system of the continuous process industries in order to test the different aspects of the created model. This implies that carrying out this process requires direct application of the model in one or more of the continuous process plants.

In this chapter, the discussion will focus on this testing process. Specifically, it will focus on the objectives of model testing, the model testing plan, the testing process of the created SMWAM model, the results of the testing process and the final version of the SMWAM model.

8.2 OBJECTIVES OF MODEL TESTING:

The main objectives of the model testing process are to ensure that the model performs as expected and that the model does actually represent a viable and useful means to achieve the aim of this model (Andersen et al, 1990; Andriole, 1989; Jeffers, 1982; Mitchell, 1993). In addition to these objectives, there are other objectives for the model testing process, which are considered to be important. These objectives are the following (Capron, 1986; Edwards, 1985, FitzGerald and FitzGerald; 1987; Kendall and Kendall, 1995):

1. Developing a good technical design for the model.
2. Making the model relevant, useful, understandable to, and acceptable by others. In other words, reaching general satisfaction with the model.
3. Giving users the opportunity to participate in the formulation of the model design by applying the model in the real working environment.
4. Eliciting the model strengths and weaknesses and refining those parts of the model that are associated with the model weaknesses.
5. Showing that all parts of the model are behaving in predictable and correct ways.
6. Examining all possible situations that might occur in the future and locating errors that might hamper the model.
7. Making sure that the users have understandable and adequate documentation to run the model.

In this thesis, these objectives were adopted in order to reach the final version of the created (SMWAM) model. Their focus in this thesis was on making sure that the created model performs as expected and that all of its parts are compatible with the real system of the continuous process industries. In particular, their focus was on the following:

1. Making sure that the operational issues, safety issues, economic issues are compatible with those issues in the real system.
2. Making sure that all of the model steps are coupled together in a proper and correct way.
3. Giving the maintenance personnel and other users the opportunity to participate in testing and evaluating the model in order to add their valuable views.
4. Eliciting the model strengths and weaknesses and refining those parts of the model that are associated with the model weaknesses.
5. Showing that each evaluation step in the model is behaving in predictable and correct way.
6. Making sure that the users have understandable and adequate guidelines to run the model.
7. Reaching the point where the model is relevant, useful, understandable to, and acceptable by others.

8.3 MODEL TESTING PLAN:

Planning the model testing process is important to save the modeller and the participants in the testing process a great deal of time and money since the model testing process is complex and time-consuming (Andersen et al, 1990; Andriole, 1989; Capron, 1986; Jeffers, 1982; Kendall and Kendall, 1995). In addition, it helps in achieving the model testing process objectives by developing a structured and well-organised testing process (Andersen et al, 1990; Andriole, 1989; Capron, 1986; Jeffers, 1982; Kendall and Kendall, 1995). In other words, it helps in making sure that the model is doing what is supposed to do and that users find the model useful and efficient.

The way to plan the model testing process is through applying the following key elements (Andersen et al, 1990; Andriole, 1989; Capron, 1986; Jeffers, 1982; Kendall and Kendall, 1995):

1. Distribution of test assignments: By applying this element, each individual in the model testing team will be assigned to test certain part of the model. In addition, the testing team leader will be designated as a responsible for the excruciation of the whole model testing process.
2. Determination of users participation: This element deals with the determination of the entity of the participating users and the time to bring them into the process as participating team members. This element is an informal training for the participating users and it helps to improve their faith in the model strengthens as they see the model taking shape and improving. In addition, it shows the users their own usefulness, as they see the model change in response to their suggestion.
3. Determination of test conditions (or scenario): This element deals with the selection or development of a suitable scenario (or test conditions). A suitable scenario (or test conditions) is one which permits the modeller to measure what it supposed to be measured. In this element, the way to avoid very long scenario or list of conditions is by scheduling the time to decide what kind of test conditions (or scenario) should be included.
4. Selection of test data: By applying this element, the needed data for testing is collected from its sources.
5. Preparation of a testing schedule: This element deals with preparing a detailed schedule of what will be tested and when.

6. Preparation of testing documentation: This element deals with preparing testing documentation in order to ensure that testing is thorough and complete. This testing documentation is useful before, during, at the end and long after the test is complete. It provides a valid measurement of how much has been done and what is yet to be done. In addition, it proves that the testing was as what it should supposed to be.

In this thesis, these elements were applied in order to plan the testing process of the created (SMWAM) model. The results of the application of these elements were the following:

1. All parts of the SMWAM model such as the model evaluation steps, issues (criteria) and guidelines were tested by researcher of this thesis. In addition, he was the responsible for the execution of the whole model testing process.
2. Users of the model and experts such as field operation personnel, process engineer, maintenance engineer, inspection engineer, production engineer, safety engineer, technical support personnel, shutdown maintenance planner, and maintenance manager were invited for participation. The field operation personnel, the process engineer, and the production engineer were called to participate in testing the operational issues and the evaluation process that is related to the operational issues. In the same manner, the safety engineer was called to participate in testing the safety issues and the evaluation process that is related to the safety issues. The other users and experts were asked to participate in testing the economic issues and the related evaluation process, in addition to, their participation in the whole testing process of the SMWAM model.
3. Two Saudi continuous process plants were chosen as the testing environment. The reason behind this is that these plants gave the researcher easy asses to their facilities and they were willing to provide information about the shutdown maintenance in their plants. In addition and as it has been mentioned in chapter four in this thesis, the continuous process plants in Saudi Arabia including these two are operated according to international standards which means that shutdown maintenance is being practised in these plants according to these standards.
4. The needed data for testing the SMWAM model was collected from one area in each plant. The reason behind this is that each area in these two plants has all the necessary elements that are needed for testing. In addition, performing the testing process on all areas in each plant would consume a great deal of time. The sources

of this data were the piping and instrumentation diagram, the industry operational standards, the process flow diagram, the cross sectional drawings, the equipment list and classification sheet, the previous shutdown maintenance records, the safety records, the support financial data, the rework shutdown maintenance jobs records, and other supported information.

5. A detailed schedule of what will be tested and when, was prepared. This schedule was a part of the testing documentation.
6. A testing documentation was also prepared before the execution of the SMWAM model testing process. It contained important information such as the part of the model to be tested, data used, testing date, expected results, actual results and comments. Each one of these occupied a separate column in each document of the testing documentation. A sample test document is illustrated in figure 8.1.

TEST DOCUMENT					
Model Part:					
Issue Tested	**Test Date**	**Data Used**	**Expected Results**	**Actual Results**	**Comments**

Figure 8.1 Test Document

8.4 TESTING PROCESS FOR THE SMWAM MODEL:

After setting the objectives and preparing the plan, the testing process for the SMWAM model was ready to be executed. The execution of this process on the two selected continuous process plants was divided into two parts. In the first part, the focus was on testing all parts of the SMWAM model in order to make sure that they are compatible with the real system of the continuous process industries. In the second part, the focus was on testing the whole model to make sure that it performs as expected. The following will explain the execution of the SMWAM model testing process.

8.4.1 Testing The SMWAM Model on One of Saudi Oil Refineries:

8.4.1.1 General Information About The Refinery:

The refinery is one of ARAMCO affiliates. It is 20 years old. It produces propane, butane, naphtha, gasoline, jet fuel (kerosene), diesel, engine fuel and asphalt. The refinery consists of more than fifteen production areas, which are connected to each other according to the refinery production process. The maintenance process of these areas is the responsibility of the maintenance department, which has 214 employees.

The shutdown maintenance for the refinery needs participation from all departments in the refinery. However, the responsibility of the shutdown maintenance is one of the maintenance department tasks.

For the shutdown maintenance, the maintenance department in the refinery plans and supervises the shutdown maintenance activities. In addition, it makes contracts with maintenance companies in order to provide the refinery with additional maintenance workers, machines and equipment.

8.4.1.2 Testing The Compatibility of The Model Parts With The Refinery System:

This part of the execution of the testing process on the refinery started with choosing the jet fuel or the kerosene area as the testing environment. The reason behind this is that this area has all of the necessary elements for testing such as the critical and non-critical maintenance activities and a number of these activities which is equal to the average number of the activities in other areas of the refinery.

After that, three teams were developed from the main testing team. The first one of these teams consisted of the field operation personnel for the kerosene area, the process and the production engineers for the same area, the maintenance engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. The purpose of this team was to test the operational issues and the guidelines that are related to the operational issues. The second developed team was formed to include the safety engineer, the maintenance engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. This team focused on testing the safety issues and the guidelines that are related to the safety issues. The last team among the developed teams was formed to include the maintenance engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner, the researcher of this thesis, and the maintenance manager. The focus of this team was on testing the economic issues and the related guidelines.

Each one of these teams held several meetings. The discussion on these meetings was about the compatibility of the issues in each evaluation step of the model with the refinery system and the possibility of adding other issues that are considered to be related to this system. Also, it was about the correctness of using limits on some of these issues and how these limits should look like. In addition, the discussion focused on the precision of the guidelines as well as the usefulness of the information sources and the possibility of adding other guidelines and information sources that are considered to be helpful for the evaluation process.

The results from these meetings were:

1. The addition of new issue to the operational issues which is related to the acceptable level of the product quality during the maintenance work.
2. The addition of the limit which define the level of the acceptable product quality and which is represented by the grade of the kerosene that could be reworked with the acceptable maximum cost.
3. The addition of the partial shutdown maintenance limit, which define the acceptable level of the partial shutdown maintenance and which, is represented by the acceptable maximum percentage of the production loss per day.

4. The acceptance of the model operational, safety and economic issues since they are compabile with the refinery system.
5. The addition of the guideline which is related to the usage of the information on the relations between the plant operations in order to measure the exact effect of carrying out the maintenance activity while the production line is running.
6. The addition of the guideline which is related to the usage of the information on the possibility of isolating the production areas from each other in order to determine the way of carrying out the maintenance activity and to determine the needed maintenance materials and equipment which helps in defining the maintenance cost.
7. The acceptance of the model guidelines since they help in the determination of the model issues and their limits in a way which is compatible with the refinery system.
8. The addition of the ARAMCO and the industry standards for carrying out the maintenance activities as a source of information.
9. The addition of the equipment inspection system manual as a source of information.
10. The acceptance of all other model sources of information since they help in developing the model issues and carrying out the evaluation process.

8.4.1.3 Testing The Whole Model Using The Refinery Data:

In this part of the execution of the testing process, data from the refinery records of previous shutdown maintenance was used to test the model evaluation process and to make sure that the model performs as expected. The testing environment in this part and the teams that were called for participation were the same as those in the first part of the execution of the testing process. The only difference is that the purpose of the teams in this part was to test the steps, the tables, and the forms of the model evaluation process.

The way of carrying out this part of the testing process started with testing the first step of the model evaluation process which is related to evaluating the inclusion of nominated maintenance activities for shutdown maintenance into the shutdown maintenance list according to the operational issues. The team that was involved in testing this step consisted of the field operation personnel for the kerosene area, the process and the production engineers for that area, the maintenance engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. This team performed the testing of this step by evaluating forty maintenance activities from the shutdown maintenance list, which represent all of the necessary shutdown maintenance activities for maintaining the kerosene area. The evaluation of these maintenance activities was performed according to three operational issues, which were represented by the three questions in the evaluation table. The result of the test, which is illustrated in table 8.1, showed that the evaluation of the activities was performed without any problem and the outcomes of this evaluation were:

1. Twenty-eight of these maintenance activities passed the evaluation and were classified as shutdown maintenance activities.
2. Twelve did not pass and were moved to the next step for further evaluation.

After getting this result from the first step, this part of the testing process proceeded to test the second step of the model evaluation process which is related to evaluating the inclusion of remaining maintenance activities into the shutdown maintenance list according to the safety issues. The testing of this step was performed by evaluating the remaining twelve activities from testing the first step. The evaluation of these maintenance activities was according to four safety issues, which were represented by four questions as illustrated in table 8.2. The team that was involved in this test consisted of the safety engineer, the maintenance engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. The test of this step revealed that all of the activities were evaluated without any problem as illustrated in table 8.2 and the results of this evaluation were:

1. Three of these maintenance activities passed the evaluation and were classified as shutdown maintenance activities.
2. The other nine did not pass and were moved to the next step for further evaluation.

