CHAPTER 5: ECONOMICS OF BREAKDOWNS AND RELIABILITY STUDIES IN CONSTRUCTION MACHINERY

5.1 Introduction

There is a continuous improvement taking place with the advent of newer approaches and technologies in maintenance engineering. A Sharma (2011) states that the maintenance optimization model's (MOM's) and related studies which always help the decision making process within a maintenance organization has been very limited in the past and with the development of newer models which work in combination with advanced maintenance parameters will find extensive applications in the future. There is an increased trend of fast track construction projects prevalent in the market and these projects are highly dependent on the construction machinery performance. Delays and disruptions leads to financial losses due to penalties by clients (Randy. R, 1988). It is also stated that at least 14 % of the Return on investment (ROI) potential improvements are directly related to the maintenance functions as a lost profit which is due to unplanned stoppages and bad quality end products caused by maintenance-related problems (Imad Alsyouf, 2007). It is also observed that lack of empirical support for the role of maintenance may get resulted from how the maintenance activity is measured (i.e., solely by the number of activities performed by the maintenance staff) and not by an overall measure of maintenance capabilities (Handfield, R. 1993).

Many authors have reiterated that fact that with the occurrences of frequent plant and machinery breakdowns, the associated maintenance costs will tend to increase which will directly affect the plant and machinery utilization throughout the construction sector.

The construction machinery breakdowns are inevitable due to

- Varying operating conditions prevailing in the construction sites
- Extreme climatic conditions of the region
- Usage mixed fleet (new/old/multi-brand) of machinery
- Lack of operative efficiencies
- Excessive usage of machinery
- In-effective preventive and predictive maintenance performance

- Accidents and unforeseen incidents
- Right parts/spares not fitted

As the downtime of each individual machinery not only poses threat to its own performance but as well affects series of many follow on activities which are always inter dependent in construction industry. Hence effective performance and easy recovery from breakdowns is essential for this machinery.

This thesis proposes a system based approach with the usage of breakdown codes management and a tool called Breakdown Maintenance Protocol Ruler, wherein the breakdown maintenance is performed with better efficiencies and the required optimal speed is achieved while ambiguities and unwanted delays are overcome. This modified breakdown maintenance process will be used by all the crew associated with the construction breakdowns starting from the operative to the engineer in the crew. The development of the codes is very vital at the initial phase of this process and they are developed in a very systematic manner.

We intend to use the similar principles like that of a medical/patient protocol to develop a new tool called 'Breakdown Maintenance Protocol' (BMP) which will keep the entire maintenance crew ready with required resources including spare parts, work-front/space, technicians/crew, and all other essential items. With the BMP which is available as an analytical ruler as well to the end users as a ready reckoner, 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, wherein a system of predetermined activities related to the particular type of breakdown are performed and the effective execution of breakdown maintenance process is ensured.

Whenever any breakdown occurs, the crew will get a call from the user/operator/site etc. and upon analysing the given breakdown information, the mechanics/operatives will check the BMP Ruler, identify the BMC's of the breakdown to which it aptly fits which will be very generic. Further relating it to the BSC which will provide the lead information on the specific area of breakdown, then it is further analysed for the symptom code BSyC which will reveal the closer reasoning and further when related with the reason code BSC, it reveals us the specific BMP and with that we execute the breakdowns on the basis of Resource Tool, method of rectification etc. and perform focused attention/actions for the particular breakdown.

The BMP facilitates/triggers the relative crew, to get ready with a set/system of operation, wherein the necessary tools, tackles, manpower, supervision, spares, workplaces, logistics to be prepared are kept ready/ prepared/dispatched as required/specified etc. if the breakdown is not manageable by the respective mechanic/operative and forwarded to the maintenance workshop of the organization. BMP also specifies the parameters including duration/time management, resources including spare parts, technicians/engineering skills with levels and grading required, logistics, subcontracting requirements, tools, material handling devices required etc.

5.2 Records and Data Collection

An important step in reliability and breakdown / failure analysis is the collection of appropriate data and the same has been confirmed by Blischke et al (2003) who reiterate that collections of quality failure and repair data are usually necessary in system reliability and availability analysis for getting reliable and accurate results. Hall et al, (2003) also stress that reliability and availability modelling can be viewed as an integral part of a unified ‘‘analysis’’ function, dealing with a myriad of information flows including the following:

- Data from sensors on machinery.
- Data and information from operator interfaces on-board machinery.
- Historical operational and maintenance information.
- Current operational and maintenance information

There are many sources of data for repairable systems which are of relevance to reliability modelling and failure management of machinery. In addition to the information generated by maintenance and production / construction departments in the form of reports, much of the raw data upon which these reports are based should also be accessible in order to achieve successful reliability modelling.

The data used in this research studies was collected over a period of five years for nine types/categories of machinery. The source of the data is from Associated Construction and Investment L L C, a large construction organization belonging to the ETA Ascon Group which maintains regular records of daily breakdown maintenance reports. The type of data is primarily and collected from the target company as a raw data and modified as per the requirements of the thesis. We design our own tables in order to sorting and arranging the data in a chronological order for using it various analysis and purpose. The data required for the study basically includes the failure data taken on the construction machinery. The data collection source is assumed to be realistic and authentic.

5.2.1 Target Organization

Since this study pertains to failures and breakdowns on construction machinery, a construction organization whose machinery base is good and large enough needs to be selected as the target organization. The organization should have proper maintenance/team crew in place to execute the maintenance management. The requirement is that maintenance activities/management should be well performed at fixed intervals by the teams so that the machinery available in the organization performs to the optimum level. The study also focuses on a company where the machinery is under necessary preventive maintenance and only limited breakdowns are experienced, so that the approach becomes focused.

The target organization Associated Construction and Investments Limited Liability Company (LLC) Ascon operates in the United Arab Emirates and has its operations also spread in most of the Gulf Cooperation Council (GCC) countries including Oman, Qatar, Saudi Arabia etc. and has good machinery base and a good maintenance crew for managing the maintenance operations of the machinery. A good preventive maintenance programme is in place with the target organization and the breakdown percentage is maintained at 3 to 4% average as per their database available.

5.2.1.1 ETA Ascon Star Group in the United Arab Emirates

ETA ASCON Star Group is one of the largest Contracting firm in the UAE. Its expertise ranges in all fields including Civil Construction, Electro Mechanical, Elevator Engineering, Facilities Management etc. Since its inception in 1973, the firm has completed many prestigious projects and its turnover has been in excess of US$5 Billion. Various landmark buildings and structures in the entire GCC countries portray testimony to the organization's engineering capabilities. The company is part of the Al Ghurair Group of Companies, which is the top few of the most leading business houses in the United Arab Emirates.

ETA ASCON has diversified operations to the construction industry like Wood Joinery and Interiors, Electrical, Mechanical and Plumbing Operations, Power Control systems, Low Voltage Switchgear Panels, Elevators, Structural Steel fabrication, Composite Aluminium Cladding, Facility Management, Janitorial and Cleaning services, etc.

These wide ranges of capabilities provide ETA ASCON the turnkey expertise and technological ability to deliver a project from the drawing board to the completion of entire project. The company has expertise in the construction and contracting engineering which has been gained over their 35 years of experience in the field and uses the same to the advantage of its customers and to deliver value for money.

5.2.1.2 ASCON Division

Associated Construction & Investments Company (ASCON), the Civil Engineering division of the successful ETA-Ascon Star Group, was incorporated in 1973 to undertake civil engineering projects in Dubai and other emirates. The Group has over the last three decades expanded and diversified into a wide array of activities apart from developing a nationwide presence in the entire UAE, Qatar, Oman, Saudi Arabia, India and other parts of the world.

ASCON has at present assignments worth over AED 2.0 billion with manpower resources of over 10,000 employees of whom 600 are professionals including Engineers, Surveyors, Planners, Project Managers, Construction Managers and Cost Control Engineers who have considerable experience of working in countries like South Africa, England, U.A.E, Syria, Jordan, Philippines, India and other Asian Countries. The company has successfully undertaken several core construction projects, significantly contributing to the infrastructure development in the entire region of Middle East countries. The versatility in projects scope has been significant as these projects range from hotels, commercial/residential buildings, luxury villas, shopping malls, educational/sports facilities, petrochemical plants, processing plants including flour and sugar mills, airport assignments, multi-storey parking structures, hospitals, educational institutions like BITS Pilani Dubai Campus and sub-stations. ASCON is accredited with ISO 9001 certified by Loyds Register Quality Assurance (LRQA), and

Occupational Health and Safety Advisory Services (OHSAS) 18001 for its quality and safety management.

The vision of ASCON has been 'To become the leading construction company in the Middle East that executes civil engineering projects in a safe, timely and quality-oriented manner, and to emerge as the most preferred construction solutions provider to clients.' This vision has enlightened ASCON at every step and has led to the company foraying into a wide range of relative business activities including downstream divisions like dewatering, steel trade, welding and fabrication, precast fabrication etc. Ascon has its headquarters in Dubai and has witnessed exponential growth over the past years and has changed its improvised its scope from general contracting to construction of larger projects of infrastructure for government, large buildings for well-known master developers and industrial buildings.

The market has been very volatile over the past few years, presenting great challenges in estimating costs, and responding positively, Ascon has entered into greater partnerships including Joint Ventures (JV's) with leading construction companies of world like Nasa Multiplex, Skanska, Sapurji & Pallanji etc. Its long presence and policies ensure a good relationship suppliers and partners and results in timely availability of supplies and as well effective managing of business.

5.2.1.3 Ascon as a representative of the construction companies:

- Ascon belonging to the giant corporate ETA Ascon Star Group of companies has the presence in the United Arab Emirates for more than 35 years.
- Ascon has executed many projects including residential, commercial, infrastructure, industrial, hospitality, service etc.
- Ascon has executed low height, horizontal spread, high rise, high tech buildings as its product mix.
- Ascon has executed projects ranging from AED50 million to AED700 million valued single projects.
- The turnover of the company has exceeded AED2.0 Billion for many years.
- The resources of Ascon have been its great strength over its four decades of existence. The resources included its construction technicians, financial capabilities, materials management and the very important Plant and Machinery.

- When there were many organizations striving hard without Plant and Machinery, Ascon was always marching ahead with good amount of its inventories on this front. Ascon remains within the top 5 companies of Dubai, United Arab Emirates.
- The plants of the company have mixed age, new to medium to old aged and various brands of plants, machinery and vehicles.

The Plant and Machinery Management at Ascon has been managed with a full-fledged Workshop Yard and repair facilities with all the required services built in. The company has in its roll all the construction plant and machinery varying from very small plants to major plants including tower cranes. The technicians are generally trained in their trades for the repair and maintenance of all the construction machinery. The spare parts are procured and stored in the central store and the material management is managed. Inventories are not kept at large as there are JIT availability of spare parts and lubricants locally except few.

In Dubai, the construction companies work with the plants which are of mixed age only. There is availability of many rental companies who offer hiring of machinery's in the market. The rental companies also adopt the similar practice of owning old to new machinery to remain with the profits but the maintenance is not organized to the right extent with most of the companies. Hence the construction companies have to maintain the right working of their own fleet and machinery. Majority of the construction organizations in the UAE who execute similar nature of projects like of Ascon are having their own Plant and machinery facilities and the related crew for maintenance.

All of the above facts can be attributed to as justification for considering Ascon as the representative of Construction Companies in the United Arab Emirates. This breakdown management protocol/model is evolved for the scientific approach only - as basis and it should not be subjective.

5.2.1.4 Machinery Management in Ascon:

ASCON Plant Division, the plant and machinery wing was established to ensure a satisfactory service for the plant and machinery for all ASCON projects/customers in terms of supply of machinery, formwork, transport, fabrication, mobilization and related activities, etc. The primary functions Ascon Plant Division include:

- Maintain and upkeep the Fleet, Machineries and Machinery's so that they are always available for service/supply. There are about 779 machineries excluding vehicles in the division and considered to be one of the largest fixed assets holding division in the group.

  - The machineries and vehicles include the following:
    - Cranes - Tower Cranes(51), Mobile Cranes(6)
    - Earth Moving Machinery - Wheel Loaders(3), Backhoe Loaders(5), Skid Steer Loaders(14), Roller/Plate Compactors(45)
    - Machineries-Concreting - Concrete Mixers (29), Screed pumps(3),Vibrators(115), Concrete Pump (3)
    - Machineries - Finishing-Asphalt/Concrete Cutters, Spray Plasters, Power Floats, Mosaic Polishers, Core Cutters, Vacuum Machines, Tile Cutters, Scabblers, etc.
    - Machineries- Utilities-Generators (120), Compressors (21), Bar Bending (41), Bar Cutting (41), Wood Saw (38), Jack Hammer, Dumper (20), Gas Cutter etc.
    - Machineries - Lifting - Passenger/Material Hoists (25), Forklifts (4)

  - The Fleet strength of 353 vehicles, with a mix of cars, small pick-ups, heavy pick-ups, mini buses, heavy vehicles, heavy buses, trailers, tankers and transit mixers

5.2.1.5 Data Source and Compilation

The available data should be easy to retrieve, analyze and draw conclusion on a continuous basis to bring in efficiency on the utilization of the data (Markeset et al, 2003). Yin (2009) states that considering quantitative data to be important in case studies. The data may show the actual outcomes in the evaluative studies and the quantitative data may relate to an embedded unit of analysis in the case studies. About data sourcing, Blaikie (2003) suggests that accumulated data is used to produce generalizations about the patterns of connection between events or variables. As mentioned in the previous chapters, the target company has various sources of preventive and breakdown maintenance data maintained at their plant department.

- Documents and facilities maintained for Preventive Maintenance:

- Annual Preventive Maintenance Schedule (PMS) – To know the date and time of different types of Preventive Maintenance to each machine/vehicle [daily/250hrs/quarterly/6month/Fitness Certification (FC)]
- Preventive Maintenance due dates
- Job Card- Job details complete
- Plant History Card – complete history of the plant/machinery/fleet
- Full-fledged stores department for the arrangement of spares and other resources

➢ Documents maintained for Machineries Break down Maintenance include:

- Breakdown Register - Includes the registry of all the breakdowns to the plant, machinery and fleet, date and time
- Entry of Mechanics sent –the action taken after the call on B/d
- Entry of completion of breakdowns – Duration of the breakdown
- Job Cards – Information's on every breakdown rectification details, mechanics deployed, spares, lubricants used, external agency supports etc.
- Plant History Cards – This included all the details of preventive, breakdown maintenance details, other modifications done to each individual plant, its nomenclature, cost details etc.

5.2.1.6 Preventive Maintenance at Ascon

The target organization Ascon has full-fledged maintenance management for the fleet and machinery. A team of maintenance personnel are involved in maintenance of the fleet. Annual maintenance is scheduled with a 52 week programme break up and the schedules are identified as 250 hours/ 750 hours/1500 hours and annual fitness certification works for the hourly operating machinery like wheel loaders, dumpers, compressors, generators, forklifts, roller compactors, skid-steer loaders, back hoe loaders, mobile cranes and other machinery. It is measured as monthly, quarterly, half yearly and annual maintenance for other smaller equipment. For vehicles it is done on the basis of 5000, 15000, 30,000 and annual/60000 kilometers. The ISO Procedures are maintained at the maintenance department and all the processes are audited annually and certified.

