CHAPTER 1: RATIONALE AND STRUCTURE OF THE THESIS

1.1 Introduction

Machineries are designed with the objective that their operating systems meet customer requirement with a predetermined quality level and maximize the utilization of available production capacity. As these machines age the un-planned failures occur, causing the system performance to drift away from its initial state. Therefore, the function of the system must be periodically restored to the desired level; this is practically achieved by maintenance operations. The maintenance actions which are normally classified as Corrective/break down maintenance includes all actions performed as a result of a failure to restore an item to a specified working condition, while preventive maintenance (PM) includes all actions performed on an operating machinery to restore it to a better condition. A maintenance strategy is a structured combination of these two maintenance actions, that describe the events (e.g. failure, passing of time, certain machine condition, etc.) and the type of actions they trigger (i.e. inspection, repair, maintenance or replacement).

Effective utilization of plant and machinery in construction helps to ensure timely execution and completion of projects, by minimizing the chaos and confusion created by manual means of execution methods. They provide supports to the construction contractor by providing enhanced output, reduced manpower requirement and ease of work. The plant and machinery dependency rate has become very high due to fast track projects which have always become a necessity in the present time (John.M, 2002). Moreover, the inter dependent activities in construction industry requires the continuous and consistent working of all the machineries at all times without interruption for the better progress of the projects, enhanced productivity levels and desired profits (Geert.W.L., 2002).

In the United Arab Emirates (UAE), the construction projects are generally awarded to contractors based on their past performance and the machinery resources and facilities owned by them. The construction industry of UAE generally follows planned and preventive maintenance for construction machinery while there are few organizations that do not have a proper maintenance department in place and for them the trend is the reactive maintenance

only. The preventive maintenance efficiency of the region has been generally recorded as 80 to 85 %. On the lags, 27% are attributable to breakdown maintenance issues. It gives us the inference that even with systematic preventive maintenance execution, the breakdowns are happening and further they influence in the reduction level of the preventive maintenance efficiencies. A detailed study on this has been given in subsequent chapters.

Construction machinery breakdowns are inevitable due to:

- Extreme climatic conditions prevailing
- Lack of planned maintenance practices
- Missed Preventive Maintenance Schedules
- Machinery not spared on time for preventive maintenance
- Lack of control and safety devices
- Failure of control mechanisms
- Operative's inefficiency
- Inferior parts fitment
- Poor workmanships
- Poor working environment
- Age of the machines
- Over utilization of various systems

Construction plant stumbling due to breakdown creates negative impact on the project completion time and affects the credibility of the civil contractor in the long run. A swift action during breakdowns is the need felt in the construction machinery maintenance system. Further, to cater to the fast changing environment and requirements of the industry, preventive and corrective maintenance matrix of present times need effective evaluation and continuous improvements to keep their suitability in place.

1.2 Research Problem

When a failure/breakdown occurs to a construction plant/machinery, the immediate reaction of the entire crew associated is to panic, as many activities associated with that machinery's intended output/production tend to get stopped and triggers tremendous pressure to the maintenance team. During such breakdowns, the maintenance supervisor faces a huge

amount of pressure and responsibility. In the absence of an exclusive maintenance department, the production team as well faces the pressure, as there will be dependency of external agencies. As breakdowns on plant and machinery create lot of mental agony to the end users as well as to the maintenance crew, a quick reaction time and rectification of the breakdown alone is considered to be vital for continuation of construction activities. If the breakdowns are executed in a systematic manner, it ensures:

- Minimal ambiguity to all concerned
- Reduction of chaos
- Easy approach and management of the breakdowns
- Reduction of any unwanted activities
- Reduction in delay time in the breakdown maintenance process

A maintenance questionnaire survey was conducted amongst various plant and machinery managers and maintenance crew members of construction companies, construction machinery rental companies and construction machinery dealer organizations. The questions were focused on three main areas namely, a) Breakdown maintenance concepts and beliefs b) Maintenance crew stress levels during breakdowns and c) Breakdown maintenance optimization needs. Total of 19 questions were asked. The answers as valued as - Fully Agree, Agree, Partly Agree, Partly Disagree, Disagree and No Comments. No comments answers were rechecked with the participants to know their understanding levels of the particular questions, and the necessary clarifications were recorded.

Total 72 persons who are hailing from various positions including work supervisors, foremen, service engineers, maintenance engineers, workshop managers, product support managers of various organizations in the UAE took part in the survey. The experience levels ranged from 3 years to 25 years. Most of the results were in favour of a better maintenance system, while most of them voiced their opinion in favour of the research considerations. The abstract of the survey results is detailed in table 1.1. Sample questionnaire forms with details are enclosed in Annexure B.