By the end of testing the second step of the evaluation process, the third and the last step of this evaluation process which concerned with evaluating the inclusion of the remaining maintenance activities from the second step into the shutdown maintenance list according to the economic issues was tested. The team that was involved in testing this step consisted of the maintenance engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner, the researcher of this thesis, and the maintenance manager. This team performed the test in this step by evaluating the remaining nine maintenance activities from testing the last step. The evaluation of these maintenance activities was performed according to two economic issues, which were represented by two questions in the evaluation table for this step. The result of the test, which is illustrated in table 8.3, showed that the evaluation of the activities was performed without any problem and the outcomes of this evaluation were:

1. Eight of these activities did not pass the evaluation and were classified as non-shutdown maintenance activities.
2. These activities were transferred from the shutdown maintenance list to the lists of other in-process maintenance programmes and the consequences of this action were a reduction of the shutdown maintenance duration of this area, in addition to, a reduction in the shutdown maintenance direct and overhead costs which represents a saving in the total shutdown maintenance cost and in the loss in production that is caused by shutdown maintenance by approximately $1.6M.

After testing the last step of the evaluation process, the way of carrying out this part of the testing process reached its final stage. In this stage, the final list of shutdown maintenance activities and the final list of the activities to be performed by the other in-process maintenance programmes were prepared. The preparation of these lists was carried out by the teams and they are shown in tables 8.4 and 8.5.

The above results showed that the model evaluation process was performed without any problem. The only comment that was raised during this part of the execution of the testing process was related to the first step evaluation table. It was about the addition of a third column in that evaluation table representing the answer to the quality question.

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 1: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the operational issues.	**Date: 22/ 01/ 2001**
Plant: Oil Refinery / Area E	**Plant ID: F889923**
Analysts: First Step Evaluation Team	

List of Issues

1. If the activity is performed by another maintenance programme, does it cause full shutdown maintenance to the plant?
2. If the activity is performed by another maintenance programme, does it cause more than 20% loss of production per day (more than 20% partial shutdown to the plant)?
3. If the activity is performed by another maintenance programme, does it cause a production of grade C Kerosene or less?

Activity	Answers			The Result
	Question #1	Question #2	Question #3	
201-V1/ Change The Catalyst for The NHT Reactor	N	Y	Y	SH
201-V1/ Inspection of The NHT Reactor	N	Y	Y	SH
201-E1/ Inspection of Combine Feed-Effluent Exchanger	N	Y	N	SH
201-E1/ Install Back and Hydro-Test	N	Y	N	SH
201-H1/ Inspection of The Naphtha Hydro-Treater	N	Y	Y	SH
201-E1/ Carry Out DDT	N	Y	Y	SH
210-H1/ Test and Maintain Charge Heater	N	N	N	NP
210-V2/ Change The Catalyst for The Kerosene Reactor	N	N	N	NP
210-V2/ Inspection of Kerosene Reactor	N	N	N	NP
301-V1/ Change The Catalyst for The Plat Reactor # 1	N	Y	N	SH
301-V1/ Inspection of The Plat Reactor # 1	N	Y	N	SH
301-V2/ Change The Catalyst for The Plat Reactor # 2	N	Y	N	SH
301-V2/ Inspection of The Plat Reactor # 2	N	Y	N	SH
301-V3/ Change The Catalyst for The Plat Reactor # 3	N	Y	N	SH
301-V3/ Inspection of The Plat Reactor # 3	N	Y	N	SH
301-H1,2,3/ Inspection of The Plat Charge and Inter-heaters	N	Y	N	SH
301-H1,2,3/ Replace Dampers	N	Y	N	SH
411-H1/ Inspection of The Debut Heater	N	Y	Y	SH
411-H1/ Repair The Debut Heater Floor	N	Y	Y	SH
301-C1.CT1/ PM Activity for Recycle Gas Compressor	N	Y	N	SH
301-C2.CT2/ PM Activity for Make up Gas Compressor & Turbine	N	Y	N	SH
Instrumentation and Electrical Jobs Class A	N	Y	N	SH
Instrumentation and Electrical Jobs Class B1	N	N	N	NP
Instrumentation and Electrical Jobs Class B2	N	N	N	NP
Overhaul Safety Valves Class A	N	Y	N	SH
Overhaul Safety Valves Class B	N	N	N	NP
Inspection of Injection Nozzles	N	Y	N	SH
Repair/ Replace Vents and Drains Class A	N	Y	N	SH
Repair/ Replace Vents and Drains Class B1	N	N	N	NP
Repair/ Replace Vents and Drains Class B2	N	N	N	NP
Tag Jobs Class A	N	Y	N	SH
Tag Jobs Class B1	N	N	N	NP
Tag Jobs Class B2	N	N	N	NP
Repair/ Replace Root Valves	N	Y	N	SH
301/ Renewal of Corrosion Probes	N	Y	N	SH
411/ Renewal of Corrosion Probes	N	N	N	NP
301/ Replacement of Pipes for 301 Heater	N	Y	N	SH
411/ Replacement of Pipes for 411 Heater	N	N	N	NP
301/ Replacement of Pipes for 301 Heater Cooling Water	N	Y	N	SH
Tie in Piping for New Project	N	Y	N	SH

Note: SH means that the activity passed the evaluation and was classified as shutdown maintenance activity.
NP means the activity did not pass the evaluation.

Table 8.1 The Evaluation Table For The First Step in The Structure of The SMWAM Model Applied on The Refinery's Kerosene Area

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 2: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the safety issues.	**Date: 23/01/2001**
Plant: Oil Refinery / Area E	**Plant ID: F889923**
Analysts: Second Step Evaluation Team	

List of Issues

1. If the activity is performed by another maintenance programme, does it cause any death or injury to the employees in the plant?
2. If the activity is performed by another maintenance programme, does it cause any death, injury or harm to the people out side the plant?
3. If the activity is performed by another maintenance programme, does it cause any danger or damage to the physical workplace in the plant?
4. If the activity is performed by another maintenance programme, does it cause any harm to the outside environment?

Activity	Answers				The Result
	Question #1	Question #2	Question #3	Question #4	
210-H1/ Test and Maintain Charge Heater	N	N	N	N	NP
210-V2/ Change The Catalyst for The Kerosene Reactor	N	N	N	N	NP
210-V2/ Inspection of Kerosene Reactor	N	N	N	N	NP
Instrumentation and Electrical Jobs Class B1	N	N	N	N	NP
Instrumentation and Electrical Jobs Class B2	N	N	Y	N	SH
Overhaul Safety Valves Class B	N	N	N	N	NP
Repair/ Replace Vents and Drains Class B1	N	N	N	N	NP
Repair/ Replace Vents and Drains Class B2	Y	Y	Y	Y	SH
411/ Renewal of Corrosion Probes	N	N	N	N	NP
411/ Replacement of Pipes for 411 Heater	N	N	N	N	NP
Tag Jobs Class B1	N	N	N	N	NP
Tag Jobs Class B2	Y	Y	Y	Y	SH

Note: SH means that the activity passed the evaluation and was classified as shutdown maintenance activity.
NP means the activity did not pass the evaluation.

Table 8.2 The Evaluation Table For The Second Step in The Structure of The SMWAM Model Applied on The Refinery's Kerosene Area

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 3: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the economic issues.	**Date: 24/01/2001**
Plant: Oil Refinery / Area E	**Plant ID: F889923**
Analysts: Third Step Evaluation Team	

List of Issues

1. What is the total cost of performing the activity in the shutdown maintenance programme?
2. What is the total cost of performing the activity in the *first alternative* maintenance programme?

Activity	Answers		The Result	The Type of The Maintenance Programme
	Q #1	Q #2		
210-H1/ Test and Maintain Charge Heater			304400	OP
210-V2/ Change The Catalyst for The Kerosene Reactor			327293	OP
210-V2/ Inspection of Kerosene Reactor			307901	OP
Instrumentation and Electrical Jobs Class B1			106485	OP
Overhaul Safety Valves Class B			-15000	SH
Tag Jobs Class B1			88365	OP
Repair/ Replace Vents and Drains Class B1			205329	OP
411/ Renewal of Corrosion Probes			150530	OP
411/ Replacement of Pipes for 411 Heater			136600	OP

Note: The cost figures in the middle of table have been erased because they were confidential. OP means other maintenance programmes.

Table 8.3 The Evaluation Table For The Third Step in The Structure of The SMWAM Model Applied on The Refinery's Kerosene Area

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)			
Step 4: The final list of the shutdown maintenance activities.	**Date: 24/01/2001**		
Plant: Oil Refinery / Area E	**Plant ID: F889923**		
Analysts: Main Team			
Activity	**Operationally Critical**	**Safety Critical**	**Economically Critical**
201-V1/ Change The Catalyst for The NHT Reactor	Y		
201-V1/ Inspection of The NHT Reactor	Y		
201-E1/ Inspection of Combine Feed-Effluent Exchanger	Y		
201-E1/ Install Back and Hydro-Test	Y		
201-H1/ Inspection of Naphtha Hydro-treater	Y		
201-E1/ Carry Out DDT	Y		
301-V1/ Change Catalyst Reactor #1	Y		
301-V1/ Inspection of The Plat Reactor # 1	Y		
301-V2/ Change Catalyst Reactor #2	Y		
301-V2/ Inspection of The Plat Reactor # 2	Y		
301-V3/ Change Catalyst Reactor #3	Y		
301-V3/ Inspection of The Plat Reactor # 3	Y		
301-H1,2,3/ Inspection of Plat Charge & Inter-Heater	Y		
301-H1,2,3/ Replacement of Dampers	Y		
411-H1/ Inspection of The Debut Heater	Y		
301-C2.CT2/ PM Activity for Make up Gas Compressor & Turbine	Y		
301-C1.CT1/ PM Activity for Recycle Gas Compressor	Y		
411-H1/ Repair The Floor of The Debut Heater	Y		
Instrumentation and Electrical Jobs Class A	Y		
Instrumentation and Electrical Jobs Class B2		Y	
Overhaul Safety Valves Class A	Y		
Overhaul Safety Valves Class B			Y
Inspection of Injection Nozzles	Y		
Repair/ Replace Vents and Drains Class A	Y		
Repair/ Replace Vents and Drains Class B2		Y	
Tag Jobs Class A	Y		
Tag Jobs Class B2		Y	
Repair/ Replace Root Valves	Y		
301/ Renewal of Corrosion Probes	Y		
301/ Replacement of Pipes for 301 Heater	Y		
301/ Replacement of Pipes for 301 Heater Cooling Water	Y		
Tie in Piping for New Project	Y		

Table 8.4 The Final List of Shutdown Maintenance Activities For The Refinery's Kerosene Area

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 4: The list of other maintenance programmes activities.	**Date: 24/01/2001**
Plant: Oil Refinery / Area E	**Plant ID: F889923**
Analysts: Main Team	
Activity	**Recommended Maintenance Programme**
210-H1/ Test and Maintain Charge Heater	Preventive Maintenance
210-V2/ Change Catalyst for The Kerosene Reactor	Preventive Maintenance
210-V2/ Inspection of Kerosene Reactor	Predictive Maintenance
Instrumentation and Electrical Jobs Class B1	Preventive Maintenance
Tag Jobs Class B1	Preventive Maintenance
Repair/ Replace Vents and Drains Class B1	Preventive Maintenance
411/ Renewal of Corrosion Probes	Preventive Maintenance
411/ Replacement of Pipes for 411 Heater	Preventive Maintenance

Table 8.5 The List of Other Maintenance Programmes Activities For The Refinery's Kerosene Area

8.4.2 Testing The SMWAM Model on One of Saudi Petrochemical Plants:

8.4.2.1 General Information About The Petrochemical Plant:

This petrochemical plant is one of Saudi Basic Industries Corporation (SABIC) affiliates. It is more than 16 years old since its first production. It produces two products. These are the polyethylene and the ethylene glycol.

The plant consists of more than thirteen production areas. The maintenance process of these areas is the responsibility of the maintenance department, which has more than 160 employees.

The shutdown maintenance for this plant needs participation from all departments. However, the responsibility of the shutdown maintenance is one of the maintenance department tasks.

For the shutdown maintenance, the maintenance department in this plant plans and supervises the shutdown maintenance activities. In addition, it makes contracts with maintenance companies in order to provide the plant with additional maintenance workers, machines and equipment.