5.2.1.6.1 Preventive Maintenance Lags

A total of 2000 to 2500 preventive maintenance services are planned annually for all the machines of Ascon. The preventive maintenance policy of Ascon is efficient and efficiency levels have been identified at 85 %.

The 15% reductions in PM efficiency levels are generally attributable to the following general factors and a detailed study has been carried out at the company to identify the contribution and importance of these factors. The factors include: Machinery itself at breakdown, Allotted technicians are attending to breakdowns, Technicians skill levels not optimum, Interest and commitments are not available, Necessary work instructions and check lists are not in place, Tools/tackles and consumables are not available/planned, Spare parts are not available, Reference maintenance manuals supplied by manufacturers of equipment are not in place, Adequate bay facilities are not available at workshops, Poor working environments and Mobile servicing units not arranged (for site based works)

Target organization's three year PM delay records are further analyzed to study the effect of machinery breakdowns that impact the reduction levels in the PM efficiency. The reasons are tabulated as delay reasons and missing reasons. The delay reasons are the ones for which PMS cannot be executed on the scheduled dates. The missing reasons are the ones for which PMS is missed out even with all other factors are in favor of execution of PMS.

The details of each factor and the number of occurrence of these factors in the years 2009, 2010 and 2011 are listed in the table, for all the selected nine categories of the machinery.

While analyzing the number of occurrences, 27% of the lags are due to

- Machinery under major breakdown or minor breakdown,
- Shortage of work place due to breakdown machinery occupation,
- Machine is under breakdown due to spare parts not available or
- Mechanic is doing the breakdown maintenance.

It implies that machinery breakdowns are very much contributing to the reduction of preventive maintenance efficiency levels of the target organization. This has given further insight that if the breakdowns are managed effectively in a systematic way, the preventive maintenance efficiency will have greater improvements.

Table 5.1 Preventive Maintenance Lags due to Machinery Breakdowns

2009

	Delays and Misses on the Lags	Skidsteer Loader	Compacter - Roller	Compressor - Air	Dumper	Forklift	Genset	Back Hoe Loader	Mobile Crane	Wheel Loader	Lags Due to A and B	Total Lags	Contribution
Delays (A)	Machines breakdown at site	1	0	0	1	2	4	1	1	0	**10**	273	3.7%
Delays (A)	Technician planned for PMS attends emergency breakdown works	0	0	2	3	1	3	0	2	0	**11**	273	4.0%
Delays (A)	Lubrication Vehicle Breakdown / Accident	0	1	0	0	0	0	0	0	0	**1**	273	0.4%
Misses (B)	Machine under major breakdown	2	5	19	1	0	40	0	0	2	**69**	273	25.3%
Misses (B)	Shortage of work place/bays in workshops due to other machinery breakdowns	1	0	0	2	0	0	0	1	0	**4**	273	1.5%
Misses (B)	Machine is stopped due to spare part not available	0	0	0	0	0	0	0	0	0	**0**	273	0.0%
Total		4	6	21	7	3	47	1	4	2	**95**	273	**34.8%**

2010

	Delays and Misses on the Lags	Skidsteer Loader	Compacter - Roller	Compressor - Air	Dumper	Forklift	Genset	Back Hoe Loader	Mobile Crane	Wheel Loader	Lags Due to A and B	Total Lags	Contribution
Delays (A)	Machines breakdown at site	1	0	0	0	0	1	0	0	0	2	332	0.6%
Delays (A)	Technician planned for PMS attends emergency breakdown works	0	0	0	0	0	2	0	1	0	3	332	0.9%
Delays (A)	Lubrication Vehicle Breakdown / Accident	0	0	0	0	0	1	0	0	0	1	332	0.3%
Misses (B)	Machine under major breakdown	1	10	2	6	0	31	0	2	1	53	332	16.0%
Misses (B)	Shortage of work place/bays in workshops due to other machinery breakdowns	0	0	2	0	1	0	0	0	0	3	332	0.9%
Misses (B)	Machine is stopped due to spare part not available	0	1	1	1	0	0	0	0	0	3	332	0.9%
Total		2	11	5	7	1	35	0	3	1	65	332	**19.6%**

2011

	Delays and Misses on the Lags	Skidsteer Loader	Compacter - Roller	Compressor - Air	Dumper	Forklift	Genset	Back Hoe Loader	Mobile Crane	Wheel Loader	Lags Due to A and B	Total Lags	Contribution
Delays (A)	Machines breakdown at site	1	0	0	0	0	3	0	0	0	4	329	1.2%
Delays (A)	Technician planned for PMS attends emergency breakdown works	1	0	0	0	0	7	0	0	0	8	329	2.4%
Delays (A)	Lubrication Vehicle Breakdown / Accident	0	0	0	0	0	2	0	0	0	2	329	0.6%
Misses (B)	Machine under major breakdown	3	16	1	5	1	19	2	8	5	60	329	18.2%
Misses (B)	Shortage of work place/bays in workshops due to other machinery breakdowns	0	0	0	0	1	0	0	0	1	2	329	0.6%
Misses (B)	Machine is stopped due to spare part not available	0	7	1	0	0	0	0	0	0	8	329	2.4%
Total		5	23	2	5	2	31	2	8	6	84	329	**25.5%**

5.3 Breakdown Records and Data Analysis

From previous sections, it is understood that the breakdowns are affecting the performance of the target organization in terms of reduction in preventive maintenance efficiency as well as contributing to the breakdown duration and consequential effects. Hence a proper system of management to reduce the duration and organize effective execution of breakdown maintenance is required as there is no such system presently existing with the target organization.

Primarily, nine types of machinery have been considered for analysis of breakdowns and records as listed in table 5.2. The first level of priority in consideration for the selection of machinery was given in the categories of earthmoving type for the heavy and medium duty, lifting machinery, compaction machinery of light duty, utilities etc.

Table 5.2 Types of Construction Machinery

Types of Equipment Considered for the Analysis			
Earthmoving Equipment	**Lifting Equipment**	**Compaction Equipment**	**Utilities**
Wheel Loaders	Mobile Crane	Roller Compactor	Generator
Dumpers	Forklift		Compressor
Backhoe Loader			
Skid Steer Loader			

On the earthmoving machinery side, wheel loaders, dumpers, back hoe loaders and skid steer loaders were considered. On the lifting machinery side, mobile cranes and forklifts were considered. On the compaction machinery side roller compactor was considered and on the utilities side generators and compressors were considered.

The firm under investigation has more than 779 different construction machineries which exclude transportation vehicles. The machineries mix included light machinery, heavy machinery, light machinery, heavy plant, and heavy machinery. Since light machinery (290) is relatively smaller in size, replacement is always possible. Light machinery is not included in our study. Heavy plant like tower cranes and hoists (81) which operate basically with electric power only were not considered for analysis.

The selected machinery included, Wheel Loaders, Skid Steer Loaders, Back Hoe Loaders, Dumpers, Mobile Cranes, Forklifts, Compressors, Generators and Roller Compactors. The total number of machineries considered is 180. This represents 36.81% of the population of the machinery excluding the light machinery. A total of 876 (table 5.6) breakdowns from the five year record of the breakdown maintenance data for the selected plant and machinery have been analyzed. The documents considered include the breakdown registers, jobs cards, plant history cards etc.

The aim of this section is to determine the most important machinery which will further be focused for the breakdown maintenance improvement studies. This important task of identification and selection of the machinery is done with following methodologies:

a) Failure costs – Cumulative Consequential Cost Impact Analysis

b) Critical Construction Machinery Analysis

c) Breakdown Impact Effect of Selected Machinery

5.3.1 Failure costs – Cumulative Consequential Impact Analysis

Maintenance of plant and machinery involves cost. Maintenance costs refer to cost incurred as a result of plant operation, fixed-time-to service and repair at the time of breakdowns (Edwards, 1999). Since it takes time to improve machinery reliability as it cannot be reached by simple means, the maintenance costs become inevitable. Tsang et al. (1999) studied the measure of maintenance performance and identified various important performance measures and the costs performance has been one among them.

The plant breakdowns impacts cost and makes massive disruption to the productivity and it is more felt in the construction industry. While analyzing the costs of breakdowns in construction industry, simply the direct breakdown costs alone are normally taken into consideration for calculating the loss effects on failures and breakdowns. In reality, the chain reaction effects due to breakdown/failure effects are always underestimated. The breakdowns affect many predecessors and follow on activities which multifold the failure cost impact. When we calculate the direct losses we always see the effects of hours lost with machine alone, but there are other inherent losses which costs very much to the projects / end users and the owners of the machines.

A construction project site means a stated location or area at which the client wants to build a building, which can be of commercial, residential, industrial, multipurpose, utility, recreation, multi-storey in nature. The working for machinery or a combination of machinery is always essential for the project.

The projects during construction always pass through many stages and are generally termed as Site acquisition, mobilization, excavation, dewatering, foundations, sub structure, super structure, walling, cladding and finishing. At every stage of the project there will be single and combination of machinery working together. Every machinery while working in a project site is intended for a specific work, and every work needs multiple of resources including one or more machinery, supervision, materials, inspection, technicians etc. Every activity related to one or many machinery may be having a predecessor or a follow on activity and to execute the same hundreds of workmen may have been planned and waiting. Most of the activities are time driven and any disturbance to any activity due to failures on machinery will warrant additional planning as well lead to rejection of entire activity and materials including concrete, plaster etc.

There are also other statutory requirements related to projects like delays which will be liable for severe penalties from the client and as well from the government authorities due to lack of commitments. Certain cases also demand for legal authorities' inspections and fines, as it is mandatory and statutory to keep the workplace neat and tidy always to protect the housekeeping and environment. In construction projects delays and disruptions always lead to penalties. Hence a failure or a breakdown to the machinery cannot be left casually and the consequential losses are heavy to the project team as well to the machinery owners.

The disruption effect of breakdown to any one the machinery will also lead to cancellation of many other activities and results in disruptions and delays to the contract, which gets compounded with huge fines and loss of client good will and reputation. This situation is normally viewed as the cumulative consequential cost impact.

The nine categories of vital machinery which get utilized in many stages in project execution of the construction industry are selected for analysis. Failures and breakdowns to this machinery will affect many follow on activities and the direct and indirect losses to the project will be huge some and hence the duration of the failures/breakdowns should be controlled and curtailed.

The proposed Cumulative cost effect model measures the total loss to the organization in case of failure / breakdowns to machinery. The indirect losses and other consequential losses due to breakdowns / failures are also calculated through this model.

The application of cumulative cost model to the selected nine types of machinery, in the event of breakdowns gives us average costs per breakdown for each of this machinery group. The machinery groups, with the maximum average cost per breakdowns are identified for detailed study on breakdown maintenance.

5.3.1.1 Generators

A breakdown in a generator for few hours can stop the entire project, (if the whole project is dependent on the single generator). For construction projects in the United Arab Emirates, generally 200 KVA generators would be feeding power to the tower cranes for multi-storey tower projects. In these contracts/projects, as per the contractual program, on the building structural works, every slab concrete should be executed in a 6 days cycle.

Achieving a slab in every 6 days, involves lot of planning of many sequential activities, and even losing of 5 hours as breakdowns, would have knock down effect on the casting of the slab in the 6th day by at least one day. The recovery of one day would not be possible in the multi-storey towers, all the slabs casting must be achieved in 6 days. If the breakdowns are very often then it will result in multifold delays and loss to the project.

There are also other range of generators like 100 KVA capacity which are feeding the other machineries and power tools at the project site, and breakdowns to these generators will affect all the related activities. The subcontractors would also claim for the man-hours lost due to the power shutdown.

A structured breakdown maintenance management will substantially reduce the break duration and will save good amount of time and money to the project.

5.3.1.2 Mobile Cranes / Tower Cranes

Activities executed at the project site, using Tower Cranes are as follows:

a) Slab / column / beam shuttering activities

b) Slab / column / beam steel reinforcement activities

c) Slab / column / beam concreting works using tower crane buckets

d) Loading/offloading of materials from the trailers/vehicles

e) Loading, segregation and shifting of materials like blocks, sand and finishing material into the respective floors

In Case of Breakdown of Tower Cranes/Mobile Cranes, all the above activities planned for the given day, would be greatly affected, and the knock-down effect on activities affected would have a cascade effect on the succeeding activities, the worst would be in the case of a multi-storey tower constructions, where the machinery mobilized Vs. utilized will be always kept on a "Hand to Mouth Basis", since the fixed plant cannot be easily mobilized.

In case of delays in offloading of the trailers, the trailers succeeding programs for other projects would be also affected, as the UAE Roads are not allowed for trailer movement for 24x7 and there are restricted road timings applicable for heavy vehicles. As always, the subcontractor's will have his right for claims due to the non-availability of tower crane / mobile crane, is always there.

5.3.1.3 Wheel Loaders

These are versatile machinery which is used extensively in every project. The back hoe loader has the options of fork facility as well.

Activities executed at the project site, using wheel loaders and back hoe loaders include the following:

1) Excavations, levelling works
2) Clearing the Debris
3) Loading and Unloading the Materials
4) Loading the Excavated soil into the Trucks

In case of a breakdown of this machinery, the complete site activities get hampered. Even though it doesn't look so prominent, only a construction team can understand the pain of the breakdown on this machinery. The effect of breakdowns will be more severe with the projects, where only one of this machinery is available.

5.3.1.4 Back hoe Loaders

The back hoe loaders are commercially called as JCB's which is manufactured by a company called JCB. The back hoe loaders are also versatile machinery since they are fitted always with two kinds of buckets, the smaller buckets for excavation and the larger buckets for loading and levelling. They are mostly used for the following activities:

1) Excavation of trenches

2) Smaller capacity loading and unloading works

3) Levelling of smaller areas

4) With required attachments, breaking of concrete

5) Dewatering well point drilling works

In case of breakdowns to back hoe loaders many other related works will get affected including compaction of trenches, laying of underground services, loading and unloading works, concreting breaking and further trimming works and also the dewatering works. The duration of the breakdown rectification is very important as the related works impact loss of costs to the works.

5.3.1.5 Dumpers

Dumpers and bobcat are multipurpose machineries, which comes in handy to any construction operations where multiple requirements exist as per the site conditions and needs.

The dumpers are used for the following purposes.

1) Transporting of diesel from the main tanks to the 200 litres barrels. Transportation of diesel to multiple locations at the site, generator yards etc.

2) Moving construction materials including blocks, cement bags, shutters, etc. from yard to the lifting locations

3) Shifting the de-shuttered scaffolding materials to the loading yard

4) Collection of the garbage from garbage collection points to the debris yard

5) Distributing cold water filled thermos to the respective workmen areas and distributing in the hot working conditions.

A breakdown of even one hour would have an effect on each of the above activities and its succeeding activities and reflects on the progress of the site.

5.3.1.6 Skid Steer Loaders

The skid steer loader is commercially termed as Bobcat in the construction industry. The prime functions of Bobcat include the following:

1. Transportation of smaller quantities of soils upon excavation
2. Entry and egress with constrained areas where heavier machineries cannot enter
3. Similar works of wheel loaders, back hoe loaders but smaller volumes
4. Transportation of materials to constrained areas
5. Attachments will facilitate drilling and breaking operations

5.3.1.7 Compressors

The air compressor is used for mainly two kinds of activities namely cleaning of the slab during concreting where lots of debris, dust, left over cut pieces of wood, binding wires, structural steel rods would be present. The cleaning of this is essential as otherwise the Engineer would reject the slab concreting works. If left over this debris would stick with the concrete and end up in poor finishing of the works. The other major work executed by compressors is the pile breaking and concrete breaking works. Any pile cast should be broken and trimmed to the required level to facilitate further coping and other beams which are normally part of foundations. Also other breaking works at site requirements are also some times required from this machinery. Any failure to this machinery will cause delays and disruptions to the project as, if any concrete works interrupted then multifold of other activities gets hampered.