It is evident from most of the maintenance personnel of the United Arab Emirates that if there is a proper system of approach designed to manage nearly all the construction plant and

machinery failures/breakdowns, as to: how to approach it, how to relate it, detailing the whole list of activities to be performed, etc. which all be part of a breakdown maintenance management, it will lead to better result in the management of breakdown maintenance. Additionally the maintenance crew will also be prepared with the right tools, tackles, spares, workplace, supervision, outside repair facilities, general readiness with predetermined time frame and have a manageable situation for any complicated breakdown issues. This situation will facilitate an effective breakdown maintenance management system to the owner of the plant and will result in reduction of overall duration of the construction machinery breakdowns.

Table 1.1 Compilation of Questionnaire results on breakdown maintenance of Construction Plant and Machinery

Questionaire Survey Results on Construction Machinery Breakdown Maintenance		
Attributes	**Questions**	**Survey Results**
Breakdown Maintenance Concepts and Beliefs	Goals - Zero Breakdown	88%
	Breakdown Effects other machinery/trade	83%
	Breakdowns happen even with planned maintenance	79%
	Machinery Mix of old and new at projects	79%
	Multiple machinery brands of same machinery	58%
	Loss of Morale of Crew	50%
	Crew Interest is less	50%
	Turn Around Time difficult to estimate	71%
	Techincian Competency - Key Factor	83%
	Level of Understanding less for new technicians	75%
Maintenance crew stress levels - Conventional Breakdown Rectification	Maintenance Call makes crew panic	25%
	Responsibility of Technicians high during breakdowns	71%
	Responsibility of Supervisor high during breakdowns	88%
	Shifting tendency of work prevails	54%
	Breakdown Cause - knowledge lacking	50%
Breakdown Maintenance Optimization	Planning and Methodology required	83%
	Resources - always lacking	83%
	Method of Rectification helps	88%
	BMP Process felt as a need	79%