8.4.2.2 Testing The Compatibility of The Model Parts With The petrochemical Plant System:

In the same manner as with the refinery, the way of carrying out this part of the execution of the testing process on this petrochemical plant started with selecting a production area in the plant to be the testing environment for this part of the testing process. The area that had been selected for this purpose was the total pellet area. The reason behind selecting this area was the availability of all the necessary testing elements in this area such as the critical and non-critical maintenance activities and a number of these activities which is equal to the average number of the activities in other areas of the plant.

After that, three teams were developed from the main testing team in order to carry out this part of the execution. The first one of these teams consisted of the field operation personnel for the pellet area, the production engineer for the same area, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. The purpose of this team was to test the operational issues and the guidelines that are related to the operational issues. The second developed team was formed to include the safety engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. This team focused on testing the safety issues and the guidelines that are related to the safety issues. The last team among the developed teams was formed to include the inspection engineer, the technical support personnel, the shutdown maintenance planner, the researcher of this thesis, and the maintenance manager. The focus of this team was on testing the economic issues and the related guidelines.

Each one of these teams held several meetings. The discussion on these meetings was about the compatibility of the issues in each evaluation step of the model with the plant system and the possibility of adding other issues that are considered to be related to this system. Also, it was about the correctness of using limits on some of these issues and how these limits should look like. In addition, the discussion focused on the precision of the guidelines as well as the usefulness of the information sources and the possibility of adding other guidelines and information sources that are considered to be helpful for performing the evaluation process. The issues, the guidelines and the information sources that were discussed in these meetings were the revised one after testing the model on the refinery.

The results from these meetings were:

1. The acceptance of the model operational, safety and economic issues since they are compatible with the plant system.
2. The acceptance of the model guidelines since they help in the determination of the model issues and their limits in such a way that is also compatible with the plant system.
3. The addition of the support financial data system software as a source of information.
4. The addition of the material safety data sheet as a source of information.
5. The addition of the equipment data sheet as a source of information.
6. The acceptance of the other model sources of information since they help in developing the model issues and carrying out the evaluation process.

8.4.2.3 Testing The Whole Model Using The Petrochemical Plant Data:

Similar to the way that had been applied to the refinery, data from the petrochemical plant that is related to a previous shutdown maintenance was used in this part of the execution of the testing process in order to test the model evaluation process and to make sure that the model performs as expected. The testing environment in this part and the teams that were called for participation were the same as those that were used in the previous part of the execution of the testing process on this plant. The only difference was that the purpose of the teams in this part was to test the steps, the tables, and the forms of the model evaluation process.

The way of carrying out this part of the testing process on the petrochemical plant and its results were the following:

1. Forty three maintenance activities from the shutdown maintenance list which represent all of the necessary maintenance activities for maintaining the pellet area were used to test the first step of the model evaluation process. The team that was involved in testing this step consisted of the field operation personnel for the pellet area, the process and the production engineers for that area, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. This team performed the testing of this step by

evaluating these maintenance activities according to three operational issues, which were represented by the three questions in the evaluation table. The result of the test which is illustrated in table 8.6 showed that the evaluation of the activities was performed without any problem and the outcomes of this evaluation were:

A. Thirteen of these maintenance activities passed the evaluation and were classified as shutdown maintenance activities.
B. Thirty did not pass and were moved to the next step for further evaluation.

2. After getting this result from the first step, the way of carrying out this part of the testing process proceeded to test the second step of the model evaluation process which is related to evaluating the inclusion of the remaining maintenance activities into the shutdown maintenance list according to the safety issues. The testing of this step was performed by evaluating the remaining thirty maintenance activities from testing the first step. The evaluation of these maintenance activities was according to four safety issues, which were represented by four questions as illustrated in table 8.7. The team that was involved in this test consisted of the safety engineer, the inspection engineer, the technical support personnel, the shutdown maintenance planner and the researcher of this thesis. The test of this step revealed that all of the activities were evaluated as illustrated in table 8.7 and the results of this evaluation were:
   A. Nine of these maintenance activities passed the evaluation and were classified as shutdown maintenance activities.
   B. The other twenty-one activities did not pass and were moved to the next step for further evaluation.

3. By the end of testing the second step of the evaluation process, the third and the last step of this evaluation process which is related to evaluating the inclusion of remaining maintenance activities from the second step into the shutdown maintenance list according to the economic issues was ready to be tested. The team that was involved in testing this step consisted of the inspection engineer, the technical support personnel, the shutdown maintenance planner, the researcher of this thesis, and the maintenance manager. This team performed the test on this step by evaluating the remaining twenty-one maintenance activities from testing

the earlier step. The evaluation of these maintenance activities was performed according to two economic issues, which were represented by two questions in the evaluation table of this step. The result of the test which is illustrated in table 8.8 showed that the evaluation of the activities was performed without any problem and the outcomes of this evaluation were:

A. Twenty of these maintenance activities did not pass the evaluation and were classified as non-shutdown maintenance activities.

B. These maintenance activities were transferred from the shutdown maintenance list to the lists of other in-process maintenance programmes and the consequences of this action were a reduction of the shutdown maintenance duration of this area, in addition to, a reduction in the direct and the overhead costs of shutdown maintenance which in turn represent a reduction in the total shutdown maintenance cost and in the loss in production that is caused by shutdown maintenance by approximately $0.4M.

4. After testing the last step of the evaluation process, the way of carrying out this part of the testing process reached its final stage. In this stage, the final list of shutdown maintenance and the final list of the activities to be performed by the other in-process maintenance programmes were prepared. The preparation of these lists was performed by the teams and they are shown in tables 8.9 and 8.10.

The above results showed that the model evaluation process was performed without any problem. However, there was a comment that was raised during this part of the execution of the testing process. This comment was related to the addition of an equation to the third step of the model evaluation process and a space for the result of this equation in the evaluation table of this step. The purpose of this equation is to calculate the total savings in the maintenance cost and the loss of production that occurs as a result of transferring some of the shutdown maintenance activities from the shutdown maintenance list to the list of other in-process maintenance programmes.

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 1: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the operational issues.	**Date: 28/02/2001**
Plant: Petrochemical Plant / Pellet Area	**Plant ID:**
Analysts: First Step Evaluation Team	

List of Issues

1. If the activity is performed by another maintenance programme, does it cause full shutdown maintenance to the plant?
2. If the activity is performed by another maintenance programme, does it cause more than 25% loss of production per day (more than 25% partial shutdown to the plant)?
3. If the activity is performed by another maintenance programme, does it affect the quality of the product?

Activity	Answers			The Result
	Question #1	Question #2	Question #3	
XV2525/ Inspection of Granule Hopper Diverter Valve	N	N	N	NP
XV2713/ Inspection of Pellet Diverter Valve	N	N	N	NP
B2521A/ Inspection and Repair The Direction Blower Suction Valve	N	N	N	NP
V2511/ Inspection of Granule Hopper # 1	N	N	N	NP
V2512/ Inspection of Granule Hopper # 2	N	N	N	NP
V2513/ Inspection of Granule Hopper # 3	N	N	N	NP
E2521/ Inspection of Granule Suction Cooler	N	N	N	NP
F2521A/ Replacement of Granule Suction Cooler Filter A	N	N	N	NP
F2521B/ Replacement of Granule Suction Cooler Filter B	N	N	N	NP
F2504/ Replacement of Equalising Filter	N	N	N	NP
TV2614/ Overhaul Temperature Valve A	N	N	N	NP
TV2624/ Overhaul Temperature Valve B	N	N	N	NP
F2601/ Change Demoralise Water or Clean	N	N	N	NP
F2602/ Inspection and Change Steam Filter	N	N	N	NP
V2607/ Inspection of Steam Flush pot	N	N	N	NP
S2622/ Inspection of Additive Hopper	N	N	N	NP
Z2802/ Inspection and Repair of Heater Ms	N	N	Y	SH
Z2803/ Inspection and Repair of Heater Ls	Y	Y	Y	SH
E2731/ Inspection and Repair of Pellet Convey Line	N	N	N	NP
S2722/ Inspection of Internal Pellet Silo Storage	N	N	N	NP
E2401/ Inspection of Cycle Gas Cooler	Y	Y	Y	SH
R2401/ Cleaning Distributor Plate	Y	Y	Y	SH
R2401/ Replacement of The Reactor Taps	Y	Y	Y	SH
24LZ08/ Cleaning of Suction Compressor	Y	Y	Y	SH
V2501/ Inspection of The Product Purge Pin	Y	Y	Y	SH
F2503/ Cleaning of The Filter	N	N	N	NP
K2101A/ Overhaul Nitrogen Compressor A	N	N	N	NP
K2101B/ Overhaul Nitrogen Compressor B	N	N	N	NP
N2401/ Inspection & Change of The Static Probe	Y	Y	N	SH
Z2612/ Inspection of Pelleter Coupling	N	N	N	NP
G2611/ Overhauling Continuous Mixer	N	Y	Y	SH
W2611/ Overhauling Granule Weigher	N	N	N	NP
W2612/ Overhauling Solid Additive Weigher	N	N	N	NP
SC2611/ Overhauling Screw Conveyor	N	N	N	NP
G2611B/ Inspection & Overhauling Continuous Mixer Pump	N	N	N	NP
G2611Z/ Inspection & Overhauling Bearing Unit	N	N	N	NP
M2302/ Overhauling of Mix Vessel Agitator	N	N	Y	SH
RV2701/ Overhauling Rotary Valve	N	N	N	NP
BM2735/ Overhauling Blower	N	N	N	NP
ZM2503/ Overhauling Granule Screener	Y	N	N	SH
RV2501/ Overhauling Rotary Feeder	Y	N	N	SH
RV2503/ Overhauling Rotary Feeder	Y	N	N	SH
K2401/ Overhauling Cycle Gas Compressor	Y	N	N	SH

Note: SH means that the activity passed the evaluation and was classified as shutdown maintenance activity.

NP means the activity did not pass the evaluation.

Table 8.6 The Evaluation Table For The First Step in The Structure of The SMWAM Model Applied on The Petrochemical Plant

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 2: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the safety issues.	**Date: 01/03/2001**
Plant: Petrochemical Plant / Pellet Area	**Plant ID:**
Analysts: Second Step Evaluation Team	

List of Issues

1. If the activity is performed by another maintenance programme, does it cause any death or injury to the employees in the plant?
2. If the activity is performed by another maintenance programme, does it cause any death, injury or harm to the people out side the plant?
3. If the activity is performed by another maintenance programme, does it cause any danger or damage to the physical workplace in the plant?
4. If the activity is performed by another maintenance programme, does it cause any harm to the outside environment?

Activity	Answers				The Result
	Question #1	Question #2	Question #3	Question #4	
XV2525/ Inspection of Granule Hopper Diverter Valve	N	N	N	N	NP
XV2713/ Inspection of Pellet Diverter Valve	N	N	N	N	NP
B2521A/ Inspection and Repair The Direction Blower Suction Valve	N	N	N	N	NP
V2511/ Inspection of Granule Hopper # 1	N	N	N	N	NP
V2512/ Inspection of Granule Hopper # 2	N	N	N	N	NP
V2513/ Inspection of Granule Hopper # 3	N	N	N	N	NP
E2521/ Inspection of Granule Suction Cooler	N	N	N	N	NP
F2521A/ Replacement of Granule Suction Cooler Filter A	Y	N	N	N	SH
F2521B/ Replacement of Granule Suction Cooler Filter B	Y	N	N	N	SH
F2504/ Replacement of Equalising Filter	Y	N	N	N	SH
TV2614/ Overhaul Temperature Valve A	N	N	N	N	NP
TV2624/ Overhaul Temperature Valve B	N	N	N	N	NP
F2601/ Change Demoralise Water or Clean	N	N	N	N	NP
F2602/ Inspection and Change Steam Filter	N	N	N	N	NP
V2607/ Inspection of Steam Flush pot	N	N	N	N	NP
S2622/ Inspection of Additive Hopper	Y	N	N	N	SH
E2731/ Inspection and Repair of Pellet Convey Line	N	N	N	N	NP
S2722/ Inspection of Internal Pellet Silo Storage	Y	N	N	N	SH
F2503/ Cleaning of The Filter	Y	N	N	N	SH
K2101A/ Overhaul Nitrogen Compressor A	N	N	N	N	NP
K2101B/ Overhaul Nitrogen Compressor B	N	N	N	N	NP
Z2612/ Inspection of Pelleter Coupling	N	N	N	N	NP
W2611/ Overhauling Granule Weigher	Y	N	N	N	SH
W2612/ Overhauling Solid Additive Weigher	Y	N	N	N	SH
SC2611/ Overhauling Screw Conveyor	N	N	N	N	NP
G2611B/ Inspection & Overhauling Continuous Mixer Pump	N	N	N	N	NP
G2611Z/ Inspection & Overhauling Bearing Unit	N	N	N	N	NP
RV2701/ Overhauling Rotary Valve	N	N	N	N	NP
BM2735/ Overhauling Blower	N	N	N	N	NP

Note: SH means that the activity passed the evaluation and was classified as shutdown maintenance activity.