5.3.1.8 Forklifts

Forklift is normally used for the loading and unloading of materials in a construction site. Material handling is one of the prime activities in the project and any failure and breakdown happening to this machinery will stop many other related works.

5.3.1.9 Roller Compactors

The Roller Compactors are one of the machinery generally used for the compaction of earth.

Compaction of the soil is very important in any construction activity. The earth excavated to its depth should be prepared for plain cement concrete (PCC) Works and other concrete works. Normally the compaction is influenced by the load application after completion of works. Some places there is a layered compaction when the depth of excavation and filling is of huge volume.

Failures and breakdowns to this machinery will affect many other follow on activities and also the waiting of workmen.

5.3.2 Machinery Failures / Breakdowns Control and importance

In general the maintenance costs are calculated as the sum of the wage costs, the hired machinery costs, the costs for the maintenance support system and the costs for the parts replaced (C. Anderson et al, 2011). There is always a conservative understanding that only direct costs are the loss to the organization, in case of breakdowns to construction machinery.

It is evident from the above analysis that, in construction industry and projects, the plant and machinery have to work consistently in close coordination with each other and inter dependency of activities and machinery are most common. Every machinery/machinery is interlinked with the performance of the other machinery. A breakdown / failure happening to any one of the machinery will contribute a great loss to the productive hours of that particular machinery. At the same time the other associated machinery is also affected along with the associated activities. It makes chaos and disturbances as manual and machinery resources are at loss and the cumulative effect of this loss is substantial to the project.

A detailed analysis of costs, associated costs, the direct and indirect losses and the cumulative cost effect are made for failures/breakdowns on selected machinery and are listed below. The analysis includes two categories at large:

5.3.2.1 Total losses to the project

The project while utilizing the services of any machinery has lots of preplanning works. For example, if there is a concrete work, the sequence of works related to various machinery is as follows:

a. Completion of formwork
b. Completion of reinforcement steel works
c. Completion of all shuttering works
d. Completion of all cleaning works
e. Preparation of vibrators
f. Preparation of power floats
g. Preparation of Compressors

h. Ordering of Concrete with the plant
i. Organization of Concrete Pumps, Transit Mixers
j. Organization of Cube testing with third party agencies
k. Request for inspection of the slab by Consultant and Government Agency
l. Concrete teams
m. Curing teams
n. Shuttering teams
o. Safety teams
p. Plant teams

From the above lists, it is clearly understood that the planning of a single activity alone is having such multiple resource planning including Engineers, Consultants, Government Authorities, Machinery, Tradesmen, Operators, etc. All these activities are inter - dependent as, if one activity fails either the follow on or the predecessor activity in other areas end up in stoppage.

When there is a failure or breakdown to any machinery related to the above activities, the projects surely makes cumulative losses, in terms of trade manpower costs, material wastage, activities stoppage, related plant and machinery idle, penalties and statutory losses including client goodwill.

The proposed cost model (Figure 5.1) can be used to measure the total loss to the organization in case of failure / breakdowns to machinery. The indirect losses and other consequential losses due to breakdowns / failures are calculated through this model.

As detailed above, any machinery working in a project site is intended for a specific work, and every work needs multiples of resources including one or more machinery, supervision, materials, inspection, technicians etc. Some activities are time bound as any disturbance to the planning will lead to rejection of the entire materials, like concrete, plaster etc. Certain cases demand for legal authorities fines, as it is statutory to keep the workplace clean to protect the housekeeping and environment. The compounding effect of breakdown to one machine will lead to many activities disrupted wherein there are huge fines, loss of client good will and reputation.

The total cumulative loss to the project due to failures/ breakdowns is calculated as follows:

$T_P = T_a$ (Trade Cost) + T_b (Materials Wastage / Activities Lost) + T_c (Machinery / Vehicle Idle Cost) + T_d (Other Time Losses)

$T_P = T_a + T_b + T_c + T_d$

5.3.2.2 Total losses to the machinery department

The machinery department also makes indirect and consequential losses during failures and breakdowns of machinery. They need to arrange alternate machinery to manage the planned works of the project. It needs to be leased and the costs are always debited to machinery department. The broken down machinery needs to be repaired and the cost of repair including the technicians, supervisors, spare parts need to be taken into account as a cost. The broken as well loses the revenue along with the failures and these losses also to be taken into account during breakdowns.

Total Losses to the Machinery Department

$T_E = T_f$ (Revenue lost from machinery) + T_g (Replacement Machinery costs) + T_h (Breakdown Rectification Costs)

Therefore **$T_E = T_f + T_g + T_h$**

Hence an effective mechanism to control and curtail the breakdown duration is very much essential in construction industry. Calculations are made for breakdown effect on cost to nine categories of machinery based on the Consequential Cost Effect Model and analyzed for various durations and their effects on the cost. The detailed calculations for the machinery dumper are listed in Table 5.2 and the details for other machinery are enclosed in the Appendix A.

Consequential loss to the organization is the sum of total losses to the project and total losses to the machinery department **$T_O = T_P + T_E$**.

Detailed Cost working due to breakdowns based on the Cumulative Consequential Cost Effect Model is listed in table 5.3 as a sample, while the analysis done for all nine selected machinery are listed in Appendix A. The analysis of the same for different duration segments of breakdowns is listed in table 5.4.

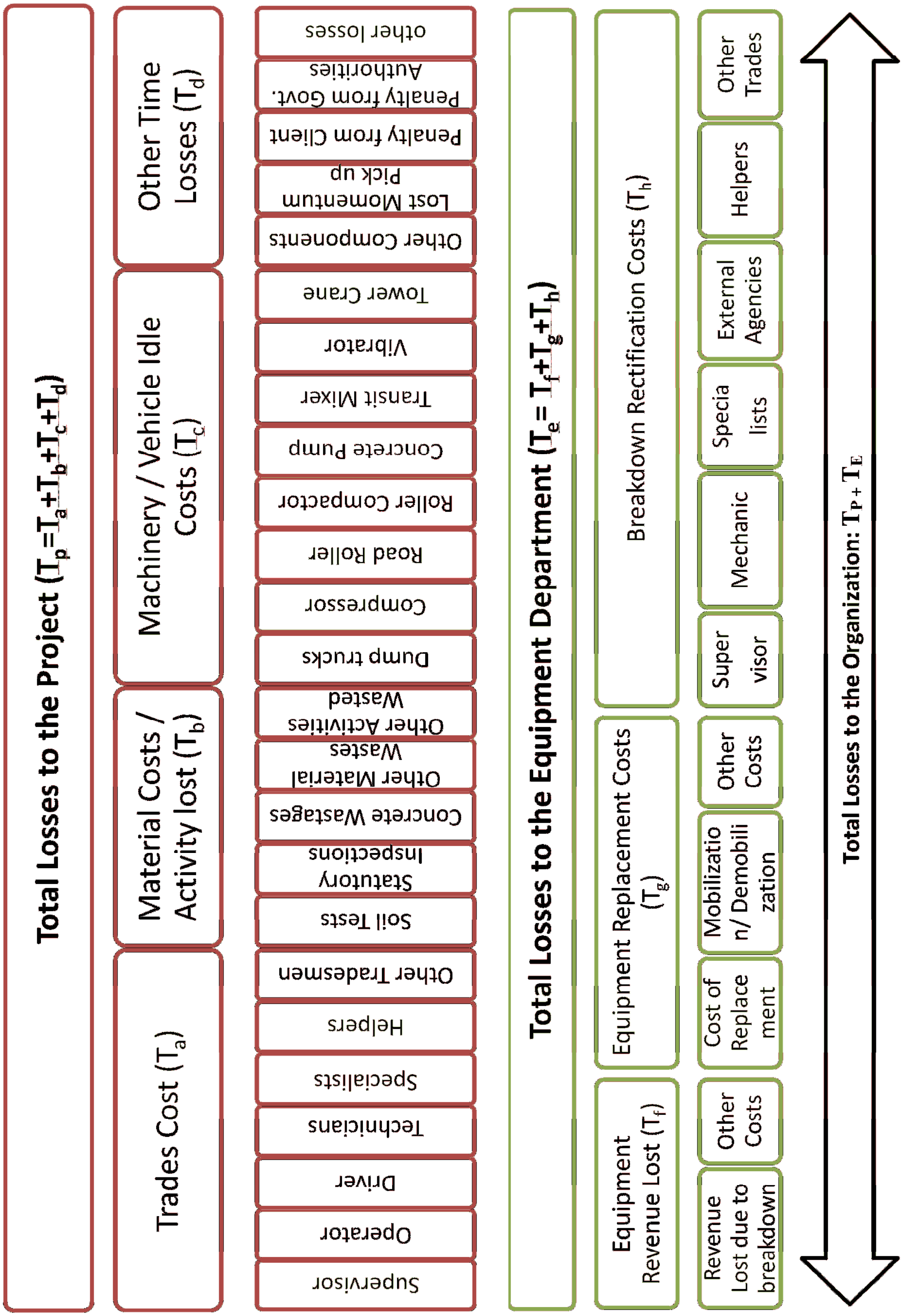


Fig 5.1 Cumulative Consequential Cost Effect Model – For construction machinery

Table 5.3 Breakdown Consequential Costs – Dumper breakdowns

Breakdown of Dumper - Consequential Losses

S.No	Prime Activities	Actual BD hours	Delay Duration in hours	Delays/effects to follow on/related activities	Trades Manpower cost								Other Machinery /vehicles Idle charges						Effective losses	Repaired equipment Momentum gain costs	Penalty loss	Total Effective loss on project	Breakdown equipment revenu loss	Equip. replacement cost		BD repair manpower charges			Effective loss for Equipment supplier (without spares)	Total loss to the organisation
					Supervisor	Operator	Driver	Technicians	Trdesman	Hlpers	Municipality	Concrete	Truck	Compressor	vibrator	Road roller	Others	Concrete Pump						Dumper	Mob&Demob	Supervisor	Mechanic	Helper		
					50.00	25.00	20.00	15.00	14.00	12.00	500.00	450.00	70.00			90.00		200.00		120.00			120.00	120.00	500.00	50.00	20.00	10.00		
1	Rubbish removal	1	1	Cleaning	1	1				5			10						835	120	10,000	10,955	120	120	500	5	40	20	805	11,760
	Chemical Shifting	1	1	Finishing works	1	1		4		10			10						955	120		1,075	120	120	500	5	40	20	805	1,880
	Diesel shifting	1	1	Fuel for Plants									10						700	120		820	120	120	500	5	40	20	805	1,625
	Scaffolding shifting	1	1	Seggregation of materials	1	1		5		5			10						910	120		1,030	120	120	500	5	40	20	805	1,835
2	Rubbish removal	2	2	Cleaning	1	1				5			10						1,670	120	10,000	11,790	240	240	500	10	80	40	1,110	12,900
	Chemical Shifting	2	2	Finishing works	1	1		4		10			10						1,910	120		2,030	240	240	500	10	80	40	1,110	3,140
	Diesel shifting	2	2	Fuel for Plants									10						1,400	120		1,520	240	240	500	10	80	40	1,110	2,630
	Scaffolding shifting	2	2	Seggregation of materials	1	1		5		5			10						1,820	120		1,940	240	240	500	10	80	40	1,110	3,050
3	Rubbish removal	3	3	Cleaning	1	1				5			10						2,505	120	10,000	12,625	360	360	500	15	120	60	1,415	14,040
	Chemical Shifting	3	3	Finishing works	1	1		4		10			10						2,865	120		2,985	360	360	500	15	120	60	1,415	4,400
	Diesel shifting	3	3	Fuel for Plants									10						2,100	120		2,220	360	360	500	15	120	60	1,415	3,635
	Scaffolding shifting	3	3	Seggregation of materials	1	1		5		5			10						2,730	120		2,850	360	360	500	15	120	60	1,415	4,265
4	Rubbish removal	5	5	Cleaning	1	1				5			10						4,175	120	10,000	14,295	600	600	500	25	200	100	2,025	16,320
	Chemical Shifting	5	5	Finishing works	1	1		4		10			10						4,775	120		4,895	600	600	500	25	200	100	2,025	6,920
	Diesel shifting	5	5	Fuel for Plants									10						3,500	120		3,620	600	600	500	25	200	100	2,025	5,645
	Scaffolding shifting	5	5	Seggregation of materials	1	1		5		5			10						4,550	120		4,670	600	600	500	25	200	100	2,025	6,695
5	Rubbish removal	7	7	Cleaning	1	1				5			10						5,845	120	10,000	15,965	840	840	500	35	280	140	2,635	18,600
	Chemical Shifting	7	7	Finishing works	1	1		4		10			10						6,685	120		6,805	840	840	500	35	280	140	2,635	9,440
	Diesel shifting	7	7	Fuel for Plants									10						4,900	120		5,020	840	840	500	35	280	140	2,635	7,655
	Scaffolding shifting	7	7	Seggregation of materials	1	1		5		5			10						6,370	120		6,490	840	840	500	35	280	140	2,635	9,125
6	Rubbish removal	9	9	Cleaning	1	1				5			10						7,515	120	10,000	17,635	1,080	1,080	500	45	360	180	3,245	20,880
	Chemical Shifting	9	9	Finishing works	1	1		4		10			10						8,595	120		8,715	1,080	1,080	500	45	360	180	3,245	11,960
	Diesel shifting	9	9	Fuel for Plants									10						6,300	120		6,420	1,080	1,080	500	45	360	180	3,245	9,665
	Scaffolding shifting	9	9	Seggregation of materials	1	1		5		5			10						8,190	120		8,310	1,080	1,080	500	45	360	180	3,245	11,555
7	Rubbish removal	10	10	Cleaning	1	1				5			10						8,350	120	10,000	18,470	1,200	1,200	500	50	400	200	3,550	22,020
	Chemical Shifting	10	10	Finishing works	1	1		4		10			10						9,550	120		9,670	1,200	1,200	500	50	400	200	3,550	13,220
	Diesel shifting	10	10	Fuel for Plants									10						7,000	120		7,120	1,200	1,200	500	50	400	200	3,550	10,670
	Scaffolding shifting	10	10	Seggregation of materials	1	1		5		5			10						9,100	120		9,220	1,200	1,200	500	50	400	200	3,550	12,770
8	Rubbish removal	21	10	Cleaning	1	1				5			10						8,350	120	10,000	18,470	2,520	2,520	500	###	840	420	6,905	25,375
	Chemical Shifting	21	10	Finishing works	1	1		4		10			10						9,550	120		9,670	2,520	2,520	500	###	840	420	6,905	16,575
	Diesel shifting	21	10	Fuel for Plants									10						7,000	120		7,120	2,520	2,520	500	###	840	420	6,905	14,025
	Scaffolding shifting	21	10	Seggregation of materials	1	1		5		5			10						9,100	120		9,220	2,520	2,520	500	###	840	420	6,905	16,125

Table 5.4 Consequential Losses of Breakdowns with Durations

Consequential Losses on failures / breakdowns to Construction Equipment

Cost Incurred for 1-2 hours (in AED)