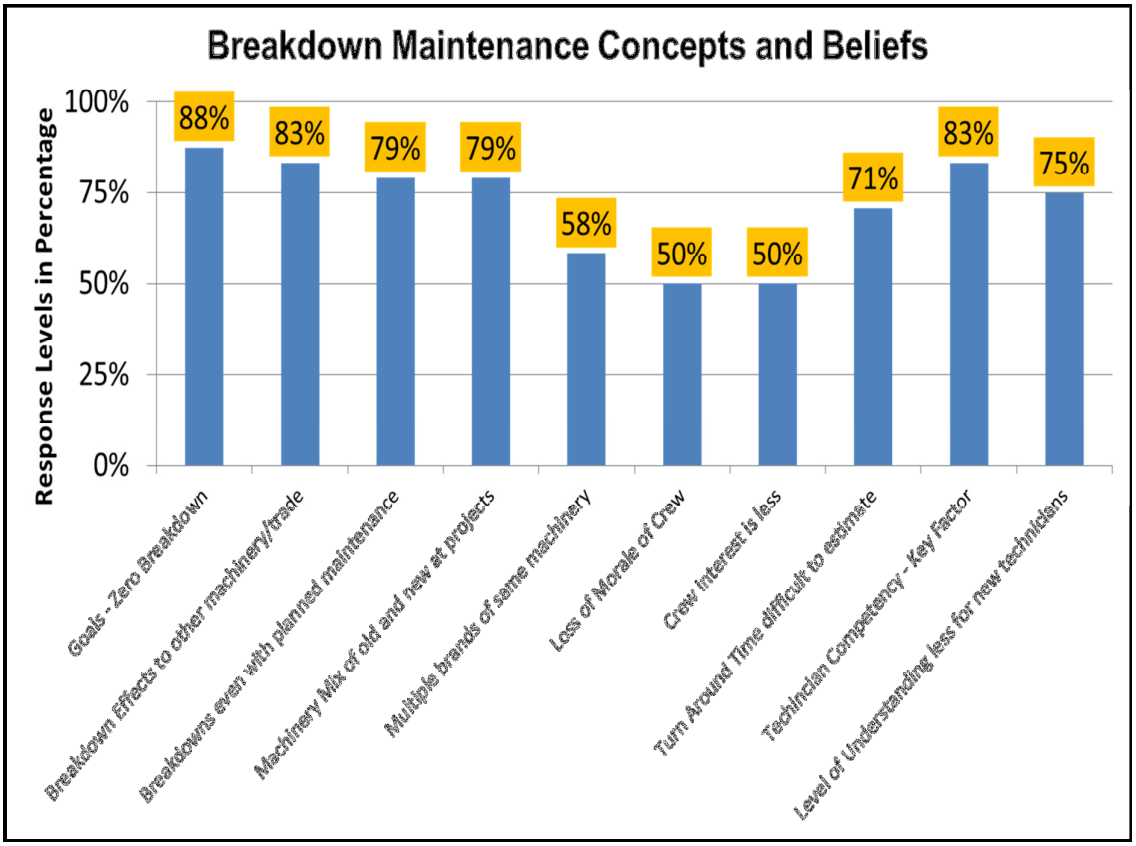

Figure 1.1 Survey Results on Breakdown Maintenance Concepts and Beliefs for Construction Machinery

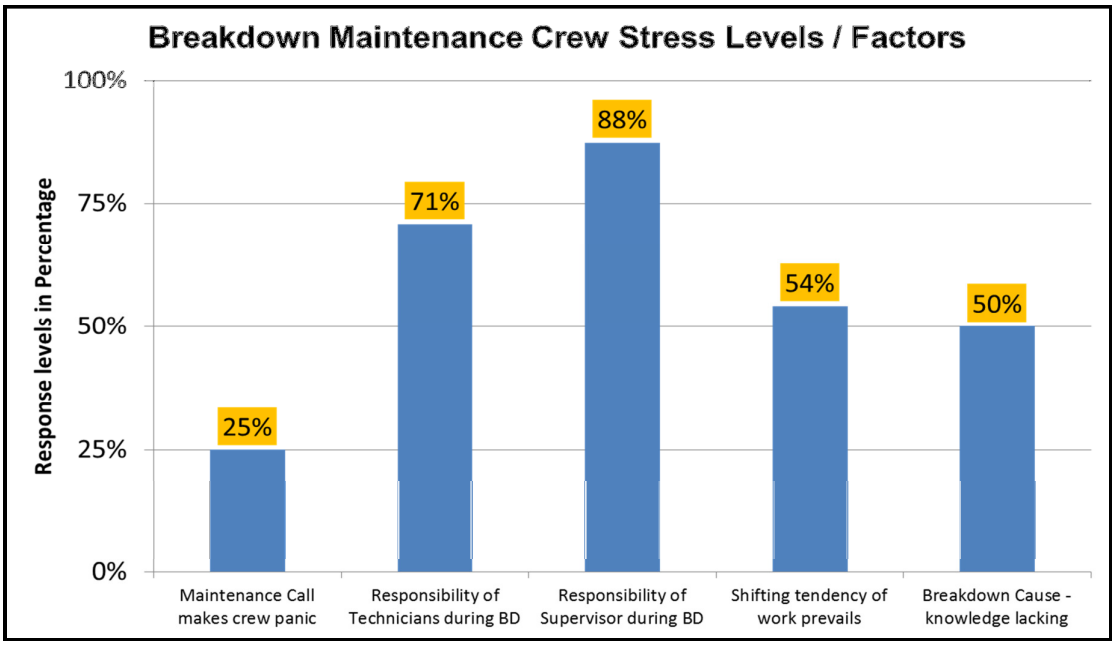

Figure 1.2 Survey Results on Breakdown Maintenance Crew Stress Levels during Breakdowns on Construction Machinery