NP means the activity did not pass the evaluation.

Table 8.7 The Evaluation Table For The Second Step in The Structure of The SMWAM Model Applied on The Petrochemical Plant

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)				
Step 3: Evaluating the inclusion of maintenance activities into the shutdown maintenance list according to the economic issues.		**Date: 02/03/2001**		
Plant: Petrochemical Plant / Pellet Area		**Plant ID:**		
Analysts: Third Step Evaluation Team				
List of Issues 1. What is the total cost of performing the activity in the shutdown maintenance programme? 2. What is the total cost of performing the activity in the *first alternative* maintenance programme?				
Activity	**Answers**		**The Result**	**The Type of The Maintenance Programme**
	Q #1	**Q #2**		
XV2525/ Inspection of Granule Hopper Diverter Valve			6764	OP
XV2713/ Inspection of Pellet Diverter Valve			2731	OP
B2521A/ Inspection and Repair The Direction Blower Suction Valve			-2439	SH
V2511/ Inspection of Granule Hopper # 1			2510	OP
V2512/ Inspection of Granule Hopper # 2			2510	OP
V2513/ Inspection of Granule Hopper # 3			2510	OP
E2521/ Inspection of Granule Suction Cooler			6130	OP
TV2614/ Overhaul Temperature Valve A			4071	OP
TV2624/ Overhaul Temperature Valve B			2672	OP
F2601/ Change Demoralise Water or Clean			1950	OP
F2602/ Inspection and Change Steam Filter			2960	OP
V2607/ Inspection of Steam Flush pot			2249	OP
E2731/ Inspection and Repair of Pellet Convey Line			2586	OP
K2101A/ Overhaul Nitrogen Compressor A			11580	OP
K2101B/ Overhaul Nitrogen Compressor B			11580	OP
Z2612/ Inspection of Pelleter Coupling			48804	OP
SC2611/ Overhauling Screw Conveyor			5122	OP
G2611B/ Inspection & Overhauling Continuous Mixer Pump			110244	OP
G2611Z/ Inspection & Overhauling Bearing Unit			13380	OP
RV2701/ Overhauling Rotary Valve			2206	OP
BM2735/ Overhauling Blower			155070	OP
Total Savings			$397629	

Note: The cost figures in the middle of table have been erased because they were confidential. OP means other maintenance programmes.

Table 8.8 The Evaluation Table For The Third Step in The Structure of The SMWAM Model Applied on The Petrochemical Plant

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)			
Step 4: The final list of the shutdown maintenance activities.	**Date: 03/ 03/ 2001**		
Plant: Petrochemical Plant / Pellet Area	**Plant ID:**		
Analysts: Main Team			
Activity	**Operationally Critical**	**Safety Critical**	**Economically Critical**
Z2802/ Inspection and Repair of Heater Ms	Y		
Z2803/ Inspection and Repair of Heater Ls	Y		
E2401/ Inspection of Cycle Gas Cooler	Y		
R2401/ Cleaning Distributor Plate	Y		
R2401/ Replacement of The Reactor Taps	Y		
24LZ08/ Cleaning of Suction Compressor	Y		
V2501/ Inspection of The Product Purge Pin	Y		
N2401/ Inspection & Change of The Static Probe	Y		
G2611/ Overhauling Continuous Mixer	Y		
M2302/ Overhauling of Mix Vessel Agitator	Y		
ZM2503/ Overhauling Granule Screener	Y		
RV2501/ Overhauling Rotary Feeder	Y		
RV2503/ Overhauling Rotary Feeder	Y		
K2401/ Overhauling Cycle Gas Compressor	Y		
F2521A/ Replacement of Granule Suction Cooler Filter A		Y	
F2521B/ Replacement of Granule Suction Cooler Filter B		Y	
F2504/ Replacement of Equalising Filter		Y	
S2622/ Inspection of Additive Hopper		Y	
S2722/ Inspection of Internal Pellet Silo Storage		Y	
F2503/ Cleaning of The Filter		Y	
W2611/ Overhauling Granule Weigher		Y	
W2612/ Overhauling Solid Additive Weigher		Y	
B2521A/ Inspection and Repair The Direction Blower Suction Valve			Y

Table 8.9 The Final List of Shutdown Maintenance Activities For The Petrochemical Plant

Shutdown Maintenance Scope of Work Assessment Model (SMWAM)	
Step 4: The list of other maintenance programmes activities.	**Date: 03/ 03/ 2001**
Plant: Petrochemical Plant / Pellet Area	**Plant ID:**
Analysts: Main Team	
Activity	**Recommended Maintenance Programme**
XV2525/ Inspection of Granule Hopper Diverter Valve	Routine Maintenance
XV2713/ Inspection of Pellet Diverter Valve	Routine Maintenance
V2511/ Inspection of Granule Hopper # 1	Preventive Maintenance
V2512/ Inspection of Granule Hopper # 2	Preventive Maintenance
V2513/ Inspection of Granule Hopper # 3	Preventive Maintenance
E2521/ Inspection of Granule Suction Cooler	Preventive Maintenance
TV2614/ Overhaul Temperature Valve A	Preventive Maintenance
TV2624/ Overhaul Temperature Valve B	Preventive Maintenance
F2601/ Change Demoralise Water or Clean	Preventive Maintenance
F2602/ Inspection and Change Steam Filter	Preventive Maintenance
V2607/ Inspection of Steam Flush pot	Preventive Maintenance
E2731/ Inspection and Repair of Pellet Convey Line	Routine Maintenance
K2101A/ Overhaul Nitrogen Compressor A	Routine Maintenance
K2101B/ Overhaul Nitrogen Compressor B	Routine Maintenance
Z2612/ Inspection of Pelleter Coupling	Routine Maintenance
SC2611/ Overhauling Screw Conveyor	Routine Maintenance
G2611B/ Inspection & Overhauling Continuous Mixer Pump	Routine Maintenance
G2611Z/ Inspection & Overhauling Bearing Unit	Routine Maintenance
RV2701/ Overhauling Rotary Valve	Routine Maintenance
BM2735/ Overhauling Blower	Routine Maintenance

Table 8.10 The List of Other Maintenance Programmes Activities For The Petrochemical Plant

8.5 DISCUSSION OF THE RESULTS OF THE TESTING PROCESS AND THE FINAL VERSION OF THE SMWAM MODEL:

8.5.1 Discussion of The Results of The Testing Process:

The testing process revealed several important results about the SMWAM model that could be classified into two categories. In the first category, the testing process revealed those results that were related to the usefulness of the SMWAM model characteristics. In particular, the testing process revealed three important results about this subject in this category.

The first one was related to the usefulness of the SMWAM model adaptation and flexibility. This had been shown when the model accepted the addition of a third column in the first step evaluation table representing a space for the answer to the quality question. Also, these characteristics had been shown when the model accepted the following as sources of information:

1. The ARAMCO and the industry standards for carrying out the maintenance activities.
2. The oil refinery equipment inspection system manual.
3. The petrochemical plant support financial data system software.
4. The petrochemical plant material safety sheet.
5. The petrochemical plant equipment data sheet.

In addition to this, the testing process revealed as a second result in this category how easy the model was to be controlled. This was revealed when the limit, which defines the acceptable level of the product quality and that which define the acceptable level of the partial shutdown, were added to the model issues. The addition of these limits was to control the acceptable level of the product quality and that of the partial shutdown when the shutdown maintenance activity is performed by one of the in-process maintenance programmes.

The third result in this category was related to how easily the steps of the model evaluation process and their outcomes were followed and communicated by the members of the participating teams. This had been shown when the team members used the outcomes of the last tested evaluation step to test the next one and when the team members were able to use the evaluation tables without any problem.

In addition to these results, the testing process also revealed as a second category of results, those results which were related to the necessary additions that should be added to different parts of the SMWAM model in order to make the model complete, useful and easy to use. Such results were revealed when the model accepted the addition of a new issue to the operational issues. Also, they were revealed when the model accepted the addition of two new guidelines to its general guidelines.

In addition to these two results, the testing process revealed another very important result in this category. This was related to the addition of an equation to the third step of the model evaluation process in order to calculate the total savings in the maintenance cost and the loss of production that occurs as a result of transferring some of shutdown maintenance activities from the shutdown maintenance list to the lists of other in-process maintenance programmes.

8.5.2 The Final Version of The SMWAM Model:

During the testing process, several modifications were suggested to be made to the SMWAM model in order to make it more useful and complete. These modifications which were mentioned in the previous subsection were in a form of additions to different parts of the SMWAM model. In particular, they were in a form of additions to the model evaluation steps and guidelines as follows:

1. In the first evaluation step, the modification was in form of adding a new issue to the operational issues that deals with the acceptable level of the product quality during the maintenance work. This modification which is illustrated in figure 8.2 was necessary in order to account for the quality issue when the shutdown maintenance activity is performed by one of the in-process maintenance programmes.
2. In the third step of the evaluation process, the modification was in form of adding the following equation to the step, in addition to, a space for the result of this equation in the evaluation table of this step:

   $$Y = \sum_{i=1}^{m} Yi \qquad \forall Yi > 0$$

   Where

   Y = The total savings in the maintenance cost and the loss of production.

   Yi= The maximum saving in the total cost of performing the ith activity.

   m = The total number of the evaluated shutdown maintenance activities.

   The purpose of this equation is to calculate the total savings in the maintenance cost and the loss of production that occurs as a result of transferring some of the shutdown maintenance activities from the shutdown maintenance list to the lists of other in-process maintenance programmes.
3. In the model guidelines, the modifications were in the form of adding two guidelines to those in chapter seven. The first one was related to the usage of the information on the relations between the plant operations in order to measure the exact effect of carrying out the maintenance activity while the production line is

running. The other one was related to the usage of the information on the possibility of isolating the production areas from each other in order to determine the way of carrying out the maintenance activity and to determine the needed maintenance materials and equipment which helps in defining the maintenance cost.

All of these modifications are summarised in table 8.11. In addition, they were made in the SMWAM model in order to reach the final version, which is illustrated in figure 8.2.

Part of The MSWAM Model	Type of Modification	The Modification
The First Step of The Evaluation Process	Addition	Adding an issue that is related to the acceptable level of the product quality during the maintenance work.
The second Step of The Evaluation Process	Nothing	Nothing
The Third Step of The Evaluation Process	Addition	Adding an equation that calculates the total savings in the maintenance cost and the loss of production that occurs as a result of transferring some of the maintenance activities from the shutdown maintenance list to the lists of other in-process maintenance programmes.
The Fourth Step of The SMWAM model	Nothing	Nothing
The Model Guidelines	Addition	Adding two guidelines. One is related to the usage of the information on the relations between the plant operations in order to measure the exact effect of carrying out the maintenance activity while the production line is running. Th other is related to the usage of the information on the possibility of isolating the production areas from each other in order to determine the way of carrying out the maintenance activity and to determine the needed maintenance materials and equipment which helps in defining the maintenance cost.