Equipment Details	Activity 1	Activity 2	Activity 3	Activity 4	Most affected Activity(s)	Momentum Pickup Costs	Penalties from Client	Penalties from Govt. Depts.	Total Losses to Project	Losses to Equipt. Dept.	Total Losses to Company
Generator	1790	820	0	0	1790	40	0	0	1830	790	2620
Forklift	986	0	0	0	986	100	0	0	1086	1030	2116
Compressor	2950	346	0	0	2950	25	0	0	2975	480	3455
Mobile Crane	1510	600	1260	0	3370	200	0	0	3570	1430	5000
Back Hoe Loader	562	246	326	0	1134	100	0	0	1234	1030	2264
Skid Steer Loader	442	622	0	0	1064	50	0	0	1114	630	1744
Wheel Loader	1532	722	0	0	2254	120	0	0	2374	1110	3484
Dumper	1670	1910	1400	1820	1670	120	0	0	1790	1110	2900
Roller Compactor	442	622	0	0	1064	25	0	0	1089	530	1619

Cost Incurred for 3-4 hours (in AED)

Equipment Details	Activity 1	Activity 2	Activity 3	Activity 4	Most affected Activity(s)	Momentum Pickup Costs	Penalties from Client	Penalties from Govt. Depts.	Total Losses to Project	Losses to Equipt. Dept.	Total Losses to Company
Generator	3580	1640	0	0	3580	40	0	0	3620	1080	4700
Forklift	1972	0	0	0	1972	100	0	0	2072	1560	3632
Compressor	5990	692	0	0	5990	25	0	0	6015	710	6725
Mobile Crane	3020	1200	1260	0	5480	200	0	0	5680	2360	8040
Back Hoe Loader	1124	492	652	0	2268	100	0	0	2368	1460	3828
Skid Steer Loader	884	1244	0	0	2128	50	0	0	2178	960	3138
Wheel Loader	3064	1444	9020	0	13528	120	0	0	13648	1720	15368
Dumper	4175	4775	3550	4550	4175	120	0	0	4295	1415	5710
Roller Compactor	884	1244	0	0	2128	25	0	0	2153	760	2913

Cost Incurred for 5-6 hours (in AED)

Equipment Details	Activity 1	Activity 2	Activity 3	Activity 4	Most affected Activity(s)	Momentum Pickup Costs	Penalties from Client	Penalties from Govt. Depts.	Total Losses to Project	Losses to Equipt. Dept.	Total Losses to Company
Generator	5370	2460	0	0	5370	40	0	0	5410	1370	6780
Forklift	2958	0	0	0	2958	100	0	0	3058	2090	5148
Compressor	8850	1038	0	0	8850	25	0	0	8875	1170	10045
Mobile Crane	4530	1800	1260	0	7590	200	0	0	7790	3290	11080
Back Hoe Loader	1686	738	978	0	3402	100	0	0	3502	2090	5592
Skid Steer Loader	1326	1866	0	0	3192	50	0	0	3242	1290	4532
Wheel Loader	4596	2166	9020	0	15782	120	50000	0	65902	2330	68232
Dumper	7515	8595	6300	8190	7515	120	50000	10000	67635	2025	69660
Roller Compactor	1326	1866	0	0	3192	25	0	0	3217	990	4207

Cost Incurred for 7-10 hours (in AED)

Equipment Details	Activity 1	Activity 2	Activity 3	Activity 4	Most affected Activity(s)	Momentum Pickup Costs	Penalties from Client	Penalties from Govt. Depts.	Total Losses to Project	Losses to Equipt. Dept.	Total Losses to Company
Generator	7160	3280	0	0	7160	40	50000	0	57200	1660	58860
Forklift	4930	0	0	0	21410	100	0	0	21510	3150	24660
Compressor	14750	1730	0	0	14750	25	0	0	14775	1400	16175
Mobile Crane	7550	3000	1260	0	11810	200	0	0	12010	5150	17160
Back Hoe Loader	2810	1230	1630	0	5670	100	50000	0	55770	3100	58870
Skid Steer Loader	2210	3110	0	0	5320	50	0	0	5370	1950	7320
Wheel Loader	7660	3610	9020	0	20290	120	50000	0	70410	3550	73960
Dumper	8350	9550	7000	9100	8350	120	50000	10000	68470	3550	72020
Roller Compactor	2210	3110	0	0	5320	25	0	0	5345	1450	6795

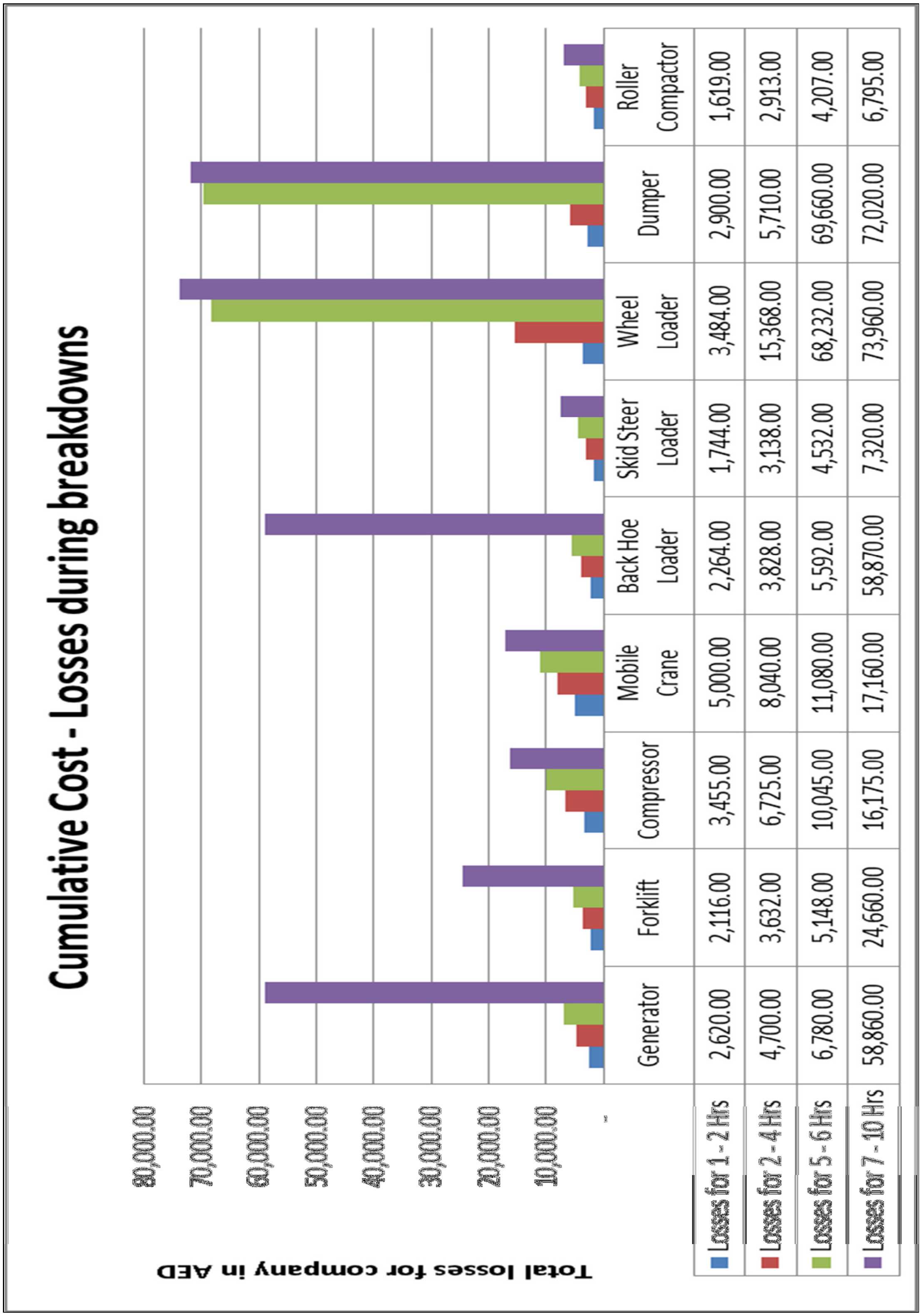


Fig 5.2 Cumulative Cost Effects during Breakdowns with durations

Table 5.5 Average Cost per Breakdown

Cost Analysis for Breakdowns / Failures to 9 Construction Equipment

Equipment Details	Total Losses for Company for 1-2 hours (in AED)					Total Losses for Company for 2-4 hours (in AED)					Total Losses for Company for 5-6 hours (in AED)					Total Losses for Company for 7 - 10 hours (in AED)					Total Costs of breakdowns for three years in AED	Average Cost Per Breakdown in AED
	Basic Cost	Occurences of Breakdowns 2007	2008	2009	Total Costs	Basic Cost	Occurences of Breakdowns 2007	2008	2009	Total Costs	Basic Cost	Occurences of Breakdowns 2007	2008	2009	Total Costs	Basic Cost	Occurences of Breakdowns 2007	2008	2009	Total Costs		
Generator	2,620	4	5	7	41,920	4,700	8	8	21	173,900	6,780	2	6	13	142,380	58,860	22	34	44	5,886,000	6,244,200	35,886
Forklift	2,116	1	1	1	6,348	3,632	0	2	1	10,896	5,148	0	0	0	-	24,660	1	5	5	271,260	288,504	16,971
Compressor	3,455	0	0	0	-	6,725	0	6	1	47,075	10,045	0	6	1	70,315	16,175	7	14	15	582,300	699,690	13,994
Mobile Crane	5,000	0	0	5	25,000	8,040	3	2	1	48,240	11,080	2	2	3	77,560	17,160	9	10	16	600,600	751,400	14,177
Back Hoe Loader	2,264	0	1	0	2,264	3,828	0	5	2	26,796	5,592	1	4	2	39,144	58,870	2	6	1	529,830	598,034	24,918
Skid Steer Loader	1,744	0	1	0	1,744	3,138	1	3	6	31,380	4,532	2	1	1	18,128	7,320	5	10	6	153,720	204,972	5,694
Wheel Loader	3,484	0	3	3	20,904	15,368	5	6	23	522,512	68,232	2	5	5	818,784	73,960	2	4	13	1,405,240	2,767,440	38,978
Dumper	2,900	0	0	0	-	5,710	1	5	3	51,390	69,660	2	2	3	487,620	72,020	20	18	17	3,961,100	4,500,110	63,382
Roller Compactor	1,619	0	1	0	1,619	2,913	0	0	0	-	4,207	0	3	1	16,828	6,795	10	5	11	176,670	195,117	6,294

While analyzing the figure 5.2 and table 5.5, it is found that maximum numbers of breakdowns are in the range between 7 to 10 hours or more. Further scrutiny reveals that 61

% of the breakdowns of all these machinery are falling in this range only. Generally if machinery is breaking for more than 7 to 10 hours, replacement machinery is always inevitable and hence the effective affected duration of such breakdowns is taken as 10 hours only. As the duration of the breakdowns increase the cost impact gets multifold as the replacement machinery is inevitable. Hence by all means the breakdown duration to be curtailed and controlled.

It is also evident from the above table that the average cost per breakdown is highest for the dumpers followed by the wheel loaders. Both these machinery are vital in construction projects as they contribute effectively throughout the duration of the project. As the breakdowns are falling generally in the range of 7 to 10 hours (61 %), particularly for the machinery dumper and wheel loader, it is AED 6,338/-per hour and AED3,898/- per hour respectively. Any improvements to reduce the duration of the breakdown hour will have greater reduction in the cost and study on the breakdown improvement systems will yield better results to the organization's losses. Also, the replacement of these machines during breakdowns is normally difficult as spare availability is always less for these two groups of machinery. These conditions also initiate further detailed study on this machinery for curtailing the breakdown duration with a proper control measures so that the costs and the duration can be reduced.

5.3.3 Critical Construction Machinery Analysis

In this analysis the machines with the highest breakdown ratio are identified. The ratio of total number of breakdowns to the total number of machines available in each category is termed as breakdown ratio. This is calculated for a five year failure data available with the target company and the machinery with the maximum ratios are identified as critical machinery. This ratio is very important, as it determines the maximum breakdown or failure prone machinery and the same need to be controlled and curtailed.

The breakdown data of selected nine machinery group have been taken from the list of total breakdown records of all the machinery available with the target organization. Since the focus is on these nine machinery lists of 876 breakdown data pertaining only to these machineries have been considered for the analysis. To determine the most critical machine in the system, the ratio of the number of breakdown to available machines is calculated. The machine with the highest ratio is identified as the critical machine as indicated in Table 5.6. Wheel loader with highest breakdown ratio is identified as the most critical machine followed by mobile cranes, back hoe loaders and dumpers in the ranking.

Mobile Cranes are general utility machinery. They are not considered as core construction machines as they find general application in other fields of industry also. They are abundantly available in the local market on rental basis at JIT.

The back hoe loaders are generally utilized for limited application only in the construction sites due to their specific application nature which is mostly excavation. They find greater application in the road works projects rather than building construction projects. The number of available machines on this category with the target company is limited. Hence they are not considered for detailed analysis in the present study.

Table 5.6 Critical Machinery based on Breakdown Ratio (2007 - 2011)

Breakdown Ratio of Critical Machines in the System																			
		2007			2008			2009			2010			2011			Summary		
Sl. No.	Machine	No. of Machines	No. of Breakdowns	Breakdowns / Machine Ratio	No. of Machines	No. of Breakdowns	Breakdowns / Machine Ratio	No. of Machines	No. of Breakdowns	Breakdowns / Machine Ratio	No. of Machines	No. of Breakdowns	Breakdowns / Machine Ratio	No. of Machines	No. of Breakdowns	Breakdowns / Machine Ratio	No. of Machines	No. of Breakdowns	Breakdowns / Machine Ratio
1	Wheel Loader	2	9	4.50	2	18	9.00	2	44	22.00	3	35	11.67	3	35	11.67	12	141	11.75
2	Mobile Crane	6	14	2.33	4	14	3.50	4	25	6.25	5	20	4.00	6	8	1.33	25	81	3.24
3	Back Hoe Loader	2	2	1.00	2	16	8.00	2	5	2.50	5	10	2.00	5	2	0.40	16	35	2.19
4	Forklift	5	2	0.40	4	8	2.00	4	7	1.75	4	3	0.75	4	2	0.50	21	22	1.05
5	Skid Steer Loader	4	8	2.00	11	15	1.36	11	13	1.18	14	9	0.64	14	9	0.64	54	54	1.00
6	Generator	29	36	1.24	31	53	1.71	39	85	2.18	97	79	0.81	97	43	0.44	293	296	1.01
7	Dumper	21	23	1.10	19	26	1.37	19	23	1.21	19	20	1.05	19	24	1.26	97	116	1.20
8	Air Compressor	14	20	1.43	21	26	1.24	21	17	0.81	21	17	0.81	21	8	0.38	98	88	0.90
9	Roller Compactor	9	10	1.11	8	9	1.13	11	7	0.64	11	7	0.64	11	10	0.91	50	43	0.86

In the construction field the utilization of these wheel loaders and dumpers exist almost to the entire duration of the project for various earth moving and material handling operations and as well the availability of dumper on rental basis is almost scarce in the market and wheel loader always find lots of demand with various construction companies and the demand in the market is always high for this machinery. They are versatile machinery and useful to one and many activities in the project. Due to all these facts wheel loaders and the dumpers are considered for further study.