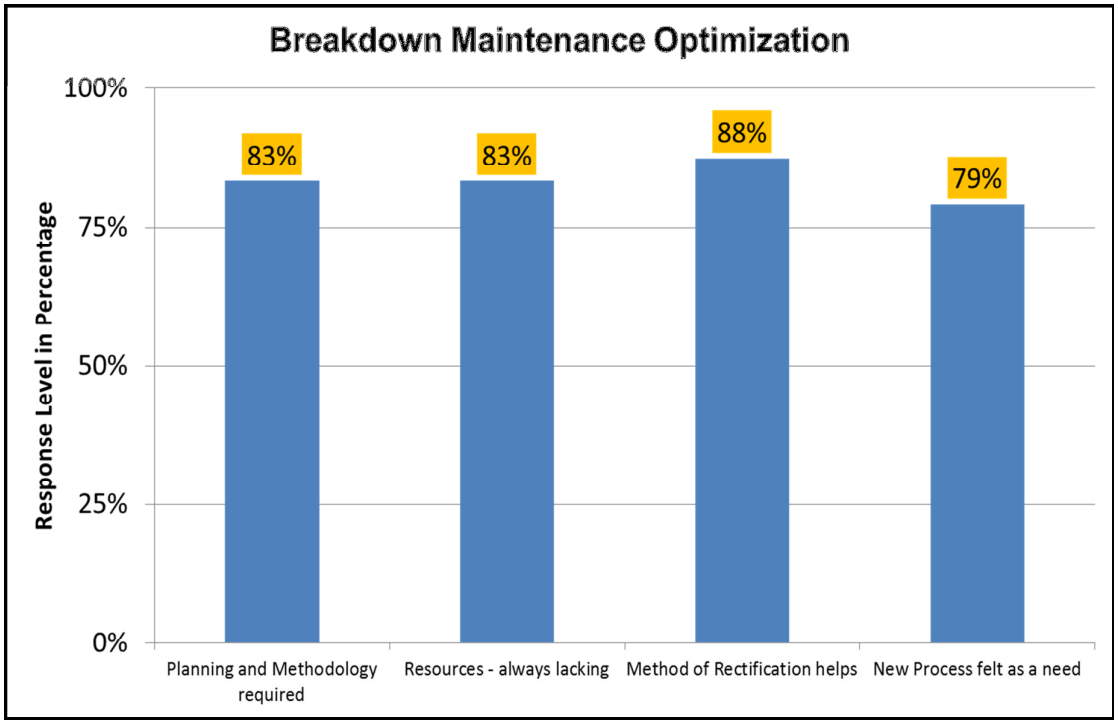

Figure 1.3 Survey Results on needs of Breakdown Maintenance Optimization for Construction Machinery

1.3 Purpose of the research study

It is a known practice in industries that even if preventive and predictive maintenance schedules are reached the production lines cannot be stopped; the maintenance department postpones the maintenance at the insistence of production department due to various operational reasons including emergency works, replacements not available, concreting planned, consultant insisting the continuity, workmen not available etc. As this planned machinery maintenance is not implemented on time, it results in failures and breakdowns and seriously affects the production and maintenance plans (Tsu-Ming Yeh et al 2011). Canter M.R., (1993) mentions that such failures/breakdowns can be related to a state at which the machinery or its item is temporarily, or permanently, unusable by the end user.

The breakdown of machinery in construction industry occurs due to the unpredictable failure of components and due to gradual wear and tear of the parts, which cannot be prevented. These breakdowns result in massive disruption to the smooth activities and affect the overall productivity and efficiency of the construction schedules as well. These breakdowns should not be underestimated as they tend to make the project overrun on time and result in

subsequent loss of revenue to the project. Repeated breakdowns will almost certainly result in delays to the contract, loss of client goodwill, loss of company reputation, risk to safety etc. Breakdown or reactive maintenance costs three to four times more than the same repair activity when it was executed under planned maintenance (Mobley 2008 Sullivan et al. 2004). During breakdown of the construction machinery, if we consider the breakdown maintenance itself as a production process, we can arrive at detailed list of activities which does not yield any value addition to the rectification process or in other words, these are wasteful activities in the process. This approach is similar to the lean study approach in a production process which helps in reducing the unwanted activities and as well re-engineering of the entire breakdown process.

In the conventional breakdown approach in construction industry, when a breakdown develops in construction machinery, a maintenance crew member is dispatched to troubleshoot and correct the failure or deficiency. Usually, he makes multiple trips to the tool room and maintenance office for additional tools, for additional technical information/manuals, and to the spare parts storeroom to get spare parts to repair the problem. In most of these conventional cases, this approach always results in excessive repair time and lower availability of machinery. This reactive unplanned maintenance management method forces the maintenance department to maintain extensive spare parts inventories and additional resources of manpower that results in higher maintenance cost.

This thesis aims to study the detailed aspects of the breakdown performance in a construction industry, analyze the causes/reasons of breakdowns which are generally, unplanned. The study also focuses on the nature of breakdowns and analyzes the real-time reporting of the plant and machinery failure data to understand and determine the factors affecting these breakdowns and overcoming these factors to manage the breakdowns effectively.

In the medical field, if a patient is under an emergency condition or ‘broken down’ due to an illness, the first aider arrives at the spot and does the initial paramedical procedures and informs the medical crew. Upon receiving the information either from the patient/patient’s attendees/first aiders etc. the hospital prepares a protocol which includes preparation of the specialist doctors, paramedical staff, medicines, theatres, anaesthetists, special instruments, blood, oxygen etc. so that upon arrival of the patient there is no ambiguity/waiting period and the immediate treatment in response to the identified problem is executed immediately.