Table 8.11 Summary of The Modifications on The SMWAM Model

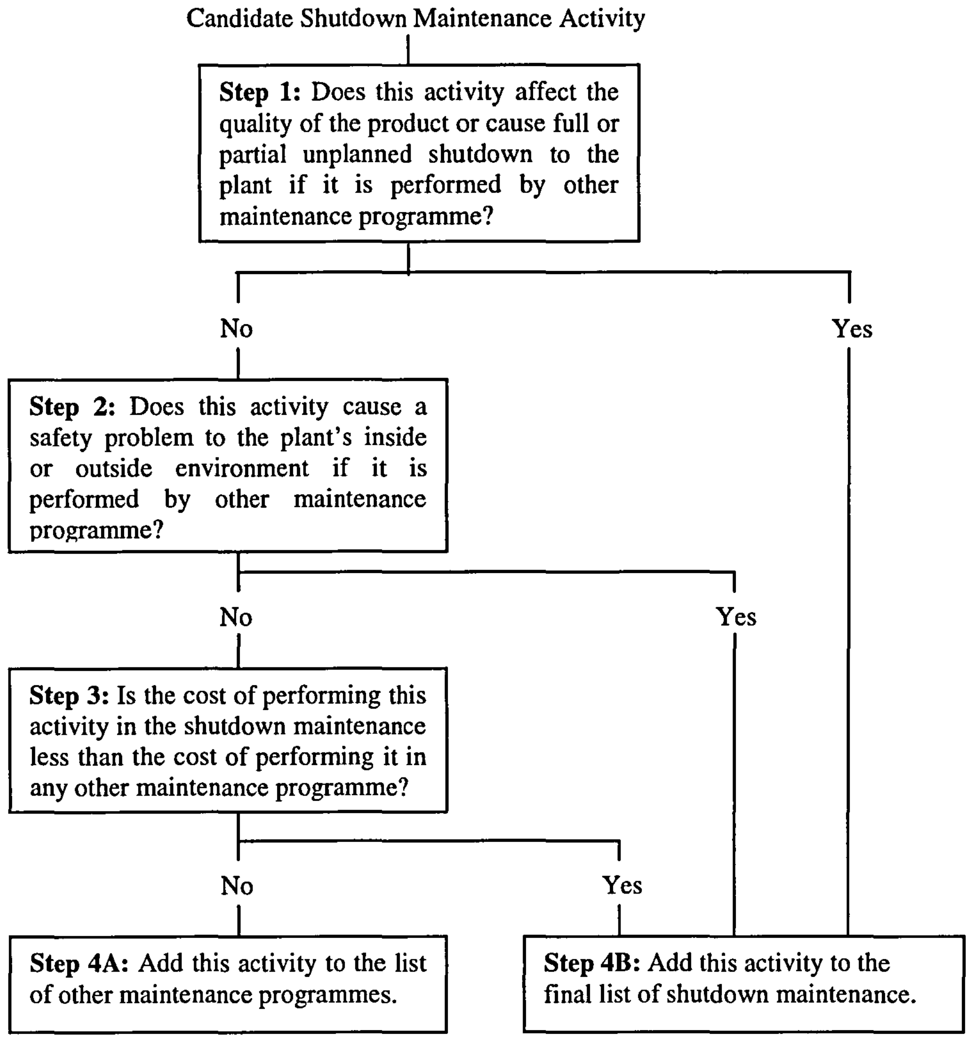

Figure 8.2 The Structure of The Final Version of The Shutdown Maintenance Scope of Work Assessment Model (SMWAM)

8.6 SUMMARY:

In this chapter, the SMWAM model was tested in order to ensure that the model performs as expected and that all parts of the model such as the operational issues, safety issues, economic issues, and the general guidelines are compatible with the real system of the continuous process industries. In other words, the purpose of this chapter was to test the model in order to reach its final version that satisfies the objectives of building it.

The testing process of the SMWAM model in this chapter was carried out on two of the Saudi continuous process plants. The results of this process revealed the usefulness of the model characteristics, in addition to, several important modifications that had been made on the model to make it more useful and complete.

In the next chapter, the main conclusions drawn from the research described in this thesis will be discussed. In addition, the chapter will also provide some suggestions for further research work.

CHAPTER 9

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH WORK

9

9.1 INTRODUCTION:

This thesis has described the research directed to reducing the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that occurs as a result of performing shutdown maintenance in the continuous process industries. It investigated the creation of a model, which has the ability to reduce the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production by the reduction of the scope of work of shutdown maintenance and without creating any operational, safety or economic problems.

In the previous chapters, the work that has been undertaken to facilitate this effort was discussed. In addition, the findings of this work were reported and then discussed in terms of the objectives that have been formulated at the beginning of the thesis.

This chapter which is also the last chapter of the thesis details the main conclusions that have been found during the work of the thesis. Also, it details the relationship of the thesis research to the literature review and the limitations of this research. In addition, it provides several suggestions for further work in this research area.

9.2 THE MAIN CONCLUSIONS:

The research methodology of this thesis was divided in to three stages in order to achieve the aim of this thesis. Each one of these stages is dedicated to achieve an objective or several objectives among the thesis objectives that were formulated at the beginning of this thesis. These stages and their main conclusions are discussed in the following subsections.

9.2.1 The Main Conclusions of The First Stage of The Thesis:

This stage was concerned with the thesis objectives that are related to the investigation of the need to reduce the shutdown maintenance cost and frequency and the loss of production, the investigation of the current methods for reducing the above mentioned issues and the investigation of the importance of the number of shutdown maintenance activities (the scope of work of shutdown maintenance) as a major variable that affect each one of the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production. The main conclusions of this stage were the following:

1. It has been found from the literature at the beginning of this thesis (chapters two and three, sections 2.5 and 3.1), how important the reduction of the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production is for supporting the overall strategy in the continuous process industries. This was shown from the experience of the continuous process industries in the field of reducing these issues that has been discussed in the literature (chapter two, section 2.5).
2. It has been found from studying the current methods of reducing the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production in chapter three how the limitations of these methods provided insight for the development of a model to reduce these variables of interest. In particular, studying these methods has revealed possible areas for new contributions in the research area of interest. Also, it provided valuable information on the relationships between the scope of work of shutdown maintenance and each one of the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production, in addition to, the information on the variables that constitute these relationships.
3. From the investigation process of this stage, it has been found that the findings that have been extracted from the literature reviews (summarised in section 4.3) and the findings from conducting the interviews (summarised in subsection 4.4.4) were useful sources of information in the development of a theoretical framework that describes the relationships of interest and the variables that constitute these relationships.

4. From the analysis of the data that have been collected by the investigation process survey (chapter six, section 6.3 and subsection 6.4.2), several important points of information were revealed. One of these points was related to the effect of the unavailability of the shutdown maintenance resources and the effect of the inaccuracy of scheduling shutdown maintenance activities on the cost of shutdown maintenance and on the loss of production. These effects of these variables were found to be small positive effects and they were not negligible as it has been found in the results of the interviews in chapter four (subsection 4.4.4). In addition to this point, there is another point of information, which was related to the effect of the timing of shutdown maintenance on the loss of production, which was found to be almost large effect. In particular, this effect makes this variable one of the major variables that affect the loss of production. All of these findings provide insight to develop models that are based on them to reduce the shutdown maintenance cost and the loss in production.
5. The most important results and findings from the analysis of the data that have been collected by the investigation process survey (chapter six, section 6.3) were those that are related to the relationships between the number of shutdown maintenance activities and each one of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production that occurs as a result of performing shutdown maintenance. These findings and results showed that the number of shutdown maintenance activities is the major variable that affects the shutdown maintenance cost and frequency and the loss in production.

9.2.2 The Main Conclusions of The Second Stage of The Thesis:

In addition to the first stage of this thesis, the second stage is concerned with the achievement of the objective that is related to the development of a model to reduce the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production. The main conclusions of this stage were the following:

1. From the discussion of the model development process (chapter seven, subsection 7.2.2), it has been realised that the development process of the model was based on the results of the evaluated relationships of interest from the first stage. This enhances the importance of the model as a tool for reducing the shutdown

maintenance cost, the shutdown maintenance frequency and the loss of production since the evaluated relationships concerned with these important variables.

2. Also, from the same discussion (chapter seven, subsection 7.3.2), it has been found that the development process has used the separate preference elimination method, which is one of the decision analytic methods. The use of this method makes the model easy to understand since this method is compatible with the way many people solve problems.
3. Th discussion in this stage (chapter seven, section 7.4) showed that the structure of the model was based on four important evaluation steps. Also, it showed that the main factors that affect the evaluation process of the model are represented in a simple and understandable way. All of these important features increase the simplicity of the model structure. In addition, it simplifies the way of using the model as a tool to reach the proper assessment of the scope of work of shutdown maintenance.

9.2.3 The Main Conclusions of The Third Stage of The Thesis

The third stage of this thesis is concerned with the achievement of the objective, which is related to the validation, and the verification of the developed model. In other words, the purpose of this stage is to ensure that the model performs in accordance with what the model should intend to do and to ensure that all parts of the model such as the operational issues, safety issues, economic issues, and the general guidelines are compatible (complete and enough) with the real system of the continuous process industries. The main conclusions of this stage were:

1. The testing process of the developed model (chapter eight, sections 8.4 and 8.5) showed the usefulness of the model adaptation and flexibility. By showing this feature, the testing process illustrates the ability of the model to accept the addition or the removal of different models' evaluation issues.
2. The testing process of the developed model also revealed how easy the model was to be controlled (chapter eight, sections 8.4 and 8.5). By revealing this important feature, the testing process also shows how important this feature is in facilitating the way to define the limits that are related to the model's evaluation issues.
3. In addition the process showed how easily the steps of the model evaluation process and their outcomes were followed and communicated by the people who

use the model (chapter eight, sections 8.4 and 8.5). By showing this feature, the testing process gives an insight of the degree for the needed simplicity when an improvement is to be made in the model.

9.3 THESIS RESEARCH CONTRIBUTION AND LIMITATIONS:

The work in this thesis as mentioned in chapter one is an effort to contribute to the area of research that is concerned with finding a way or a method to reduce the shutdown maintenance cost, the shutdown maintenance frequency and the loss of production that is caused by performing shutdown maintenance. In this respect, the research in this thesis expanded the list of the variables that have been found in the literature survey (chapter two) to include variables that affect the cost and the frequency of shutdown maintenance and the loss of production that is caused by shutdown maintenance. The expansion in this list was a result of the interviews described in chapter four and also confirmed by the findings of the survey described in chapter six. The research in this thesis clarified the relationships between these variables and the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production. This has been done by means of discussing the results of the interview in chapter four and the results of analysis process of the survey data in chapter six.

The main contribution of the research in this thesis was the creation of the (SMWAM) model. This model is useful to help the maintenance departments in reducing the shutdown maintenance cost, frequency and the loss in production. In addition, it is useful to be used by these departments for assessing and reassessing the scope of work of shutdown maintenance. The creation, the testing and the way of using this model were discussed in chapters seven and eight of this thesis.

However, the research described in this thesis is limited by a number of issues. It is limited by its focus since it concentrated on the reduction of the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production where it could concentrate, for example, on the reduction of the cost and the frequency of other maintenance programmes. This is because the shutdown maintenance programme represents the most expensive programme amongst other maintenance programmes, at the same time; it is one of the important types which in turn makes the reduction of its cost and frequency a challenging issue in the research area.

Also, the research in this thesis is limited by the environment on which this research was carried on. In this sense, the research of this thesis was carried on the continuous process industries in Saudi Arabia since these industries provide the researcher easy access to the data that is needed to be collected. As a result, the findings of the research of this thesis are applicable to continuous process industries on environments similar to the environment of the continuous process industries in Saudi Arabia.

In addition to all of this, the research in this thesis is limited by its approach to reduce the shutdown maintenance cost, frequency and the loss in production. In particular, it reduces these variables of interest by means of the reduction in the number of shutdown maintenance activities (the scope of work of shutdown maintenance) and without creating any operational, economic or safety problems. The reason behind using the number of shutdown maintenance activities in this approach was because it is the major variable that affects all of these variables of interest, which in turn satisfies the aim of the thesis. However, there are other variables that could affect one or some but not all of these variables of interest as shown in chapter six. These variables could be investigated in further research work, as discussed in the suggestions for further research.

9.4 SUGESTIONS FOR FURTHER RESEARCH WORK:

In addition to the work in this thesis, several further works and studies are needed to enhance this area of research. These further works and studies could be classified into three categories. Each one of these categories are related to different area of contribution to the research in the reduction of shutdown maintenance cost, shutdown maintenance frequency and the loss in production that occurs as a result of performing shutdown maintenance activities in the continuous process industries. The discussion of these categories is summarised in the following subsections.