5.3.4 Breakdown Impact Effect of Selected Machinery

The information taken from the available failure data of nine categories of machinery is further analyzed and the contribution of these machinery breakdowns to the organizations over all breakdown percentage is identified. Further, specific influence of earthmoving machinery to this breakdown effect is also identified. The selected earthmoving machinery consists of dumpers, wheel loaders, back hoe loaders and the skid steer loaders. Of these four categories of machinery, the most contributing machinery of the earthmoving group is identified as dumper and wheel loader.

The tables consist of following information for a period of five years pertaining to nine categories of the machinery:

- monthly breakdown hours for the month and year
- total working hours for the month and year
- total breakdown hours of all the machinery
- breakdown percentage of the individual machinery
- their contribution to the total breakdown hours of this selected category of machinery
- Over-all contribution of this machinery to the overall breakdown percentage of organization considering the organization's complete plant and machinery.

The complete plant and machinery working hours and the total breakdown hours and overall breakdown percentage of all the machinery are taken from the data base of the target company and listed in Annexure C. All the tables are not fully listed in the main thesis due to their voluminous nature and only the values are taken here for analysis. Between years 2007 – 2011, as per the data available on the tables 5.7, if we consider the earthmoving machinery alone, which are wheel loaders, back hoe loaders, dumpers and skid steers, their total contribution to the overall breakdown percentage is calculated at 13.0%, 20.9%, 15.0%, 16.5% and 14.0% to the total breakdown percentage of nine which are 62.2%, 59.5%, 62.4%, 51.3% and 57.6% for the years 2007, 2008, 2009, 2010 and 2011 respectively.

From Table 5.6, from the four categories of earthmoving machinery, the additional impact of machinery group which includes wheel loader and dumper is further analyzed. This critical machinery group is contributing to 95%, 70.4%, 87%, 81.7% and 58.3% respectively for the years 2007 to 2011.

Table 5.7 Selected Machinery Contributions to Breakdowns (2007- 2011)

Year	Selected 9 Equipment's Contribution to Organization's Breakdowns Percentage	Breakdown Contribution by Earth Moving Equipments	Percentage Impact to nine equipt breakdown contribution	Breakdown effect of Wheel Loader and Dumper	Wheel Loader and Dumper Effect to Breakdowns of Earthmoving Equipment
2007	62.2%	13.0%	21.0%	19.0%	95.0%
2008	59.5%	20.9%	35.1%	24.7%	70.4%
2009	62.4%	15.0%	23.6%	20.6%	87.0%
2010	51.3%	16.5%	32.3%	26.4%	81.7%
2011	57.6%	14.0%	24.2%	14.1%	58.3%

All of the above data analysis reveals that the impact of earthmoving machinery to the overall breakdowns percentage of the target organization and it is substantially high to a level of 27 % to the selected nine categories of machinery and worth for further analysis to make a better breakdown maintenance system for the organization. Further the importance of studying earthmoving machinery is justified as they have all the systems and components of a complex natured machine with it and a study of this will facilitate similar and easy approach for other machinery as well if need be.

Further sections of thesis will concentrate on the Wheel Loaders and Dumpers since this machinery have severe influential effect of breakdowns on to the overall breakdown effect of the earth moving group of machinery. If these breakdowns are properly managed and reduced, the organization’s overall breakdown percentage will get reduced and may even target to zero breakdowns with the extension of these failure studies to other type of machinery as well. Based on these analyses, we infer the following information which will be used for detailed analysis in further parts of this study.

a) Failure costs – Cumulative Consequential Cost Impact Analysis

The Cumulative Failure Cost per breakdown is done with nine categories of machinery based on their consequential effect to various activities.

- It is evident from the above analysis that out of nine categories of machinery selected, the average cost per breakdown is highest for the dumpers followed by the wheel loaders.
- As these machinery are vital in construction projects and the breakdowns on these machinery falling generally in the range of 7 to 10 hours (61%), particularly for the machinery dumper and wheel loader and dumpers which are AED 6,338/-per hour and AED 3,898/- per hour respectively, any improvements to reduce the duration of the breakdown hour will have greater reduction in the cost and study on the breakdown improvement systems will yield better results to the organization's losses.
- The replacement of these machines during breakdowns is normally difficult as spare availability is always less for these two groups of machinery.
- These conditions initiate further detailed study on this machinery for reducing the effective breakdown duration with a proper control measures so that the costs and the duration can be reduced

b) Critical Construction Machinery Analysis

- Wheel loader with highest breakdown ratio is identified as the most critical machine followed by mobile cranes, back hoe loaders and dumpers in the ranking.
- The utilization of these wheel loaders and dumpers exist almost to the entire duration of the construction project for various earth moving and material handling activities.
- There is also bigger demand for this machinery in the market on lease basis. They are also versatile and useful to many activities in the project.

c) Breakdown Impact Effect of Selected Machinery

- The analysis with method of breakdown impact with selected machinery reveals that out of four categories of earthmoving machinery, the group, wheel loader and dumper have critically impact on the overall earth moving group to a level of 79 % and hence further detailed study of this machinery is justified.

5.4 Reliability Studies for Construction Machinery

Reliability is the probability that a component, system, or process will function without failure for a specified length of time when operated correctly under specified conditions. Reliability is also defined as the probability that a system (and component in the system) will function over some time period 't' (Ebeling, 1997). For any organization, which is involved in manufacturing, services or processing, it always takes a longer time to build up reputation for reliability, and it will be only a short time to be branded as "unreliable" after shipping a flawed product or service or a process (Croarkin et al, 2005).

The basic objective of system reliability and availability analysis in the maintenance management is to identify various weak areas persisting in a system and also to quantify the impact of component failures (Wang et al 2004). It is also stated that the component reliability is an important measure which is defined as the probability that any component in the system is critical to the system failure (Andrews et al 2003).

5.4.1 Reliability Predictions

Reliability is achieved to higher levels by means of design efforts, right choice of materials and other resource inputs. It is also related to the level of high productivity, quality assurance efforts, execution of proper maintenance, and many other related decisions and activities all of which add to the costs of production, purchase, and product ownership (Blischke et al, 2003).

Reliability predictions are one of the most common forms of reliability analysis. Reliability predictions predict the failure rate of components and overall system reliability. These predictions are used to evaluate design feasibility, compare design alternatives, identify potential failure areas, trade-off system design factors, and track reliability improvement.

The reliability analysis in terms of reliability predictions is very vital for the construction machinery / system, as the breakdown hours and the number of occurrences of these breakdowns always pose a threat to the end users of these machines. Hence further analysis on reliability including the failure rate, MTBF, MTTR, reliability and availability calculations are performed on this machinery.

In construction projects, dependency rate of the machineries are crucial as one activity interruption makes the follow on activities very much disturbed. Even though the breakdown of one machine may be less in impact to the individual machine efficiency the effect of these breakdowns on the overall project are always compounded and these breakdowns cannot be over sighted. A detailed calculation of reliability study is performed on selected machinery namely dumpers and wheel loaders on the following manner to estimate the values of failure rate, mean time between failures, mean time to repair and availability are calculated based on the formulae as mentioned in the following sections.

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 is assumed to be at standard conditions for the purpose of reliability predictions.

5.4.1.1 Role of Reliability Prediction

In the recent years we find there is high level of importance given to system reliability, availability and maintainability (RAM). RAM has assumed greater significance in these times due to competitive environment prevailing and as well due controls required on overall operating cost and production cost. One of the main purposes of system reliability and availability analysis is to identify the weaker points available in a system and also to quantify the impact of various component failures (Wang et al 2004). Reliability Prediction has many roles in the reliability engineering process. The impact of proposed design changes on reliability is determined by comparing the reliability predictions of the existing and proposed designs. The complex systems of reliability are generally specified in terms of cost and availability. They are also specified in terms of mean operating time and/or mean time but under cost constraint conditions. To find out the appropriate reliability and availability of the components of the system these requirements have to be taken into consideration during the design stage itself (Eleqbede & Adjallah, 2003).

The ability of the design to maintain an acceptable reliability level under environmental extremes can be assessed through reliability predictions. The effects of complexity on the probability of mission success can be evaluated by performing a reliability prediction analysis. Results from the analysis may determine a need for redundant systems, back-up systems, subsystems, assemblies, or component parts.

5.4.2 Failure Rate

The system's performance is evaluated through availability and reliability of the system and its components. Their good and bad values depend on the system's structure as well as on the components' performance with availability and reliability. These values decrease when the age of the components increase. The effective serving times of these components are influenced by their interaction with one another, the applied maintenance policy and their environments (Samrout et al, 2005). More robust utilization of these components will naturally lead them to failures which cannot be avoided. Failure is any event that impacts a system in a way that adversely affects the system criteria. For example, the criteria could include output in a sold-out condition, or maintenance cost or capital resources in a constrained budget cycle, environmental excursions or safety. A failure definition should contain specific criteria and not be ambiguous. Failure definition can change on a given system over time.

The bathtub curve has been generally accepted as a common representative of the hazard or the failure rate for the machinery over a period/time (Murthy 2003). Field failures do not generally occur at a uniform rate, but follow a distribution in time as commonly described in figure 5.3, as "bathtub curve." The life of a device can be divided into three regions: Infant Mortality Period, where the failure rate progressively improves; Useful Life Period, where the failure rate remains fairly constant; and Wear out Period, where failure rates start to increase.

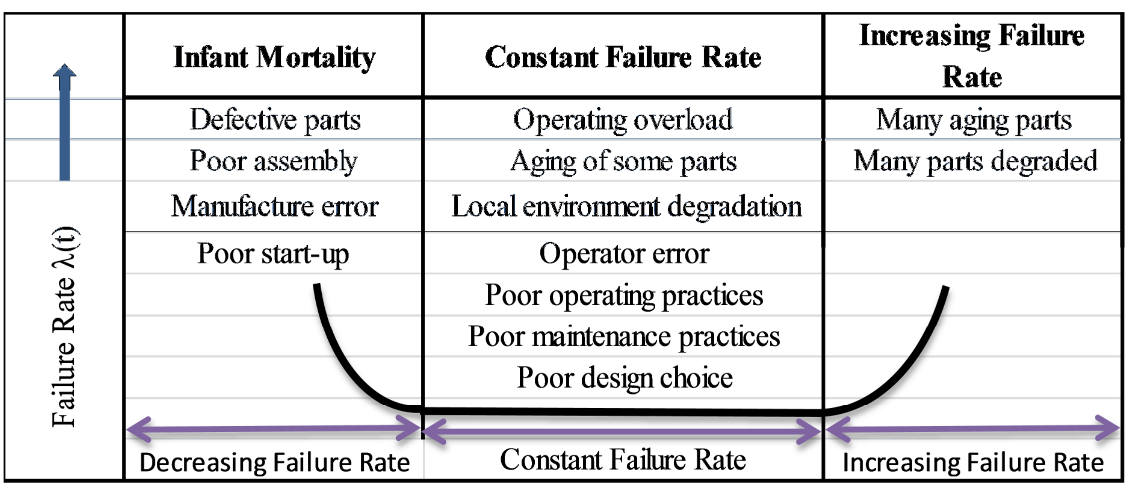


Figure 5.3 Bathtub Curve on Failures (Source: www.weibull.com)

Within a population of components units of machinery there will be a small sub-group of component or part units with latent defects that will fail when exposed to a stress that would otherwise be benign to a good unit. With exception to the failure of the weak components/parts/units, the remaining population is more reliable, and the failure rate is known to decrease. Components or units that cross the Infant Mortality Period (which is the setting period for any newer machinery or a machinery put forth on a newer environment), have a high probability of surviving the conditions provided by the system and its environment. Failures that occur during the Useful Life Period are residual defects surviving Infant Mortality, unpredictable system or environmental conditions, or premature wear out.

Wear out failures are generally associated with such failure mechanisms as metal migration, hot electron effects, wire bond inter metallic, or thermal fatigue. Typically, the wear out of a semiconductor occurs after many years or even decades, and outlives the lifespan of the system in which the component is used. In the construction machinery the wear out is also attributable with the excessive usage of the machinery, faulty operations, operative efficiency, environmental conditions, preventive maintenance lags. We have assumed the conditions attributable to the failure rate to be standard conditions for our analysis purposes.

Reliability predictions are based on failure rates. Conditional Failure Rate or Failure Intensity, $\lambda(t)$, can be defined as the anticipated number of times an item will fail in a specified time period, given that it was as good as new at time zero and is functioning at time 't'. It is a calculated value that provides a measure of reliability for a product. This value is normally expressed as failures per million hours (fpmh or 10^6 hours). For example, a component with a failure rate of 2 failures per million hours would be expected to fail 2 times in a million-hour time period. The purpose for quantitative reliability measurements is to define the rate of failure relative to time and to model that failure rate in a mathematical distribution for the purpose of understanding the quantitative aspects of failure.

The most basic building block is the failure rate, which is estimated using the following equation:

Failure Rate is expressed as Lambda (λ).

λ = No. of Failures / Total Working Hours (or)

$\lambda = r/T$

Where: λ = Failure rate (sometimes referred to as the hazard rate), T = Total running time/cycles/miles during an investigation period for both failed and non-failed items and r = the total number of failures occurring during the investigation period.

5.4.3 Mean Time Between Failures

Mean time between failures (MTBF) is a basic measure of reliability for repairable items. MTBF can be described as the time passed before a component, assembly, or system fails, under the condition of a constant failure rate. Another way of stating MTBF is the expected value of time between two consecutive failures, for repairable systems. It is also a basic measure of reliability for repairable items: the mean number of life units during which all parts of the item perform within their specified limits, during a particular measurement interval under stated conditions.

It is a commonly used variable in reliability and maintainability analyses.

MTBF can be calculated as the inverse of the failure rate, λ, for constant failure rate systems.

MTBF = (Working Hours - Breakdown Hours) / No. of Breakdowns

(or)

MTBF = 1/Failure Rate = $1/\lambda$

5.4.4 Mean Time to Repair (MTTR):

Mean time to repair (MTTR) is defined as the total amount of time spent performing all corrective or preventative maintenance repairs divided by the total number of those repairs. It is the expected span of time from a failure (or shut down) to the repair or maintenance completion. This term is typically only used with repairable systems. It is also basic measure of maintainability: the sum of corrective maintenance times at any specified level of repair, divided by the total number of failures within an item repaired at that level, during a particular interval under stated conditions.

MTTR = Total time spent for performing maintenance / Total number of repairs

5.4.5 Availability:

Availability is denoted by A is the proportion of time; machine is actually available out of time it should be available. It is the probability that a system remain in its intended functional condition and hence capable of being used in a stated environment. Availability deals with the duration of up-time for operations and is a measure of how often the system is alive and well. There is also the concern for availability, A(t), of repairable items since repair takes time. Availability, A(t), is affected by the rate of occurrence of failures (failure rate, λ) or MTBF plus maintenance time; where maintenance can be corrective (repair) or preventative (to reduce the likelihood of failure). Availability, A (t), is the probability that an item is in an operable state at any time.