We intend to use the similar principles for developing a system/tool called 'Breakdown Maintenance Protocol' (BMP) which will keep the entire maintenance crew ready with required resources. The resources will include spare parts, work-front/space, technicians/crew, and all other related and essential items. With the availability of BMP which is also available as an analytical ruler and ready reckoner to the end users, a broken down plant, either at site or at the repair yard, when subjected to a breakdown complaint, gets focused and immediate attention upon its arrival to the site/workshop, and immediately a system of predetermined activities related to any particular type of breakdown is performed and the effective execution of breakdown maintenance process is ensured.

1.4 Literature Survey

1.4.1 Maintenance and Reliability

Maintenance always to be considered as a business process turning inputs into usable outputs (Campbell J.D, 2001). The inputs include right maintenance strategy, resources, right planning, periodic execution and the output will be uninterrupted machinery availability which will yield the desired productivity and results to the organization. Hisham B.J., (2003) states that ensuring good maintenance to plant and machinery can significantly reduce the overall operating cost and will further boost the morale of all associated trades and team and hence the productivity improvement of the overall plant and machinery can be ensured. Achieved availability is the probability that a system or machinery, when used under stated conditions in an ideal support environment (i.e., tools, spares, personnel and resources are readily available), will operate satisfactorily at any point in time (Blanchard, 1998). Hisham B J (2003) reiterates that overall operating costs will be controlled and productivity can be attained if proper maintenance is ensured with plant and machinery along with maintenance teams which are effectively functioning.

In the past, many authors have investigated and proposed numerous models to improve the plant's performance based on planned maintenance strategies. Number of decision rules were developed and tested based on individual machine utilization, scheduling of maintenance activities, selected performance criteria and operating conditions. Maintenance costs are a major part of the total operating costs of all manufacturing or production plants, and depending on the specific type of industry, it can vary between 15 and 60 % to the cost of the goods produced (Mobley, 2002).

The successful future business entities are the organizations which are able to control the reliability of their systems and products and this statement has been reaffirmed by Kececioglu D., (2002) et al. Reliability and availability modelling can also be viewed as an integral part of a unified ‘‘analysis’’ function, dealing with a myriad of information flows including data from sensors on machinery, data and information from operator interfaces on-board machinery, historical operational and maintenance information, current operational and maintenance information (Hall et al., 2003) . In line with the above the logical relationships between each plant component, system and human actions concerning their effects on generation have been represented through Reliability, Availability and Maintenance (RAM) models and it is useful to predict the magnitude of each individual contributor to failures and losses (described by the plant load duration curve) in a quantitative manner (International Atomic Energy Agency, 2001). Understanding the RAM as an important strategic element to the business and its contribution to the significant cost savings, Ford, the American organisation issued its first Repairs and Maintenance (R&M) Guideline for Manufacturing Machinery in 1990 (Brall et al, 2001).

Consistent collections of quality data on failure and repair are usually necessary in system reliability and availability analysis for getting reliable and accurate results (Blischke W R, 2003). Lu et al (1993) developed general statistical models and data analysis for using degradation measures to estimate a time-to-failure distribution, which allows us to focus and apply the same to the construction machinery also. Huitian (2007), extended the problem of reliability estimation to a component operating in real-time changing environments. Gabraeel N (2005), proposed an exponential model in which the deterministic parameters represent a constant physical phenomenon which is common to all the components of a given population. The non- deterministic parameters follow a specific distribution and capture variations among individual components, which are nominally identical. K.T. Meselhy (2010) developed a periodicity metric functional resetting procedure which can evaluate and quantify function resetting for a given maintenance policy which can reduce complexity in the system. The developed periodicity metric has to be used as a criterion for comparison studies for predicting system performance of maintenance policies.

1.4.2 Performance Measurement in maintenance management

It is very much essential in industries to engage performance measurement methods which can be used as tools to compare different types of maintenance policies and also to predict and achieve system controls that will reduce maintenance costs. To ensure the desired level of performance to machinery, maintenance managers should keep good track of records and results of performance on predictive, preventive and breakdown maintenance process.

Parida A, (2006) reiterated the need for measuring the system's performance in context to plant and machinery. As there is changes found with maintenance strategies of organizations, where increased amount of outsourcing and / with separation of original equipment manufacturers' (OEMs) have taken the lead, it is crucial to measure and improve the assets' maintenance performance (Parida et al., 2009). As maintenance process duration is always vital for every organization since it consumes time and cost, Giuseppe Curcur U (2010) proposed a procedure for computation of the maintenance time that minimizes the global maintenance cost. Banerjee et al (1990) also made studies through series of simulation experiments to examine the performance of a dynamic job shop, where the machinery is subjected to failure.