9.4.1 Further Studies Related to The Improvement of The SMWAM Model:

The work in this thesis results in the SMWAM model which reassesses the scope of work of shutdown maintenance in order to reduce the shutdown maintenance cost, frequency and the loss in production in the continuous process industries. Incorporating this model with the other models in the same area of research will enhance the purpose of this model. This means that further studies could be developed to incorporate this model with either the models that focused on optimising the frequency of shutdown maintenance or with those that focused on optimising the duration or with both in such away the SMWAM will be used to assess the activities of the shutdown maintenance and the other models will be used to find the optimum frequency or duration of these activities or both.

9.4.2 Further Studies Related to The Creation of Other Models:

In the first stage of this thesis, two variables other than the number of shutdown maintenance activities were found to have great effects on the frequency of shutdown maintenance and on the loss in production that occurs as a result of performing shutdown maintenance. These variables were the frequency of each shutdown maintenance activity and the timing of the shutdown maintenance. The reduction in the effects of these variables contributes to the reduction in the frequency of shutdown maintenance and in the loss in production. Therefore, further studies are needed to use the reduction of the effects of these variables as bases for the development of new models to reduce the frequency and the loss in production.

9.4.3 Further Studies Related to The General Area of Reducing The shutdown Maintenance Cost, Frequency and The Loss in Production:

In addition to the creation of models to contribute to the area of research of reducing the shutdown maintenance cost, the shutdown maintenance frequency and the loss in production, several further studies are required to contribute to this area of research in general through the following:

1. The development of technologically advanced maintenance tools and equipment that allow the shutdown maintenance activity to be carried out by in-process

maintenance programme, which will reduce the shutdown maintenance cost, frequency and the loss in production.

2. The development of technologically advanced materials and spare parts that help in extending the time between subsequent maintenance actions, which in turn reduce the shutdown maintenance frequency and the maintenance frequency in general. In addition these technologically advanced materials and spare parts could be very simple in such a way that they are easy to be fitted or used which reduce the time of performing the shutdown maintenance activity and the shutdown maintenance duration. Also, the simplicity of these technologically advanced materials and spare parts could help in carrying out the shutdown maintenance activity by in-process maintenance programme instead of the shutdown maintenance which will reduce the shutdown maintenance cost, frequency and the loss in production.
3. The development of advanced procedures for carrying out each shutdown maintenance activity and the shutdown maintenance in general which will reduce the shutdown maintenance cost and loss of production by the reduction of the following:
    a. The number of labour, materials, spare parts, tools and equipment used to perform shutdown maintenance activities.
    b. The labour and equipment working hours needed to perform shutdown maintenance activities.
    c. The number of technologically advanced materials, spare parts, tools and equipment that are used in the shutdown maintenance.
    d. The number of skilled labour needed to perform shutdown maintenance activities.
    e. The duration of shutdown maintenance.
4. The development of the quality of carrying out each shutdown maintenance activity and the shutdown maintenance in general which will reduce the shutdown maintenance cost, frequency and loss of production that occurs as a result of performing shutdown maintenance.

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APPENDICES

A

APPENDICES

1. SAMPLES OF THE LETTERS THAT HAVE BEEN SENT TO THE INTERVIEWS PARTICIPANTS:

Department of Manufacturing Engineering
Loughborough University Loughborough Leicestershire LE11 3TU UK
Switchboard: +44 (0) 1509 263171

Loughborough University

The Director of Public Relations Department
Eastern Petrochemical Company (SHARQ), SABIC Affiliate
Riyadh
Saudi Arabia

Direct Line: +44 (0) 1509 222902
Fax: +44 (0) 1509 267725
E-mail: N. D. Burns@lboro.ac.uk
http:// info.lboro.ac.uk/home.html

5 August, 1999

Dear Sir

Mr. Adel Al-Shayea is planning to conduct a survey to verify the relationship between the scope of work of shutdown maintenance and the shutdown maintenance cost and the relationship between this scope and the frequency of shutdown maintenance, in addition to, the relationship between this scope and the loss in production that is caused by performing shutdown maintenance activities. This survey is a part of the PhD research currently being performed by Mr. Adel Al-Shayea under my supervision in the Department of Manufacturing Engineering at Loughborough University.

As an important stage of this survey, Mr. Al-Shayea wants to collect information on the above relationships and on the variables that constitute them. By the help of the staff in the maintenance department in your plants, Mr. Al-Shayea can find out and understand the needed information which will be valuable to clarify the picture of these relationships and which will be kept strictly confidential.

I would appreciate it if you could allow Mr. Adel Al-Shayea (email address a.al-shayea@lboro.ac.uk or adel1414@yahoo.com or Fax No. 44 1509 238025) to collect the necessary information by conducting an interview with the staff in the maintenance department in your plant. Finally, I want to thank you and the people within the maintenance department in advance for any assistance you are able to offer.

Yours faithfully

N D Burns
Professor of Manufacturing Systems

(This is a translation of the actual letter that has been written in Arabic)

Kingdom Of Saudi Arabia
Ministry of High Education
King Saud University

4 September, 1999

The Director of Public Relations Department
Eastern Petrochemical Company (SHARQ), SABIC Affiliate
Riyadh
Saudi Arabia

Mr. Adel Al-Shayea is one of our academic staff in the University. He is conducting his PhD research on the reduction of the cost and the frequency of shutdown maintenance and the loss in production that is caused by performing shutdown maintenance activities at Loughborough University in U.K.

Mr. Al-Shayea wants to conduct an interview with the staff of the maintenance department in your plant, particularly with the planner or the manger of this department. The purpose of the interview, as it has been explained in the letter of Mr. Al-Shayea's PhD research supervisor, is to get information on the following:

1. The relationship between the scope of work of shutdown maintenance (number of shutdown maintenance activities) and the shutdown maintenance cost.
2. The relationship between this scope and the loss in production that is caused by shutdown maintenance.
3. The relationship between this scope and the shutdown maintenance frequency.

Mr. Al-Shayea prefers to conduct the interview at any time within the next week. The interview will last for approximately one hour and any provided information during this interview will be dealt with confidentially.

Your participation in this survey will be greatly appreciated and if you have any questions about the survey, please feel free to contact the university or Mr. Al-Shayea at (.................................).

Thank you.

Respectfully,

Director of Missions & Training Division
King Saud University

2. SAMPLE OF THE INTERVIEW QUESTIONS:

Suffix Business Card

INTERVIEW QUESTIONS

Section One: Personal Information

1. Name of The Participant: ....
2. Job Title: ....
3. Organisation: ....
4. Telephone: ....
5. Fax: ....
6. E-mail: ....

Section Two: Shutdown Maintenance Cost

7. Which one or more than one of the following (is/are) (a component/components) of shutdown maintenance cost?

   (Show the respondent illustrative card #1, ask him to choose one of the response choices on the card and tick the chosen response. If he asks for clarification of the terms on this card, then define the terms for him as they have been illustrated in the box below.)

> ***1. Direct cost: is the sum of all costs that can be traced directly to shutdown maintenance activities and it includes the direct cost of labour, experts, spare parts, materials, equipment and tools.***
>
> ***2. Overhead cost: is the sum of all costs related to shutdown maintenance other than those that constitute the direct cost of shutdown maintenance and it includes the indirect cost of materials, labour, tools, equipment and other expenses that are used for carrying out the whole shutdown maintenance programme.***

A. Direct cost [1]

B. Overhead cost [2]

C. Others ***(Ask the respondent to specify)*** .... [3]

....

8. What are the signs of change in (this component/these components) that describe the change in shutdown maintenance cost?

....

....

....

....

9. Is there a relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the shutdown maintenance cost?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to question #14. Otherwise, continue to carry out the following questions.)

10. How do you explain this relationship?

(Ask the respondent to draw the relationship on illustrative card #2 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the relationship:

11. (Is /Are) there (a factor/factors) that (affects/affect) this relationship?

A. Yes [1]   B. No [2]

(If the answer to this question is "No", then skip to question #14. Otherwise, continue to carry out the following questions.)

12. What (is/are) (this factor/these factors) that (affects/affect) this relationship?

....

....

....

13. How do you explain the effect of (this factor/each one of these factors) on this relationship?

(Ask the respondent to draw the (relationship/relationships) on card #3 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the (relationship/relationships):

14. ***(Read the following question without the words (another) and (other) if you are transferred from question #9. Otherwise, read the question as it appears below.)***

(Is/Are) there (another factor/other factors) that (affects/affect) the cost of shutdown maintenance?

A. Yes [1]   B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following questions.)

15. What (is/are) (this factor/ these factors)?

....

....

....

16. How do you explain the relationship between (this factor/each one of these factors) and the shutdown maintenance cost?

(Ask the respondent to draw the (relationship/relationships) on illustrative card #4 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the (relationship/relationships):

(If there is only one factor that affects the cost of shutdown maintenance, then skip to the next section. Otherwise, continue to carry out the questions of this section.)

17. Do these factors have relationships with each other?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following question.)

18. How do you explain these relationships?

(Ask the respondent to draw these relationships on illustrative card #5 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

Drawing of the relationships:

Section Three: The Loss in Production as a Result of Performing Shutdown Maintenance

(Please, read for the participant the explanation in the box below that explains the loss in production.)

The loss in production as a result of performing shutdown maintenance is the loss of the opportunity to produce plant products as a result of preferring to shut down the production line in order to perform shutdown maintenance activities.

19. Is there a relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the loss in production that is caused by performing shutdown maintenance?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to question #24. Otherwise, continue to carry out the following questions.)

20. How do you explain this relationship?

(Ask the respondent to draw the relationship on illustrative card #6 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the relationship:

21. (Is /Are) there (a factor/factors) that (affects/affect) this relationship?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to question #24. Otherwise, continue to carry out the following questions.)

22. What (is/are) the (factor/factors) that (affects/affect) this relationship?

....

....

....

23. How do you explain the effect of (this factor/each one of these factors) on this relationship?

(Ask the respondent to draw the (relationship/relationships) on illustrative card #7 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the (relationship/relationships):

24. ***(Read the following question without the words (another) and (other) if you are transferred from question #19. Otherwise, read the question as it appears below.)***

(Is/Are) there (another factor/other factors) that (affects/affect) the loss in production that is caused by performing shutdown maintenance?

A. Yes [1]   B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following questions.)

25. What (is/are) (this factor/ these factors)?

....

....

....

26. How do you explain the relationship between (this factor/each one of these factors) and the loss in production that is caused by performing shutdown maintenance?

(Ask the respondent to draw the (relationship/relationships) on illustrative card #8 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the (relationship/relationships):

(If there is only one factor that affects the loss in production, then skip to the next section. Otherwise, continue to carry out the questions of this section.)

27. Do these factors have relationships with each other?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following question.)

28. How do you explain these relationships?

(Ask the respondent to draw the relationships on illustrative card #9 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

Drawing of the relationships:

Section Four: Shutdown Maintenance Frequency

29. Is there a relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and the frequency of shutdown maintenance?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to question #34. Otherwise, continue to carry out the following questions.)

30. How do you explain this relationship?

(Ask the respondent to draw the relationship on illustrative card #10 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the relationship:

31. (Is /Are) there (a factor/factors) that (affects/affect) this relationship?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to question #34. Otherwise, continue to carry out the following questions.)

32. What (is/are) the (factor/factors) that (affects/affect) this relationship?

....

....

....

33. How do you explain the effect of (this factor/each one of these factors) on this relationship?

(Ask the respondent to draw the (relationship/relationships) on illustrative card #11 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

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....

Drawing of the (relationship/relationships):

34. ***(Read the following question without the words (another) and (other) if you are transferred from question #29. Otherwise, read the question as it appears below.)***

(Is/Are) there (another factor/other factors) that (affects/affect) the frequency of shutdown maintenance?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following questions.)

35. What (is/are) (this factor/ these factors)?

....

....

....

36. How do you explain the relationship between (this factor/each one of these factors) and the frequency of shutdown maintenance?

(Ask the respondent to draw the (relationship/relationships) on illustrative card #12 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

Drawing of the (relationship/relationships):

(If there is only one factor that affects the frequency of shutdown maintenance, then skip to the next section. Otherwise, continue to carry out the questions of this section.)

37. Do these factors have relationships with each other?

A. Yes [1]   B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following question.)

38. How do you explain these relationships?

(Ask the respondent to draw the relationships on illustrative card #13 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

Drawing of the relationships:

Section Five: Shutdown Maintenance Duration

(Use illustrative cards #3,4,7,8,11,12. If the duration of shutdown maintenance is one of the factors that have been mentioned by the respondents in any one of these cards, then continue to ask the following questions. Otherwise, skip to the next section.)