Therefore Availability: A(t) = (MTBF) / (MTBF + MTTR)

5.4.6 Reliability

Reliability is the probability that an item will perform a required function under stated conditions for a stated period of time. The probability of survival, R (t), plus the probability of failure, F (t), is always unity. The required function includes both a definition of satisfactory and unsatisfactory operation (failure). The stated conditions are the total physical environment, including mechanical, thermal, and electrical conditions. The stated period of time is the time during which satisfactory operation is desired. Reliability is calculated with the following formula:

Reliability = 1 – (Availability)

5.4.7 Reliability Predictions for Dumper

The reliability predictions for dumper are calculated based on the following process:

1. Figure 5.4 is the process flow diagram of the dumper which is made to understand the dependency rate of various components.
2. The total working hours and the breakdown hours for the Dumpers are taken from target company's records are listed in Annexure D and consolidated for the years 2007, 2008, 2009, 2010 and 2011 in the tables 5.8 and table 5.9.
3. Other data including number of breakdowns on each component versus the breakdown hours and total working hours of overall components are tabulated.
4. Various reliability values for dumper including reliability, availability, MTBF, MTTR and the failure rate of components are arrived through the relations and formulae.

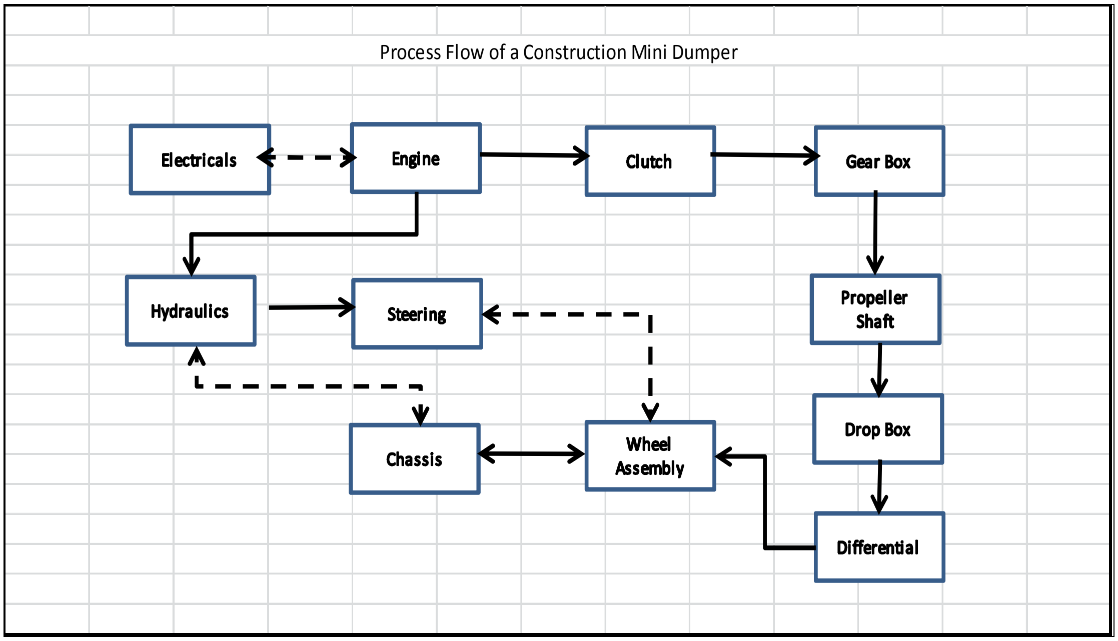


Figure 5.4 Component Block Diagram – Dumper

Table 5.8 Consolidated Breakdown Details of Components - Dumper (2007 - 2011)

Dumper - Components Breakdown Consolidated Data 2007 - 2011											
Description		Engine	Clutch	Gear box	Propeller Shaft	Drop Box	Differential	Wheel	Steering	Hydraulic	Electrical
2007	No. of Times BD	6	4	1	2	0	0	7	1	1	1
	B D Total Hours	524	134	6	65	0	0	286	25	240	15
	Working Hours	64996	65386	65514	65455	65520	65520	65234	65495	65280	65505
2008	No. of Times BD	10	2	1	3	1	0	0	1	1	7
	B D Total Hours	439	128	11	222	48	0	0	30	4	119
	Working Hours	61961	62272	62389	62178	62352	62400	62400	62370	62396	62281
2009	No. of Times BD	8	6	2	3	1	0	0	0	2	1
	B D Total Hours	188	184	46	36	60	0	0	0	12	6
	Working Hours	55972	55976	56114	56124	56100	56160	56160	56160	56148	56154
2010	No. of Times BD	4	2	7	1	2	1	0	1	0	2
	B D Total Hours	762	20	380	3.5	274	260	0	120	0	10
	Working Hours	61638	62380	62020	62396	62126	62140	62400	62280	62400	62390
2011	No. of Times BD	7	0	0	4	2	1	3	1	4	4
	B D Total Hours	128	0	0	159	25	16	196	18	50	235
	Working Hours	62272	62400	62400	62241	62375	62384	62204	62382	62350	62165
Total	Time	35	14	11	13	6	2	10	4	8	15
	Hrs	2041	466	443	485.5	407	276	482	193	306	385

Table 5.9 Consolidated Component Details with BD Percentage - Dumper (2007 - 2011)

Dumper - Components Breakdown Consolidated Data 2007- 2011													
Description		Engine	Clutch	Gear box	Propeller Shaft	Drop Box	Differential	Wheel	Steering	Hydraulic	Electrical	Total Hours	Breakdown Percentage
2007	B D Total Hours	524	134	6	65	0	0	286	25	240	15	1295	0.20%
	Working Hours	64996	65386	65514	65455	65520	65520	65234	65495	65280	65505	653905	
2008	B D Total Hours	439	128	11	222	48	0	0	30	4	119	1001	0.16%
	Working Hours	61961	62272	62389	62178	62352	62400	62400	62370	62396	62281	622999	
2009	B D Total Hours	188	184	46	36	60	0	0	0	12	6	532	0.09%
	Working Hours	55972	55976	56114	56124	56100	56160	56160	56160	56148	56154	561068	
2010	B D Total Hours	762	20	380	3.5	274	260	0	120	0	10	1829.5	0.29%
	Working Hours	61638	62380	62020	62396	62126	62140	62400	62280	62400	62390	622170	
2011	B D Total Hours	128	0	0	159	25	16	196	18	50	235	827	0.13%
	Working Hours	62272	62400	62400	62241	62375	62384	62204	62382	62350	62165	623173	

Table 5.10 Reliability Analysis Result - Dumper (2007 - 2011)

Dumper Reliability Values Identification 2007 -2011 (Components and System)												
Year	Reliability Factor	Engine	Clutch	Gear box	Propeller Shaft	Drop Box	Differential	Wheel	Steering	Hydraulic	Electrical	System
2007	Failure Rate	0.00009	0.00006	0.00002	0.00003	0.00000	0.00000	0.00011	0.00002	0.00002	0.00002	0.9996
	MTBF	10832.67	16346.50	65514.00	32727.50	0.00	0.00	9319.14	65495.00	65280.00	65505.00	
	MTTR	87.33	33.50	6.00	32.50	0.00	0.00	40.86	25.00	240.00	15.00	
	Availability	0.99200	0.99795	0.99991	0.99901	0.00000	0.00000	0.99563	0.99962	0.99634	0.99977	
	Reliability	0.99991	0.99994	0.99998	0.99997	1.00000	1.00000	0.99989	0.99998	0.99998	0.99998	
2008	Failure Rate	0.00016	0.00003	0.00002	0.00005	0.00002	0.00000	0.00000	0.00002	0.00002	0.00011	0.9996
	MTBF	6196.10	31136.00	62389.00	20726.00	62352.00	0.00	0.00	62370.00	62396.00	8897.29	
	MTTR	43.90	64.00	11.00	74.00	48.00	0.00	0.00	30.00	4.00	17.00	
	Availability	0.99296	0.99795	0.99982	0.99644	0.99923	0.00000	0.00000	0.99952	0.99994	0.99809	
	Reliability	0.99984	0.99997	0.99998	0.99995	0.99998	1.000	1.000	0.99998	0.99998	0.99989	
2009	Failure Rate	0.00014	0.00011	0.00004	0.00005	0.00002	0.00000	0.00000	0.00000	0.00004	0.00002	0.9996
	MTBF	6996.50	9329.33	28057.00	18708.00	56100.00	0.00	0.00	0.00	28074.00	56154.00	
	MTTR	23.50	30.67	23.00	12.00	60.00	0.00	0.00	0.00	6.00	6.00	
	Availability	0.99665	0.99672	0.99918	0.99936	0.99893	0.00000	0.00000	0.00000	0.99979	0.99989	
	Reliability	0.99986	0.99989	0.99996	0.99995	0.99998	1.00000	1.00000	1.00000	0.99996	0.99998	
2010	Failure Rate	0.00006	0.00003	0.00011	0.00002	0.00003	0.00002	0.00000	0.00002	0.00000	0.00003	0.9997
	MTBF	15409.50	31190.00	8860.00	62396.00	31063.00	62140.00	0.00	62280.00	0.00	31195.00	
	MTTR	190.50	10.00	54.29	3.50	137.00	260.00	0.00	120.00	0.00	5.00	
	Availability	0.98779	0.99968	0.99391	0.99994	0.99561	0.00000	0.00000	0.00000	0.00000	0.99984	
	Reliability	0.99994	0.99997	0.99989	0.99998	0.99997	0.99998	1.00000	0.99998	1.00000	0.99997	
2011	Failure Rate	0.00011	0.00000	0.00000	0.00006	0.00003	0.00002	0.00005	0.00002	0.00006	0.00006	0.9996
	MTBF	8896.00	0.00	0.00	15560.25	31187.50	62384.00	0.00	62382.00	0.00	15541.25	
	MTTR	18.29	0.00	0.00	39.75	12.50	16.00	65.33	18.00	12.50	58.75	
	Availability	0.99795	0.00000	0.00000	0.99745	0.99960	0.00000	0.00000	0.00000	0.00000	0.99623	
	Reliability	0.99989	1.00000	1.00000	0.99994	0.99997	0.99998	0.99995	0.99998	0.99994	0.99994	

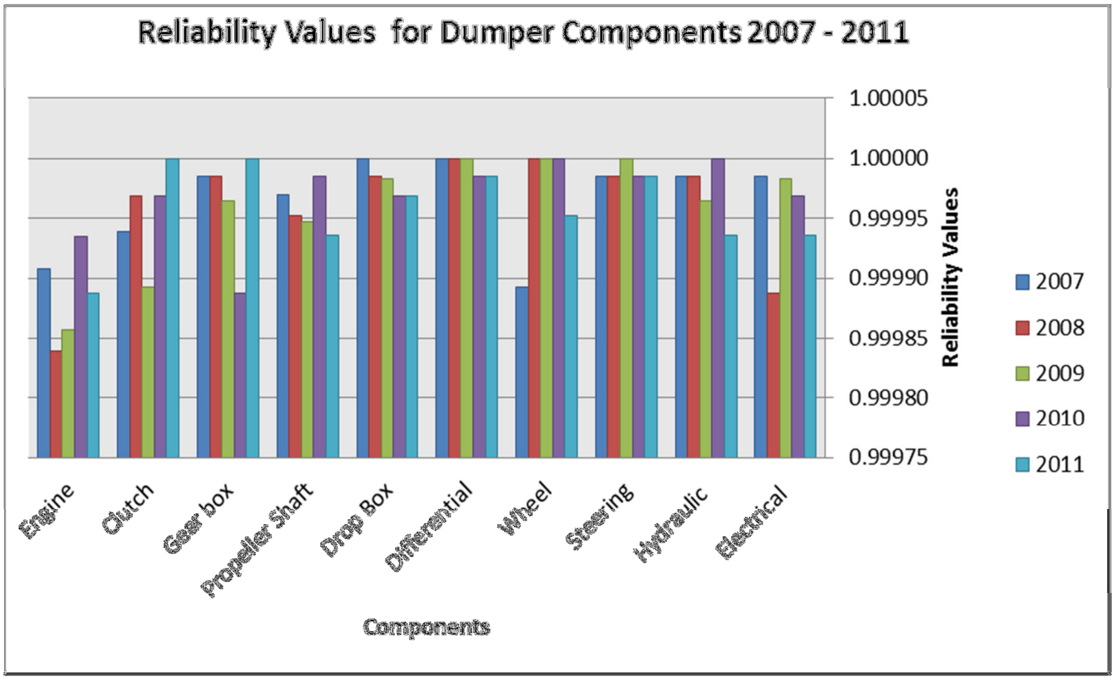


Figure 5.5 Reliability Value Bar Chart for Dumper Components (2007 - 2011)

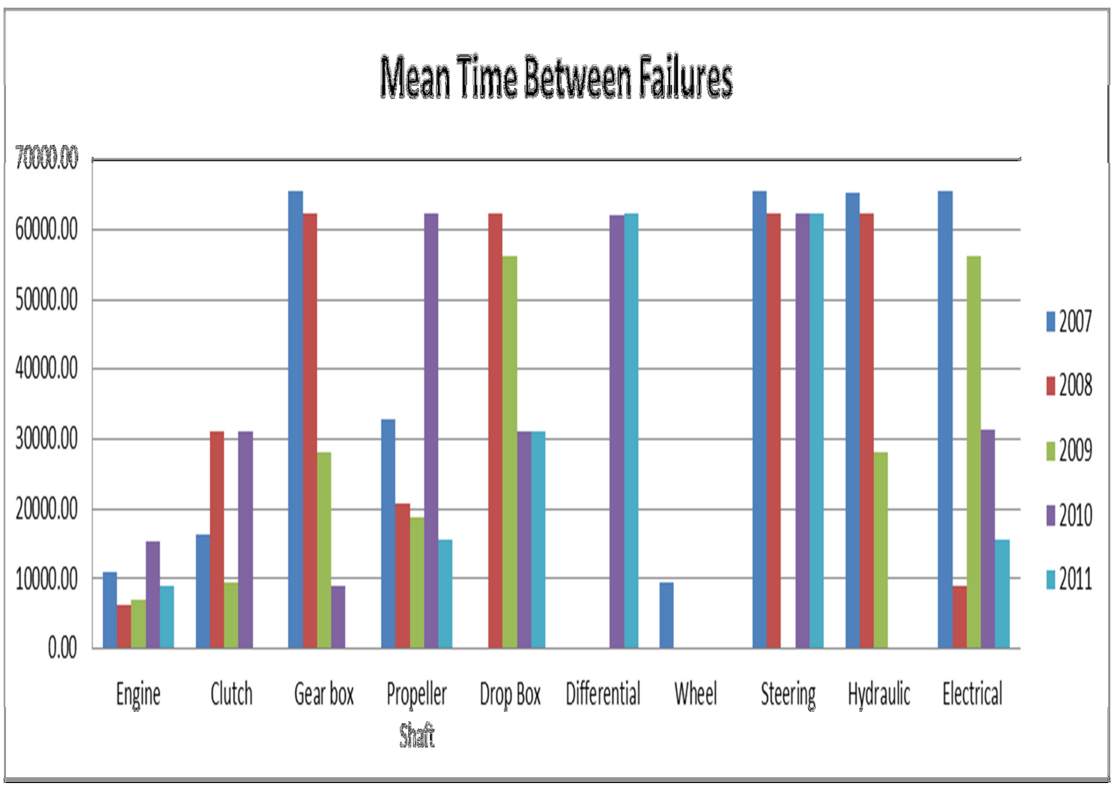


Figure 5.6 MTBF Value Bar Chart for Dumper Components (2007 - 2011)