1.4.3 Breakdowns and cost impacts to Construction Machinery

Construction plant and machinery dependency rate has become very high due to fast track projects which have become a necessity in the present time (John M, 2002). The breakdown to construction machinery impacts a huge loss to the entire system as it derails many planned activities. These breakdowns occur due to the unpredictable failure of components and gradual wear and tear of the parts, which cannot be prevented. The wear and tear rates of the machinery are likely to be very high due to extreme conditions prevailing at construction sites. Many researchers have studied data analysis and modelling of failures/breakdowns with respect to cost and time.

A Varghese M. M., (2000) state that if we assume 20 % of the cost of construction projects is machinery oriented, it is expected that the demand for the same will be increasing substantially in the coming years along with the associated maintenance spending. Oloke D.E., (2001) mentioned that the continuous failures and breakdowns on the plant and machinery makes overrun of the associated maintenance costs continue to affect the

optimization of plant and machinery utilization throughout the construction industry. Henry T.A., (1993) states that research in the UK has revealed that the plant and machinery downtime accounts for an average of four working days per item per year which will definitely result in loss of profit to the owner of the assets. Watts B.K.R., (1994) predicts that during failures/breakdowns on the construction machinery, the capital invested with the construction plant/machinery fail to work for the business, while placing severe strain on the project/site productivity, and ultimately to the organization's liquidity value of assets.

If there are occurrences of frequent plant and machinery breakdowns, the associated maintenance costs will continue to increase which will directly affect the optimization of the plant and machinery utilization throughout the construction industry (David.O, 2001). Human operators in close proximity with the work operate most of the machinery in the construction industry and the maintenance cannot be overlooked (Randy R et al., 1988).

1.4.4 Need of Modelling the Breakdown Maintenance Management

The construction machinery breakdowns are inevitable due to extreme climatic conditions prevailing at the construction sites; operative skill gaps; lags in planned maintenance; general wear and tear of components; right kinds of spare parts not fitted during maintenance; working conditions at the job site; accidents and unforeseen incidents etc.

Even though failures/breakdowns contribute lots of uncertainties to the plant and machinery performance and productivity very few researchers have conducted the studies on the data capturing and modelling of breakdowns particularly in construction machinery. Detailed algorithms and models for systematic breakdown maintenance in construction machinery based on the records of break down maintenance have generally not been found in the literature.

- Canter M.R., (1993), indicated that machinery breakdowns are related to the state at which a machinery/plant item is temporarily, or permanently, unusable. The preventive maintenance (PM) actions which are classified as minimal, imperfect or perfect are generally triggered by the age of the components and factors such as (T) Time between perfect preventive maintenance and (n) number of failures between perfect maintenance (Sheu, 1995).

- Todinov, (2006) predicts that failures in machinery and systems may lead to time or volume loss on production, negative impact on the environment, lost customers, warranty payments and hence the efficiency and effectiveness of the maintenance system are essential for organizations' success and survival.
- Unlike plant and machinery operating within the manufacturing and other sectors, construction plant and machinery is largely dependent upon operator skill and competence levels to maintain the item in a safe and fully operational condition (David J.E., 2002).
- If we analyze the maintenance literatures available at present, generally it ignores the impact of maintenance on performance and also there is no clear focus on the planning, scheduling and control of maintenance capacity (Geraerds, 1992).
- More stand-by units of resources may increase the system's availability but do not decrease the incidents of system failures (Kumar et al., 1998).

1.4.5 Research Gap

- Virtually all the commercially available CMMS software lacks decision analysis support for management and also lack in equipment failure diagnosis (Labib, A. W., 2004, Swanson, 1997)
- PMs which are copied from machine manuals may not find suitable application due to each machine working in a different environment, requiring different PMs, and also machines designers often may not have similar experience of machines failures as like operatives and maintenance crew (Labib, A. W., 2004)
- Study of Fonseca et al., (2001) reveals that very few researchers have addressed the issue of handling uncertainties related to failure data of systems on the reliability and maintainability studies.
- Rapinder S, (2009) confirms that lots of efforts have been made to develop and formulate different types of maintenance strategies for enhancing the operation and performance of plant and machinery but nothing has been actually done to streamline Breakdown Maintenance Activities (BMA).
- Damjan M, (2012) adds that though the strategy of maintenance function is age old, the necessity of continuous improvement (CI) is always inevitable and CI is known to be an effective way of improving maintenance performance.

The current research work aims to develop a systematic mechanism to identify a strategic procedure to minimize the durations of breakdown maintenance execution to construction machinery, particularly in the United Arab Emirates.

The focus of this research is to improvise the breakdown maintenance management in the system rather than developing a preventive maintenance for the breakdowns. The research also provides a detailed insight into the method of management on recovery from the failure/breakdown state of the construction machinery/system.