39. (Is/Are) there (a factor/factors) that (affects/affect) the duration of shutdown maintenance?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following questions.)

40. What (is/are) (this factor/these factors)?

....

....

....

41. How do you explain the relationship between (this factor/each one of these factors) and the duration of shutdown maintenance?

(Ask the respondent to draw the (relationship/relationships) on illustrative card #14 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

Drawing of the (relationship/relationships):

(If there is only one factor that affects the duration of shutdown maintenance, then skip to the next section. Otherwise, continue to carry out the questions of this section.)

42. Do these factors have relationships with each other?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following question.)

43. How do you explain these relationships?

(Ask the respondent to draw the relationships on illustrative card #15 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

Drawing of the relationships:

Section Six: Problems That are Associated with The Reduction of The Number of Shutdown Maintenance Activities (Scope of Work of Shutdown Maintenance)

44. (Is/Are) there (any problem/problems) that (is/are) associated with the reduction of the number of shutdown maintenance activities (scope of work of shutdown maintenance)?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following questions.)

45. What (is/are) (this problem/ these problems)?

....

....

....

46. How do you explain the relationship between the number of shutdown maintenance activities (scope of work of shutdown maintenance) and (this problem/each one of these problems)?

(Ask the respondent to draw the (relationship/relationships) on illustrative card #16 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

....

Drawing of the (relationship/relationships):

(If there is only one problem that is associated with the reduction of the number of shutdown maintenance activities (scope of work of shutdown maintenance), then skip to the next section. Otherwise, continue to carry out the questions of this section.)

47. Do these problems have relationships with each other?

A. Yes [1] B. No [2]

(If the answer to this question is "No", then skip to the next section. Otherwise, continue to carry out the following question.)

48. How do you explain these relationships?

(Ask the respondent to draw the relationships on illustrative card #17 by using boxes to represent variables and arrows with (+) sign or (-) sign to represent positive and negative relationships respectively.)

....

....

....

Drawing of the relationships:

Section Seven: General Information

49. How old is the plant?

....

50. How many machines and equipment does the plant have as a part of production facilities?

....

3. SAMPLES OF THE COVER AND THE ADVANCE LETTERS THAT HAVE BEEN SENT TO THE MAIL QUESTIONNAIRE PARTICIPANTS:

Department of Manufacturing Engineering
Loughborough University Loughborough Leicestershire LE11 3TU UK
Switchboard: +44 (0) 1509 263171

Loughborough University

The Maintenance Department Planner
National Industrial Gases (GAS), SABIC Affiliate
Jubil Industrial City
Saudi Arabia

15 March, 2000

Dear Participant:

Reducing the shutdown maintenance cost and the frequency, in addition to, the loss in production that is caused by performing shutdown maintenance activities through the reduction of the scope of work of shutdown maintenance is the subject of a PhD research currently being performed in the department of Manufacturing Engineering at Loughborough University.

The attached questionnaire is designed to help in studying this subject. In particular, it is designed to help in verifying the relationships between the above mentioned variables of interest and the scope of work of shutdown maintenance (the number of shutdown maintenance activities) by collecting data about the change in these variables after the change in the number of shutdown maintenance activities naturally occurred. In addition, it is aimed at the planner level in the maintenance department. In other words, it is aimed at your level since you are the one who can give a correct picture of the relationships between these variables. Therefore, you have been randomly selected in order to provide the required information that will help to understand this subject and which will be kept strictly confidential.

Because of the importance of the attached questionnaire to the research subject, I would appreciate it if you could take the time to complete the questionnaire and return it back to the address provided at the end of it. Also, it would be very helpful to have your completed questionnaire returned by the end of March 2000.

Finally, if you would like to receive a copy of the results, please check the box at the end of the questionnaire and complete the address. Your participation in this survey will be greatly appreciated and if you have any questions or concerns, please feel free to contact me at (Mr. Al-Shayea: email address a.al-shayea@lboro.ac.uk or adel1414@yahoo.com or Fax & telephone No. 44 1509 238025). Thank you very much for your time and co-operation.

Respectfully yours,

Adel Al-Shayea

(This is a direct translation of the actual letter that has been written in Arabic)

Kingdom Of Saudi Arabia
Ministry of High Education
King Saud University

3 March, 2000

Mr. Yousef A. Turki
The Manager of the Maintenance Department
National Industrial Gases (GAS), SABIC Affiliate
Jubil Industrial City
Saudi Arabia

Mr. Adel Al-Shayea is one of our academic staff in the University. He is conducting his PhD research on the reduction of the cost and the frequency of shutdown maintenance and the loss in production that is caused by performing shutdown maintenance activities at Loughborough University in U.K.

Mr. Al-Shayea is in process of conducting a survey about the above mentioned subject and he has randomly selected your plant from a list of different continuous process plants in Saudi Arabia to take part in this survey. He is looking for the participation of your maintenance department, particularly the participation of the planner since the information that your department will provide will help in producing accurate survey results. The purpose of the survey is to collect data about the following relationships and the variables that constitute them in order to use this data in the verification process of these relationships and in turn to use the verified relationships in the development of a model that reduces the cost and the frequency of shutdown maintenance and the loss in production that is associated with performing shutdown maintenance activities:

1. The relationship between the scope of work of shutdown maintenance and the shutdown maintenance cost.
2. The relationship between this scope and the loss in production that is caused by shutdown maintenance.
3. The relationship between this scope and the shutdown maintenance frequency.

Mr. Al-Shayea prefers to conduct the survey by sending questionnaires to each participant. Therefore, you will receive a questionnaire from Mr. Al-Shayea in the post mail, e-mail, or the fax. When you receive the questionnaire, please ask the planner or any person you think that he has the required information to fill it out and return it to Mr. Al-Shayea as soon as possible. The information that your department will provide will be dealt with confidentially.

Your participation in this survey will be greatly appreciated and if you have any questions about the survey, please feel free to contact the university or Mr. Al-Shayea at (..................................).

Thanks for your help.

Sincerely,

Director of Missions & Training Division
King Saud University

4.SAMPLE OF THE MAIL QUESTIONNAIRE:

In the following sections, please choose any two subsequent shutdown maintenance programmes between which a change in the number of shutdown maintenance activities occurred. Then answer all the questions in all sections by comparing the results of these two shutdown maintenance programmes. Also, please note the meaning of the following:

1. **Last Shutdown Maintenance: means the shutdown maintenance, which was performed directly after the occurrence of the change in the number of shutdown maintenance activities.**
2. **Previous Shutdown Maintenance: means the shutdown maintenance which is before the last shutdown maintenance and which was performed before the occurrence of the change in the number of shutdown maintenance activities.**

Section One: Changes in The Shutdown Maintenance Activities

1.1 By comparing the results of the last shutdown maintenance with those of the previous one, what is the percentage of increase or decrease in the number of shutdown maintenance activities?

% Increase [ ] % Decrease [ ]

Using the table below, please explain the change in the following variables by comparing their values in the last shutdown maintenance with their values in the previous one. Then write the results of the comparison in the cells that are provided in front of each variable in the table. The results should be written in the form of either:

1. **A percentage of increase in the <u>% of increase</u> cell if the results indicate an increase in the value.**
2. **A percentage of decrease in the <u>% of decrease</u> cell if the results indicate a decrease in the value.**
3. **A tick in the <u>unchanged</u> cell if the results indicate an unchanged in the value.**

	% of Increase	Unchanged 0%	% of Decrease
1.2 Average cost of shutdown maintenance activities.			
1.3 The shortest frequency (the time between successive actions of performing shutdown maintenance activity) among the frequencies of the shutdown maintenance activities.			
1.4 The average time length of the shutdown maintenance activities that are on the critical path.			
1.5 The average time length of the shutdown maintenance activities that are not on the critical path.			

Section Two: Changes in The Shutdown Maintenance Cost and The Variables That Are Related to It

Using the table below, please explain the change in the following variables by comparing their values in the last shutdown maintenance with their values in the previous one. Then write the results of the comparison in the cells that are provided in front of each variable in the table. The results should be written in the form of either:

1. **A percentage of increase in the % of increase cell if the results indicate an increase in the value.**
2. **A percentage of decrease in the % of decrease cell if the results indicate a decrease in the value.**
3. **A tick in the unchanged cell if the results indicate an unchanged in the value.**

	% of Increase	Unchanged 0%	% of Decrease
2.1 The shutdown maintenance direct cost.			
2.2 The shutdown maintenance overhead cost.			
2.3 Shutdown maintenance cost.			

Section Three: Changes in The Loss of Production and The Variables That Are Related to It

Using the table below, please explain the change in the following variables by comparing their values in the last shutdown maintenance with their values in the previous one. Then write the results of the comparison in the cells that are provided in front of each variable in the table. The results should be written in the form of either:

1. **A percentage of increase in the % of increase cell if the results indicate an increase in the value.**
2. **A percentage of decrease in the % of decrease cell if the results indicate a decrease in the value.**
3. **A tick in the unchanged cell if the results indicate an unchanged in the value.**

	% of Increase	Unchanged 0%	% of Decrease
3.1 The duration of shutdown maintenance (the time necessary to perform shutdown maintenance activities).			
3.2 The number of times the plant experiences unavailability of maintenance resources on time during the shutdown maintenance.			
3.3 The number of problems associated with scheduling shutdown maintenance activities such as ideal times, series scheduling instead of parallel, …, etc.			
3.4 The level of the demand of the production processes during the period of performing shutdown maintenance.			
3.5 The loss in production as a result of shutdown maintenance.			

Section Four: Changes in The Frequency of Shutdown Maintenance and The Problems That Are Associated With The Change in The Number of Shutdown Maintenance Activities

Using the table below, please explain the change in the following variables by comparing their values in the last shutdown maintenance with their values in the previous one. Then write the results of the comparison in the cells that are provided in front of each variable in the table. The results should be written in the form of either:

1. **A percentage of increase in the <u>% of increase</u> cell if the results indicate an increase in the value.**
2. **A percentage of decrease in the <u>% of decrease</u> cell if the results indicate a decrease in the value.**
3. **A tick in the <u>unchanged</u> cell if the results indicate an unchanged in the value.**

	% of Increase	Unchanged 0%	% of Decrease
4.1 The frequency of shutdown maintenance (time between successive shutdown maintenance programmes).			
4.2 The number of the safety problems associated with the change in the number of shutdown maintenance activities.			
4.3 The number of the operational problems associated with the change in the number of shutdown maintenance activities.			
4.4 The number of economical problems associated with the change in the number of shutdown maintenance activities.			

Section Five: General Information

In the following questions, please tick the appropriate box if applicable.

5.1 How old is the plant (in terms of years)?

- 5 years and Under [1]
- 6 – 10 years [2]
- 11 – 15 years [3]
- 16 – 20 years [4]
- 21 – 25 years [5]
- 26 – 30 years [6]
- 31 years and Over [7]

1.2 In which industrial sector does the plant operate?

Petroleum [1]
Petrochemicals [2]
Chemicals [3]
Plastics/Rubber [4]
Industrial Gases [5]
Other, please specify ....

1.3 In which province is the plant located?

Central [1]
Eastern [2]
Western [3]
Northern [4]
Southern [5]

1.4 How many machines and equipment does the plant have as a part of the production facilities?

(Please counts each machine and equipment either small or big)

....

Section Six: Comments

Please add any comment that you think it is relevant to the subject

....

....

....

....

Do you prefer a summary of the result to be sent to you? Yes ☐ No ☐

If yes, please fill the following:

Name: .... Address: ....

Telephone: ....

Fax: .... E-mail: ....

I scenically appreciate your time and co-operation. Please check to make sure that you have not skipped any question, and then return the questionnaire by using the provided envelope.

Adel Al-Shayea

Department of Manufacturing Engineering

Loughborough University

Loughborough, LE 11 3TU

Tel/Fax: +441509238025

E-mail: Adel 1414@yahoo.com **or A.Al-Shayea@lboro.ac.uk**

5. INTERVIEWS DATA:

Section One: Personal Information

The data in this section is about the personal information and not vulnerable to analysis.