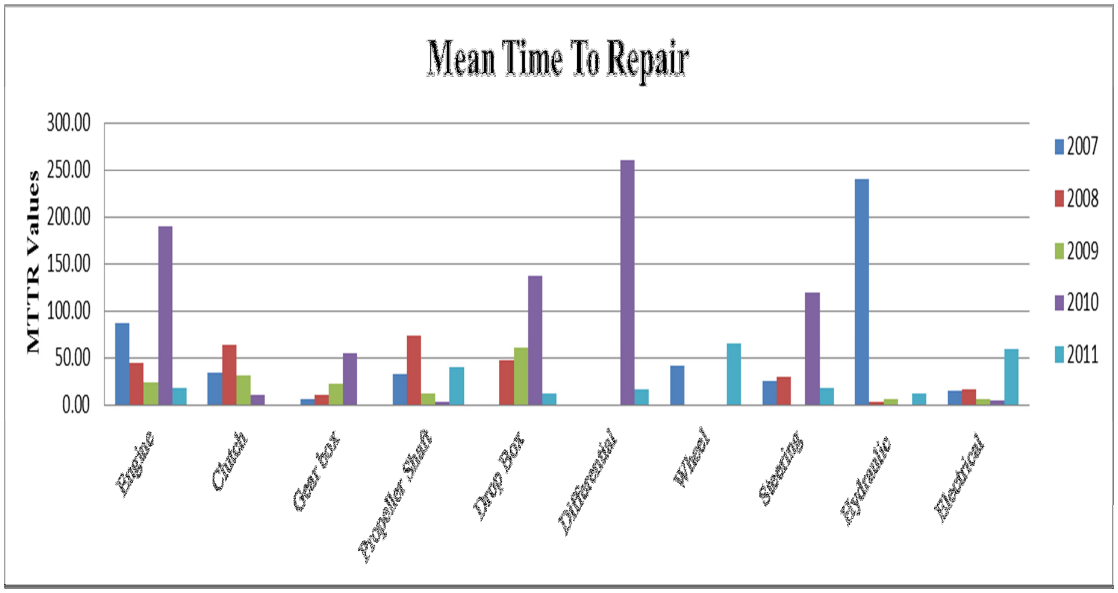


Figure 5.7 MTTR Value Bar Chart for Dumper Components (2007 - 2011)

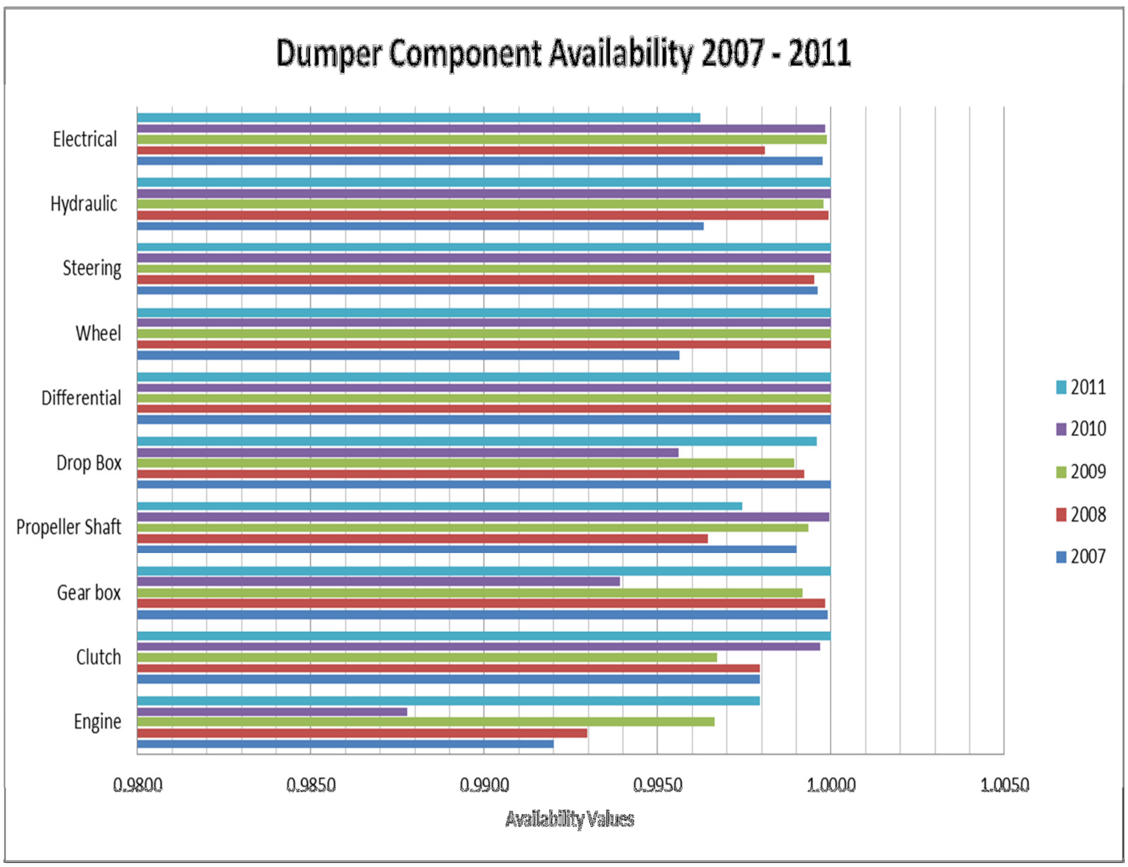


Figure 5.8 Availability Value Bar Chart for Dumper Components (2007 - 2011)

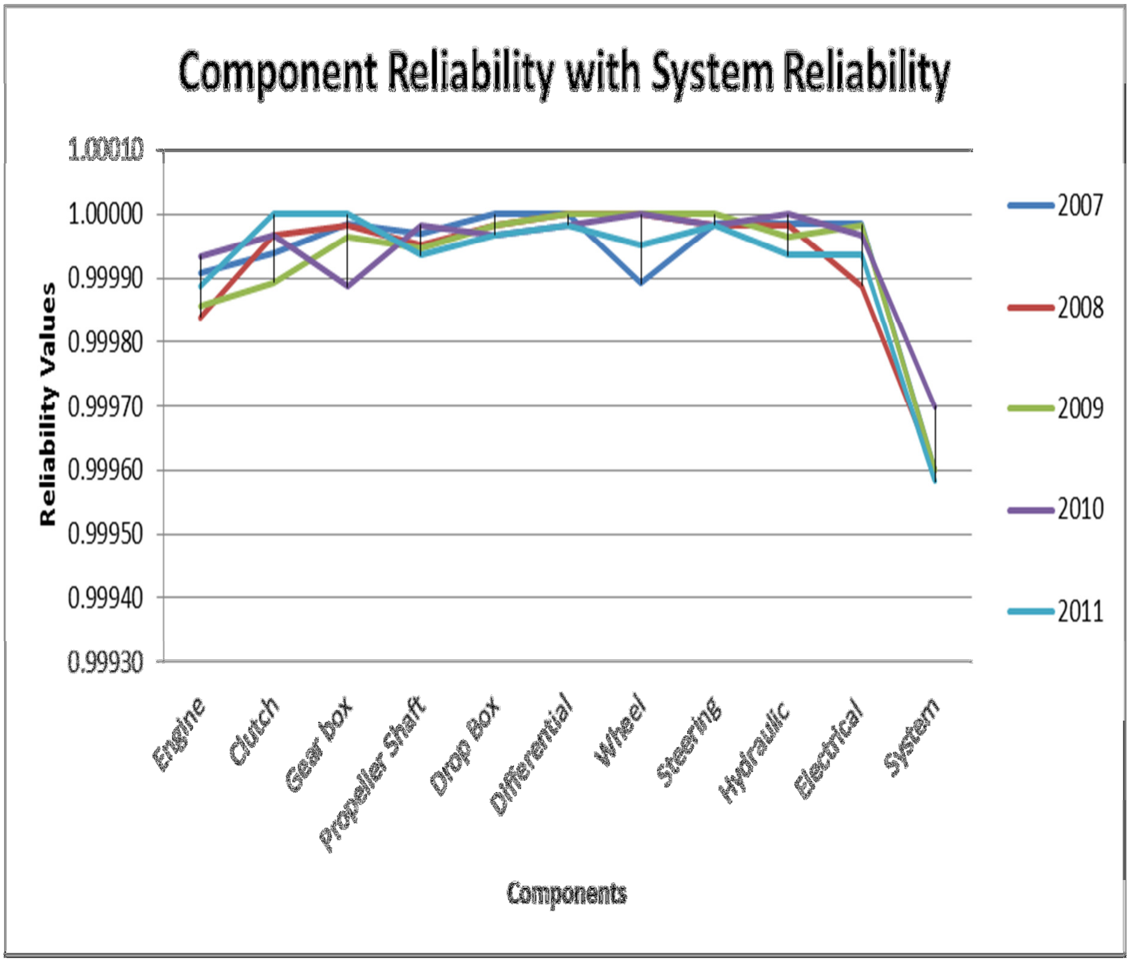


Figure 5.9 Component Reliability with System Reliability for Dumper (2007 - 2011)

The reliability values of the dumper components has been found to be generally at acceptable levels, wherein the engine, clutch, gear box has a reliability values of 99.99% and less and for other components it is generally more and these components need further attention as these are vital for the operation of the machine.

Mean time between failures for engine, clutch, gear box, propeller shaft, and electrical looks to be high, and gives the indication that the frequency of breakdowns is more with these components. Mean time to repair is high with engine, differentials and hydraulics components.

5.4.8 Reliability Predictions for Wheel Loader

The reliability predictions for dumper are calculated based on the following process:

1. The process flow diagram of the wheel loader is made in Figure 5.10 to understand the dependency rate of various components.
2. The total working hours and the breakdown hours for the Wheel Loaders are taken from target company's records are listed in Annexure D and consolidated for the years 2007, 2008, 2009, 2010 and 2011 in the tables 5.11 and table 5.12.
3. Other data including number of breakdowns on each component versus the breakdown hours and total working hours of overall components are tabulated.
4. Various reliability values for wheel loader including reliability, availability, MTBF, MTTR and the failure rate of components are arrived through the relations and formulae.

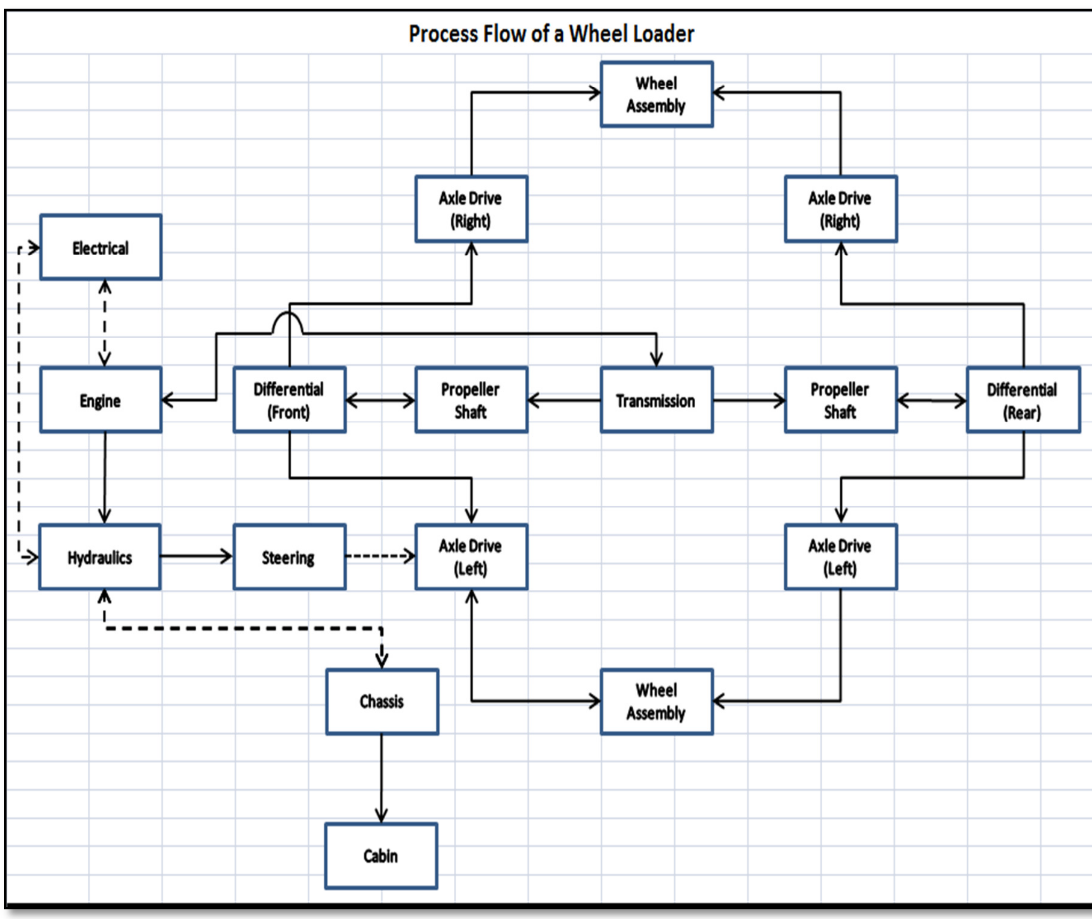


Figure 5.10 Component Block Diagram Wheel Loader

Table 5.11 Consolidated Breakdown Details of Components - Wheel Loader (2007 - 2011)

Wheel Loader Components Breakdown - Consolidated Data 2007 - 2011											
Year	Description	Engine	Transmission	Propeller Shaft	Differential	Axle Drive	Wheel Assembly	Electrical	Hyrdaulic	Steering	Total
2007	No. of Times BD	1	1	1	0	0	6	0	0	0	9
	B D Total Hours	6	4	60.5	0	0	26	0	0	0	96.5
	Total Working Hours	2670	2672	2615.5	2676	2676	2650	2676	2676	2676	
2008	No. of Times BD	0	0	0	0	1	11	3	2	1	18
	B D Total Hours	0	0	0	0	480	40	38	10	20	588
	Total Working Hours	5652	5652	5652	5652	5172	5612	5614	5642	5632	
2009	No. of Times BD	2	0	0	1	3	27	8	3	0	44
	B D Total Hours	106	0	0	6	477	119	115	28	0	851
	Total Working Hours	8403	8509	8509	8503	8032	8390	8394	8481	8509	
2010	No. of Times BD	4	1	0	1	0	24	0	3	1	34
	B D Total Hours	197	180	0	150	0	112	73	16	0	728
	Total Working Hours	8435	8452	8632	8482	8632	8520	8559	8616	8632	
2011	No. of Times BD	3	0	0	1	1	16	4	9	0	34
	B D Total Hours	217.5	0	0	180	80	75	50	163.5	0	766
	Total Working Hours	8423	8640	8640	8460	8560	8565	8590	8477	8640	
Total	Time	10	2	1	3	5	84	15	17	2	139
	Hrs	526.5	184	60.5	336	1037	372	276	217.5	20	3029.5

Table 5.12 Reliability Analysis Results for Wheel Loader (2007 - 2011)