The real-time reporting of the plant/machine history is examined to understand and determine the attributes of the breakdown factors which are the cause effect to the failures/breakdowns. Further analysis is performed on to these factors to prioritize, critically evaluate and to identify the cause/factor as codes and further strategize and propose the method of rectification to quickly overcome from the breakdowns state effectively.

1.5 Objectives of the Thesis

The objectives of the thesis are:

1. To study the maintenance management of machinery and establish the need for systematic breakdown maintenance in construction industry.
2. To identify the critical construction machinery in the entire fleet that contribute to major cost and time escalations and to list the critical systems/components and the failures on the same
3. To classify the causes, symptoms and reasons of the failures in the construction machinery.
4. To devise a tool to aide in the easy identification of root cause of breakdowns in construction machinery.
5. To develop protocols to be followed in during critical breakdown maintenance in construction machinery
6. To propose a new model for breakdown maintenance management as applicable to construction machinery and test the impact of this model on the ease of identification of the root cause of breakdowns in construction machinery

1.6 Methodology of Research

The following methodology is adopted in the research;

1. Maintenance in general and breakdown maintenance in particular with reference to machinery used in construction industry is studied with literature and current practices in the industry. The literature review also focused on maintenance management history, its evolution and trends.
2. Primary data on breakdown maintenance carried out on construction machinery in a representative construction industry is collected for the period 2007-2011.
    - Analysis of the primary data to project the cost and other implications of the breakdown of construction machinery is performed.
3. A survey is conducted with employees at different levels in different construction companies to identify the needs of these employees with respect to breakdown maintenance of construction machinery.
4. Cumulative consequential cost impact analysis, breakdown ratio analysis and breakdown percentage analysis is performed to identify the critical machinery that contributes to majority of breakdowns in the representative construction industry.
    - Reliability studies for the systems and components of critical machinery identified is carried out by calculating the Failure Rate (λ), Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), Availability and Reliability Values.
5. Systematic identification of the failure/breakdown codes for the construction machinery is performed with tools
    - Cause Effect Analysis (CEA) diagrams are drawn for the failures of systems in the critical machinery recorded during the period 2007-2011. The Root Cause Analysis (RCA) is also done to arrive at codes called as Breakdown Main Codes (BMC) and Breakdown Sub Codes (BSC)
    - Pareto analysis using charts is done on the BMC and BSC to further locate significant codes responsible for major breakdowns.
    - Failure Mode Effect Analysis (FMEA) is performed on BMC and BSC identified in the Pareto analysis to study the impact of these on system/component failures. A ranking of BSC with the highest impact is identified.
    - Fault Tree Analysis (FTA) is performed with the identified BSC to arrive at the symptoms and reasons for the failure called as Breakdown Symptom Codes (BSyC) and Breakdown Reason Codes (BRC).

6. The Breakdown Maintenance Protocol (BMP) to be followed for each failure based on BMC, BSC, BSyC and BRC is developed.
7. A BMP ruler (multiple rings) is constructed to enable easy identification of BMP to be followed in case of a breakdown.
8. A new model on Breakdown Maintenance Management (BMM) based on the study is formulated.
    - A comparative study of breakdown maintenance in the representative construction industry chosen before and after BMM Model is also carried out and reported.

1.7 Scope of the Research Thesis

The primary data collected for the research pertains to the period 2007-2011 only. Even though data is available for earlier years it is intentionally not considered for the study, reason being rapid changes in the designs and capabilities of machinery. But it is ensured that the data represented the breakdown data of machinery in any construction industry sufficiently.

Wheel loader and dumper were chosen for extensive study even though there is other machinery being used in the construction industry. The reasons for choosing these two as representatives of machinery in construction industry is sufficiently justified based on the costs, number of breakdowns and the overall impact of these machine breakdowns.

The entire study aims to develop protocols of breakdown maintenance in construction machinery. Even though there might be similar machinery or sub-systems of machinery in other industries, it may not be possible to directly apply the same model proposed in this study. The reason being the factors contributing for the failures in machinery are always different (For e.g. operating environment has a significant impact on the nature of failures).

The tools used at various stages in the thesis have already been used in maintenance management, but necessarily need not be the best available. The objective of the study was to develop protocols and hence readily available proven tools have been used in the thesis.

This breakdown maintenance management approach and model is evolved as a scientific approach only as a regional basis and it should not be subjective.

1.8 Limitations of the Research Thesis

Out of the large number of employees associated with construction machinery in United Arab Emirates (UAE) only a representative group could be considered for survey on breakdown maintenance system.