Section Two: Shutdown Maintenance Cost

Plant	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18
1	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
2	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
3	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
4	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
5	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
6	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
7	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
8	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
9	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
10	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
11	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
12	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
13	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
14	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
15	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
16	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
17	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
18	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
19	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
20	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
21	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
22	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
23	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
24	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
25	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
26	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
27	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****
28	A,B	*	1	Indirect	1	**	Intervene	1	***	Indirect	1	****

Note: (*) The participants stated that the signs that describe the changes in the shutdown maintenance cost are:

1. Changes in the number of (direct, indirect) labour, materials, spare parts, tools and equipment.
2. Changes in the number of (direct, indirect) labour and equipment working hours.
3. Changes in the number of (direct, indirect) technological advanced maintenance materials, spare parts, tools and equipment.
4. Changes in the number of skilful labour.
5. Changes in the prices of the direct and the indirect resources used in shutdown maintenance.

(**) The participants stated that the variables that affect the relationships between the number of shutdown maintenance activities and the shutdown maintenance cost are the direct cost of shutdown maintenance, the overhead cost of shutdown maintenance and the duration of shutdown maintenance.

(***) The participants stated that the other variables that affect the shutdown maintenance cost are the cost of each shutdown maintenance activity, the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, the unavailability of the shutdown maintenance resources when required and the inaccuracy of scheduling the shutdown maintenance activities.

(****) The participants stated that the relationships between the variables that affect the shutdown maintenance cost are:

1. The relationship between the number of shutdown maintenance activities and the shutdown maintenance duration.
2. The relationship between the shutdown maintenance duration and the direct cost of shutdown maintenance.
3. The relationship between the shutdown maintenance duration and the overhead cost of shutdown maintenance.

Section Three: The Loss in Production as a Result of Performing Shutdown Maintenance

Plant	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28
1	1	Indirect	1	*	Intervene	1	**	***	2	-
2	1	Indirect	1	*	Intervene	1	**	***	2	-
3	1	Indirect	1	*	Intervene	1	**	***	2	-
4	1	Indirect	1	*	Intervene	1	^^	Indirect	2	-
5	1	Indirect	1	*	Intervene	1	**	***	2	-
6	1	Indirect	1	*	Intervene	1	**	***	2	-
7	1	Indirect	1	*	Intervene	1	**	***	2	-
8	1	Indirect	1	*	Intervene	1	**	***	2	-
9	1	Indirect	1	*	Intervene	1	**	***	2	-
10	1	Indirect	1	*	Intervene	1	**	***	2	-
11	1	Indirect	1	*	Intervene	1	**	***	2	-
12	1	Indirect	1	*	Intervene	1	^^	Indirect	2	-
13	1	Indirect	1	*	Intervene	1	^^	Indirect	2	-
14	1	Indirect	1	*	Intervene	1	**	***	2	-
15	1	Indirect	1	*	Intervene	1	**	***	2	-
16	1	Indirect	1	*	Intervene	1	**	***	2	-
17	1	Indirect	1	*	Intervene	1	**	***	2	-
18	1	Indirect	1	*	Intervene	1	**	***	2	-
19	1	Indirect	1	*	Intervene	1	^^	Indirect	2	-
20	1	Indirect	1	*	Intervene	1	**	***	2	-
21	1	Indirect	1	*	Intervene	1	**	***	2	-
22	1	Indirect	1	*	Intervene	1	**	***	2	-
23	1	Indirect	1	*	Intervene	1	**	***	2	-
24	1	Indirect	1	*	Intervene	1	**	***	2	-
25	1	Indirect	1	*	Intervene	1	^^	Indirect	2	-
26	1	Indirect	1	*	Intervene	1	**	***	2	-
27	1	Indirect	1	*	Intervene	1	**	***	2	-
28	1	Indirect	1	*	Intervene	1	**	***	2	-

Note: (*) The participants stated that the variable that affects the relationship between the number of shutdown maintenance activities and the loss in production that occurs as a result of performing shutdown maintenance is the shutdown maintenance duration.

(**) These participants stated that the other variables that affect the loss in production that occurs as a result of performing shutdown maintenance are the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, the unavailability of the shutdown maintenance resources when required, the inaccuracy of scheduling the shutdown maintenance activities and the demand of the production process during the period of performing shutdown maintenance.

(^^) These participants stated that the other variables that affect the loss in production that occurs as a result of performing shutdown maintenance are the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, the unavailability of the shutdown maintenance resources when required and the inaccuracy of scheduling the shutdown maintenance activities.

(***) These participants stated that the demand of the production process during the period of performing shutdown maintenance has direct relationship with the loss in production whereas the other independent variables have indirect relationship.

Section Four: Shutdown Maintenance Frequency

Plant	Q29	Q30	Q31	Q32	Q33	Q34	Q35	Q36	Q37	Q38
1	1	Direct	2	-	-	1	*	Direct	2	-
2	1	Direct	2	-	-	1	*	Direct	2	-
3	1	Direct	2	-	-	1	*	Direct	2	-
4	1	Direct	2	-	-	1	*	Direct	2	-
5	1	Direct	2	-	-	1	*	Direct	2	-
6	1	Direct	2	-	-	1	*	Direct	2	-
7	1	Direct	2	-	-	1	*	Direct	2	-
8	1	Direct	2	-	-	1	*	Direct	2	-
9	1	Direct	2	-	-	1	*	Direct	2	-
10	1	Direct	2	-	-	1	*	Direct	2	-
11	1	Direct	2	-	-	1	*	Direct	2	-
12	1	Direct	2	-	-	1	*	Direct	2	-
13	1	Direct	2	-	-	1	*	Direct	2	-
14	1	Direct	2	-	-	1	*	Direct	2	-
15	1	Direct	2	-	-	1	*	Direct	2	-
16	1	Direct	2	-	-	1	*	Direct	2	-
17	1	Direct	2	-	-	1	*	Direct	2	-
18	1	Direct	2	-	-	1	*	Direct	2	-
19	1	Direct	2	-	-	1	*	Direct	2	-
20	1	Direct	2	-	-	1	*	Direct	2	-
21	1	Direct	2	-	-	1	*	Direct	2	-
22	1	Direct	2	-	-	1	*	Direct	2	-
23	1	Direct	2	-	-	1	*	Direct	2	-
24	1	Direct	2	-	-	1	*	Direct	2	-
25	1	Direct	2	-	-	1	*	Direct	2	-
26	1	Direct	2	-	-	1	*	Direct	2	-
27	1	Direct	2	-	-	1	*	Direct	2	-
28	1	Direct	2	-	-	1	*	Direct	2	-

Note: (*) The participants stated that the other variable that affects the shutdown maintenance frequency is the frequency of each shutdown maintenance activity.

Section Five: Shutdown Maintenance Duration

Plant	Q39	Q40	Q41	Q42	Q43	Plant	Q39	Q40	Q41	Q42	Q43
1	1	*	Direct	2	-	15	1	*	Direct	2	-
2	1	^	Direct	2	-	16	1	^	Direct	2	-
3	1	*	Direct	2	-	17	1	*	Direct	2	-
4	1	*	Direct	2	-	18	1	*	Direct	2	-
5	1	*	Direct	2	-	19	1	*	Direct	2	-
6	1	*	Direct	2	-	20	1	*	Direct	2	-
7	1	*	Direct	2	-	21	1	*	Direct	2	-
8	1	*	Direct	2	-	22	1	*	Direct	2	-
9	1	*	Direct	2	-	23	1	*	Direct	2	-
10	1	*	Direct	2	-	24	1	*	Direct	2	-
11	1	^	Direct	2	-	25	1	*	Direct	2	-
12	1	*	Direct	2	-	26	1	*	Direct	2	-
13	1	*	Direct	2	-	27	1	*	Direct	2	-
14	1	*	Direct	2	-	28	1	*	Direct	2	-

Note: (*) These participants stated that the variables that affect the shutdown maintenance duration are the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path, the unavailability of the shutdown maintenance resources when required, the inaccuracy of scheduling the shutdown maintenance activities and the number of shutdown maintenance activities.

(^) These participants stated that the variables that affect the shutdown maintenance duration are the time length of each shutdown maintenance activity on the critical path, the time length of each shutdown maintenance activity not on the critical path and the number of shutdown maintenance activities.

Section Six: Problems That are Associated with The Reduction of The Number of Shutdown Maintenance Activities (Scope of Work of Shutdown Maintenance)

Plant	Q44	Q45	Q46	Q47	Q48	Plant	Q44	Q45	Q46	Q47	Q48
1	1	*	Direct	2	-	15	1	*	Direct	2	-
2	1	*	Direct	2	-	16	1	*	Direct	2	-
3	1	*	Direct	2	-	17	1	*	Direct	2	-
4	1	*	Direct	2	-	18	1	*	Direct	2	-
5	1	*	Direct	2	-	19	1	*	Direct	2	-
6	1	*	Direct	2	-	20	1	*	Direct	2	-
7	1	*	Direct	2	-	21	1	*	Direct	2	-
8	1	*	Direct	2	-	22	1	*	Direct	2	-
9	1	*	Direct	2	-	23	1	*	Direct	2	-
10	1	*	Direct	2	-	24	1	*	Direct	2	-
11	1	*	Direct	2	-	25	1	*	Direct	2	-
12	1	*	Direct	2	-	26	1	*	Direct	2	-
13	1	*	Direct	2	-	27	1	*	Direct	2	-
14	1	*	Direct	2	-	28	1	*	Direct	2	-

Note: (*) The participants stated that there are three types of problems that are associated with the change in the number of shutdown maintenance activities. These are the safety problems, the operational problems and the economic problems.

Section Seven: General Information

Plant	Q49	Q50	Plant	Q49	Q50
1	17	1102	15	5	1056
2	6	800	16	33	1267
3	12	650	17	9	865
4	18	787	18	19	1289
5	4	481	19	4	1043
6	8	1180	20	13	561
7	17	903	21	17	973
8	27	1270	22	22	200
9	8	632	23	9	534
10	3	201	24	18	380
11	4	468	25	12	890
12	12	798	26	23	1176
13	14	1540	27	19	1512
14	18	576	28	9	551

APPENDICES

6. THE ABSTRACT AND THE INTRODUCTION OF THE PAPER REPRESENTED TO THE 8TH INTERNATIONAL ANNUAL CONFERENCE OF THE EUROPEAN OPERATIONS MANAGEMENT ASSOCIATION:

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Shutdown Maintenance Scope of Work Assessment Model (SMWAM): Model for Reducing the Shutdown Maintenance Cost and the Loss of Production at the Continuous Process Plants in Saudi Arabia

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Abstract:

The aim of this paper is to find a way to reduce the shutdown maintenance cost and the loss in the production that is caused by performing shutdown maintenance activities. Following an assessment of the maintenance scope of work, the paper proposes a model for reducing the shutdown maintenance cost and the loss in production without increasing the number of unplanned shutdowns. In addition, the paper presents how the model is being applied in a Saudi Arabian continuous process plant.

Keywords: Shutdown Maintenance Scope of Work, Exclusionary screening.

Introduction:

In the industrial world, one of the challenging issues that faces continuous process industries is the reduction of shutdown maintenance cost and the loss in production that occurs as a result of performing shutdown maintenance activities while improving the availability of machines and equipment. In other words, the challenge is to increase profit whilst reducing the total maintenance cost.

This challenge stimulated the research in this paper as well as the work in previous research to find methods to reduce the cost of shutdown maintenance and the loss in production. Previous research can be classified in to three categories. In the first and second categories, the approaches are aimed at reducing either the duration of shutdown maintenance or its frequency without increasing its cost in order to reduce the loss in the production, which in turn increases profit (Ashayeri et al, 1996; Baughman et al, 1996; Chareonsuk et al, 1997; Koppelman et al. 1994; Mathew et al, 1993; Shuffelton, 1998). In the third category, the approach is aimed at the reduction in the number of shutdown maintenance activities (scope of work of shutdown maintenance) which will reduce both the duration and the frequency of shutdown maintenance (Al-Shayea, 2000). This third approach greatly contributes to the reduction of shutdown maintenance cost and the loss in production that is caused by shutdown maintenance.

In this paper, the discussion will focus on a model that is based on the positive relationship between the scope of work of shutdown maintenance and the shutdown maintenance cost and the other positive relationship between the scope of work of shutdown maintenance and the loss of production. In addition, the discussion in this paper will include an explanation of how the model is used by means of a case study in a selected Saudi-Arabian process plant.