Wheel Loader Reliability Values Identification 2007 - 2011 (Components and System)											
Year	Description	Engine	Transmission	Propeller Shaft	Differential	Axle Drive	Wheel Assembly	Electrical	Hyrdaulic	Steering	System
2007	Failure Rate	0.00037	0.00037	0.00038	0.00000	0.00000	0.00226	0.00000	0.00000	0.00000	0.99661
	MTBF	2670.00	2672.00	2615.50	0.00	0.00	441.67	0.00	0.00	0.00	
	MTTR	6.00	4.00	60.50	0.00	0.00	4.33	0.00	0.00	0.00	
	Availability	0.99776	0.99851	0.97739	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
	Reliability	0.99963	0.99963	0.99962	1.00000	1.00000	0.99774	1.00000	1.00000	1.00000	
2008	Failure Rate	0.00000	0.00000	0.00000	0.00000	0.00019	0.00196	0.00053	0.00035	0.00018	0.99678
	MTBF	0.00	0.00	0.00	0.00	5172.00	510.18	1871.33	2821.00	5632.00	
	MTTR	0.00	0.00	0.00	0.00	480.00	3.64	12.67	5.00	20.00	
	Availability	0.00000	0.00000	0.00000	0.00000	0.91507	0.00000	0.00000	0.99823	0.99646	
	Reliability	1.00000	1.00000	1.00000	1.00000	0.99981	0.99804	0.99947	0.99965	0.99982	
2009	Failure Rate	0.00024	0.00000	0.00000	0.00012	0.00037	0.00322	0.00095	0.00035	0.00000	0.99475
	MTBF	4201.50	0.00	0.00	8503.00	2677.33	310.74	1049.25	2827.00	0.00	
	MTTR	53.00	0.00	0.00	6.00	159.00	4.41	14.38	9.33	0.00	
	Availability	0.98754	0.00000	0.00000	0.99929	0.94394	0.00000	0.00000	0.00000	0.00000	
	Reliability	0.99976	1.00000	1.00000	0.99988	0.99963	0.99678	0.99905	0.99965	1.00000	
2010	Failure Rate	0.00047	0.00012	0.00000	0.00012	0.00000	0.00282	0.00000	0.00035	0.00012	0.99601
	MTBF	2108.75	8452.00	0.00	8482.00	0.00	355.00	0.00	2872.00	8632.00	
	MTTR	49.25	180.00	0.00	150.00	0.00	4.67	0.00	5.33	0.00	
	Availability	0.97718	0.00000	0.00000	0.98262	0.00000	0.00000	0.00000	0.00000	0.00000	
	Reliability	0.99953	0.99988	1.00000	0.99988	1.00000	0.99718	1.00000	0.99965	0.99988	
2011	Failure Rate	0.00036	0.00000	0.00000	0.00012	0.00012	0.00187	0.00047	0.00106	0.00000	0.99602
	MTBF	2807.50	0.00	0.00	8460.00	8560.00	535.31	2147.50	941.83	0.00	
	MTTR	72.50	0.00	0.00	180.00	80.00	4.69	12.50	18.17	0.00	
	Availability	0.97483	0.00000	0.00000	0.97917	0.99074	0.99132	0.99421	0.98108	0.00000	
	Reliability	0.99964	1.00000	1.00000	0.99988	0.99988	0.99813	0.99953	0.99894	1.00000	

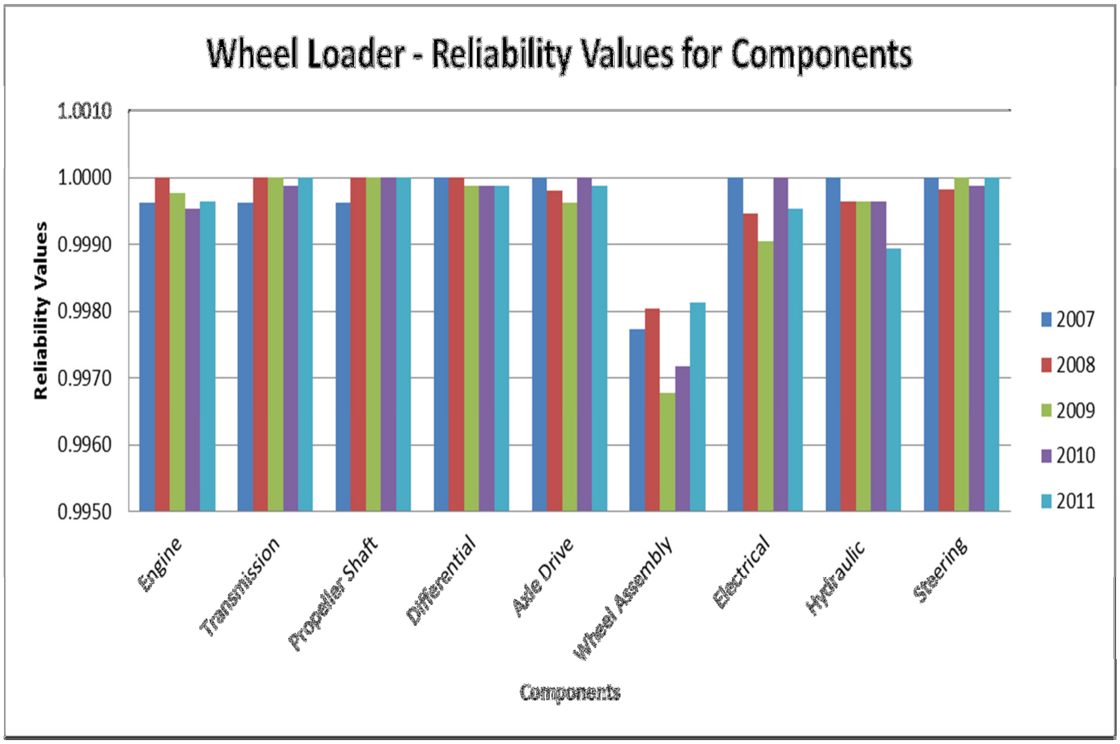
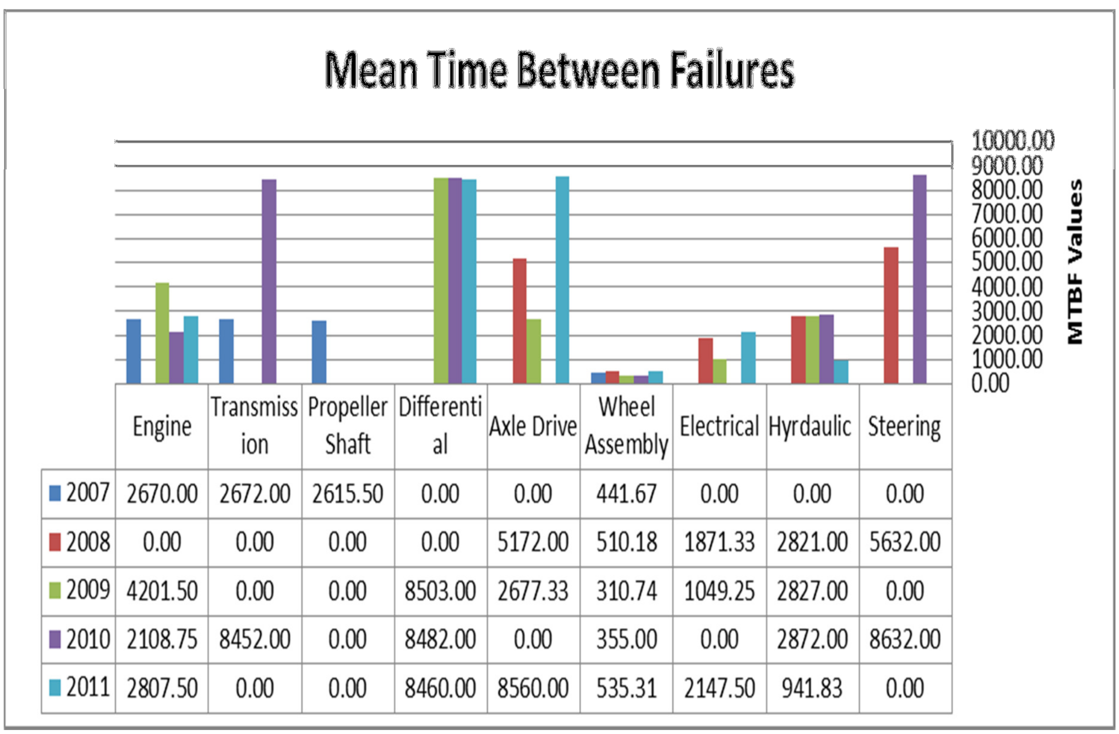


Figure 5.11 Reliability Values Bar Chart for Wheel Loader Components (2007 - 2011)



	Engine	Transmission	Propeller Shaft	Differential	Axle Drive	Wheel Assembly	Electrical	Hyrdaulic	Steering
2007	2670.00	2672.00	2615.50	0.00	0.00	441.67	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00	5172.00	510.18	1871.33	2821.00	5632.00
2009	4201.50	0.00	0.00	8503.00	2677.33	310.74	1049.25	2827.00	0.00
2010	2108.75	8452.00	0.00	8482.00	0.00	355.00	0.00	2872.00	8632.00
2011	2807.50	0.00	0.00	8460.00	8560.00	535.31	2147.50	941.83	0.00

Figure 5.12 MTBF Values Bar Chart for Wheel Loader Components (2007 -2011)

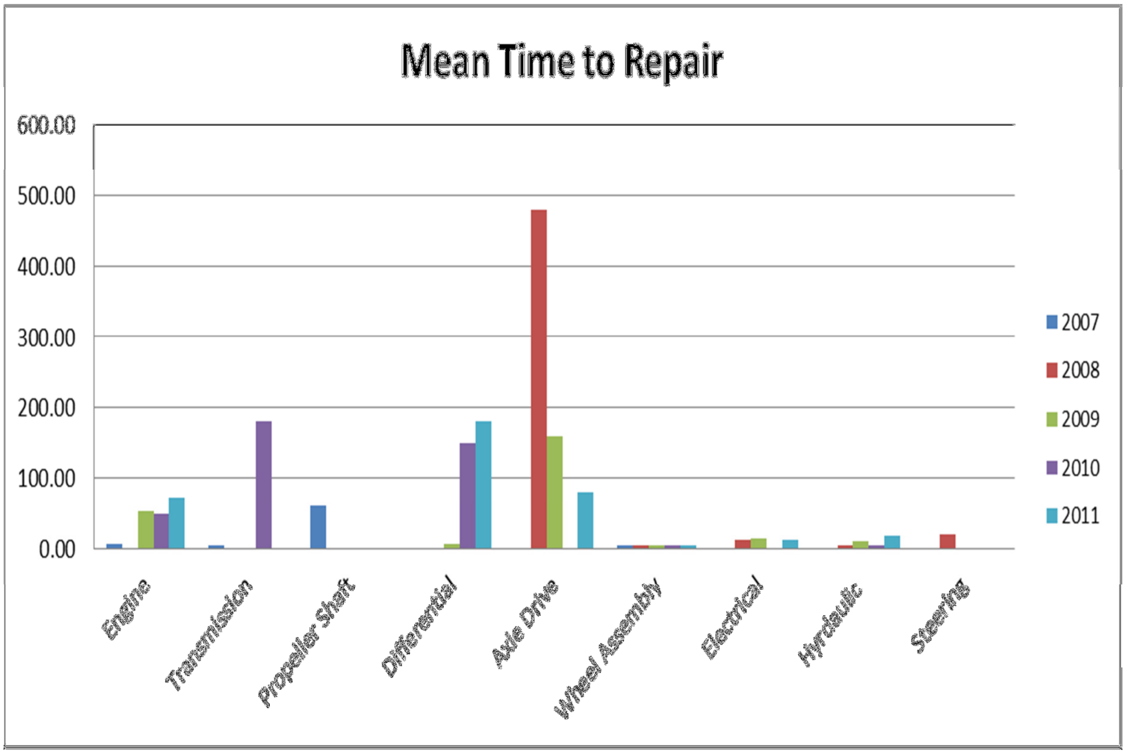


Figure 5.13 MTTR Values bar Chart for Wheel Loader Components (2007 - 2011)

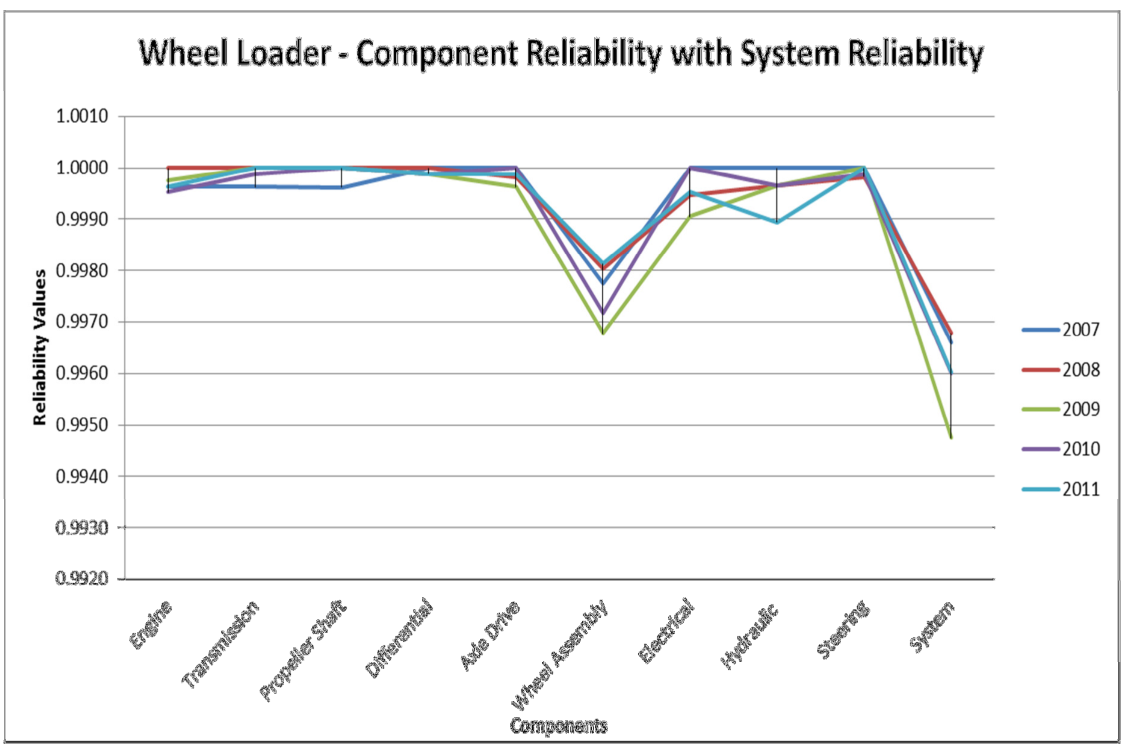


Figure 5.14 Component Reliability and System Reliability of Wheel Loader (2007 - 2011)

The reliability values of the wheel loader components has been found to be generally at acceptable levels, wherein the engine, wheels, hydraulic and electrical have reliability values of 99.96 % and less wherein the wheels have a value of 99.80 and less. These components need further attention as these are vital for the operation of the machine.

Mean time between failures for engine, electrical, hydraulic, wheel assembly, propeller shaft, and axle assembly looks to be high, and gives the indication that the frequency of breakdowns is more with these components. Mean time to repair is high with engine, transmission, differentials and axle drives components.