The thesis covers only representative machinery namely wheel loaders and dumpers, of entire fleet of construction machinery only to avoid voluminous reports. But these two studied in this research will give a clear guideline for application of similar maintenance concepts to other machinery not considered as well.

The BMP ruler constructed is for representative construction machinery only; it cannot be generalized for use with other machinery having same component systems.

The BMM model in the present form is applicable to construction machinery similar to wheel loaders and dumpers. However it is likely to work with other machinery with similar component systems and operating conditions including the environment.

1.9 Assumptions

The following assumptions were made at the beginning of the project.

1. The data are representative of the construction plant and machinery in general
2. The majority of the breakdowns on plant and machinery are considered to be same to other construction companies operating in the United Arab Emirates region.
3. Even though these machines are made by various manufacturers, perform varying actions at varying conditions, the data records are from different sites, it is assumed that the failure data is standard for the purpose of reliability predictions.
4. The BMP Ruler will be used by end users which include the operator, mechanic and the supervisors as well
5. The operators, mechanics, and supervisors will have basic relevant education to understand the technical requirements and knowledge for using the BMP ruler
6. The breakdown data were collected in a reliable manner from the target company, operating at Dubai, United Arab Emirates.

7. Each construction company in United Arab Emirates is striving hard to ensure a proper system and procedure for breakdown maintenance execution
8. The study conducted in this company, can be applicable to other construction companies, since most of the contracting and construction companies in the United Arab Emirates are generally working with similar principles of maintenance management.

1.10 Structure of the Thesis

Chapter 1 deals with the introduction of the research problem, breakdown maintenance questionnaire and the survey results, the research purpose, objectives, methodologies, scope and assumptions on the research topic.

Chapter 2 details the overview of construction industry, different types of construction, world construction, and construction in the United Arab Emirates. The chapter also covers the details on economic history of construction and construction through time. It also provides information on construction companies in the United Arab Emirates and the challenges to the construction industry.

Chapter 3 deals about the maintenance of plant and machinery. The importance of machineries and maintenance for various industries, the historical role and the objectives of maintenance are discussed. Different types of maintenance including planned and reactive maintenance, world class maintenance and newer techniques in maintenance are also discussed in detail.

Chapter 4 is on the maintenance management of plant and machinery in construction industry. The requirements, importance and classification of the plant and machinery in construction industry are discussed in detail along with the maintenance management of the same. The construction machinery breakdowns and their attributes are discussed in detail to understand the scope and effect of the same. Breakdown management is explained as a flow process.

Chapter 5 details the economics of breakdowns and reliability studies for the construction machinery. This chapter covers the data collection and methods, analysis of breakdown data,

target organization, failure patterns of breakdowns to various machinery of the target company, selection of machinery for the detailed analysis by different methods, the justifications for the selection of this machinery, breakdown impact of these selected machinery to the target organization are identified. The reliability studies and analysis are performed on to the selected machinery and the values of reliability, availability; Mean Time Between Failures and Mean Time To Failures are identified and discussed.

Chapter 6 deals about the development of breakdown codes and the breakdown maintenance protocol. The breakdown contributing factors to the organization's machinery failures are identified as primary codes through Cause Effect Analysis methods. Various tools including Cause Effect Analysis (CEA) tools, Pareto Analysis, FMEA tools, Fault Tree Analysis are used to identify the further codes namely breakdown symptom codes and the breakdown reason codes. These codes are listed as Breakdown Main Code (BMC), Breakdown Sub Code (BSC), Breakdown Symptom Code (BSyC) and the Breakdown Reason Code (BRC). With the utilization of these codes and through protocol techniques, the BMP Ruler, a four tier ring tool is identified. The structure and construction of the BMP ruler, the contents and details of the same including four levels ruler rings, development of BMP Ruler Resource Sheet, application aspects of BMP Ruler to Construction Machinery Breakdowns by different user perspectives are detailed in this chapter.

Chapter 7 is about the proposition of Breakdown Maintenance Management (BMM) as a model and its practical application to the construction machinery breakdowns. Primarily this model combined is the combination of three sub models and together termed as the BMM Model. The sub models include Failure Analyzer Model, BMP Identifier Model and the BMM Analyzer Model. The inputs, process and the outputs of the models are discussed in detail. The practical application of this model is analyzed with detailed cases of breakdowns/failure and the application and the results as benefits are discussed. The results and analysis is done for four cases of breakdowns/failures and the conventional results versus the projected or as per actual BMP application results are tabulated and analyzed.

Chapter 8 details the summary of thesis, the scope for the future research and research contribution.