Some Investigation Related to Reliability based on Preventive Maintenance Strategy for Better Management of Spare Parts

Sanjeev Kumar[1] Chetan Deka[2] Dr. Somnath Chattopadhayaya[3]
[1, 2]M. Tech [3]Associate Professor
[1, 2, 3]Department of Mechanical Engineering
[1, 2, 3]Indian School of Mines, Dhanbad-826004, India

Abstract---Reliability Centered Maintenance (RCM) is a widely practiced maintenance and repair activity for decreasing equipment downtime. In this paper we conduct an investigative case study on engine maintenance and repair hub, located in the coal mines of Eastern India, wherein breakdown maintenance was still practice. A thorough research was conducted into the causes of failure of all engines which came to the workshop during a three year period and also the various spare parts used in each type of failure, followed by classification of the various spare parts on the basis of their reliability. With the help of this failure data, reliability analysis of the various engine models was conducted using Reliasoft's Weibull++ and Mean Time To Failure (MTTF) was calculated. Based on these estimations, we scheduled a maintenance program and implemented it for six months and compared the resulting failure trends to the previous data. The results of the case study clearly show that RCM can lead to cost effective Spare Parts Management.

I. INTRODUCTION

With evolvement in the manufacturing and production sector, meticulous effort has also been directed towards optimization of resources of all kinds. For optimum use of equipment it is of utmost importance to schedule maintenance activities in a way to extract maximum possible work output without compromising the safety of the personnel or machinery involved. Reliability analysis helps us to ascertain the probable life of equipment using previous failure data and thus help one in proper scheduling of maintenance and repair activities. This study will try and form a link between the results of reliability analysis for formulation of a preventive maintenance strategy to work on the better management of spare parts.

The research we report was performed on a large engine maintenance workshop adjacent to a coalfield in Eastern India. The maintenance and repair activities of the various excavator engines were performed in this workshop. The workshop or maintenance hub considered is ill equipped and follows 'breakdown maintenance' for all of its shop floor activity, which has led to high spare parts inventory, permanent irreparable damage to costly equipment with huge downtime and critical safety functions.

Various studies on reliability estimation have already been made [1 - 4]. However since the only data available was Time to Failure of the engines, for calculation of reliability, the method suggested in Deka et al. [5] has been helpful. Using this data of reliability analysis we have formulated maintenance and repair scheduling [6] which contributes towards savings in the form of certain spare parts. Spare parts management is a widely researched foray [7-11] and inventory models such as FSN, VED, ABC are widely applied. Jaarsveld et al.[12] comes up with a way to use reliability centered maintenance data for spare parts control. As suggested in Wang et al.[13], for both scheduled or preventive maintenance as well as unplanned or repair maintenance, a safety stock policy is required. In this paper we have primarily focused on the savings in spare parts in the workshop by implementing preventive maintenance.

II. DATA COLLECTED

A. Engine Failure Data

The engines serviced in this workshop belong are used in the coalfields in various types of mining equipment like dumper, dozer, shovel, drill etc. The engines were of three different manufacturers and have been referred to in this research as Model-C, Model-T and Model-K. The data considered were the failure data of the past three years(2010, 2011, 2012). The engines coming into the workshop can be mainly categorized into two types:

- New Engines
- Already Remade Engines or Over Hauled(O/H) Engines

The second category consists of those engines which have already broken down once and were remade or repaired to be reused again. I t is worth mentioning in the same breath that sometimes due to occurrence of mass breakdown (i.e. when several engines breakdown together), it leads to shortage of manpower to attend to these and even shortage of spare parts. Thus the downtime increases quite steeply. This is yet another reason as to why we decided to apply preventive maintenance in that scenario.

As shown in Table.1, of all 200 new engines, there are a total of 130 engines of Model-C, 42 engines of Model-T and 28 engines of Model-K, which have failed during the three years. Similarly, Table.2, indicates, of all 246 O/H engines, there are a total of 192 Model-C engines, 29 Model-T engines, 25 Model-K engines which have failed during the same period. Table.3 lists the various causes of engine failure along with their respective percentages.

All rights reserved by *www.ijsrd.com*

MODEL	0-2000	2000-4000	4000-6000	6000-8000	8000-10000	10000-12000	12000-14000	14000-16000	16000-18000
MODEL-C	3	4	23	39	28	11	21	1	0
MODEL-T	0	2	0	2	2	8	13	6	9
MODEL-K	2	3	8	5	2	2	5	1	0

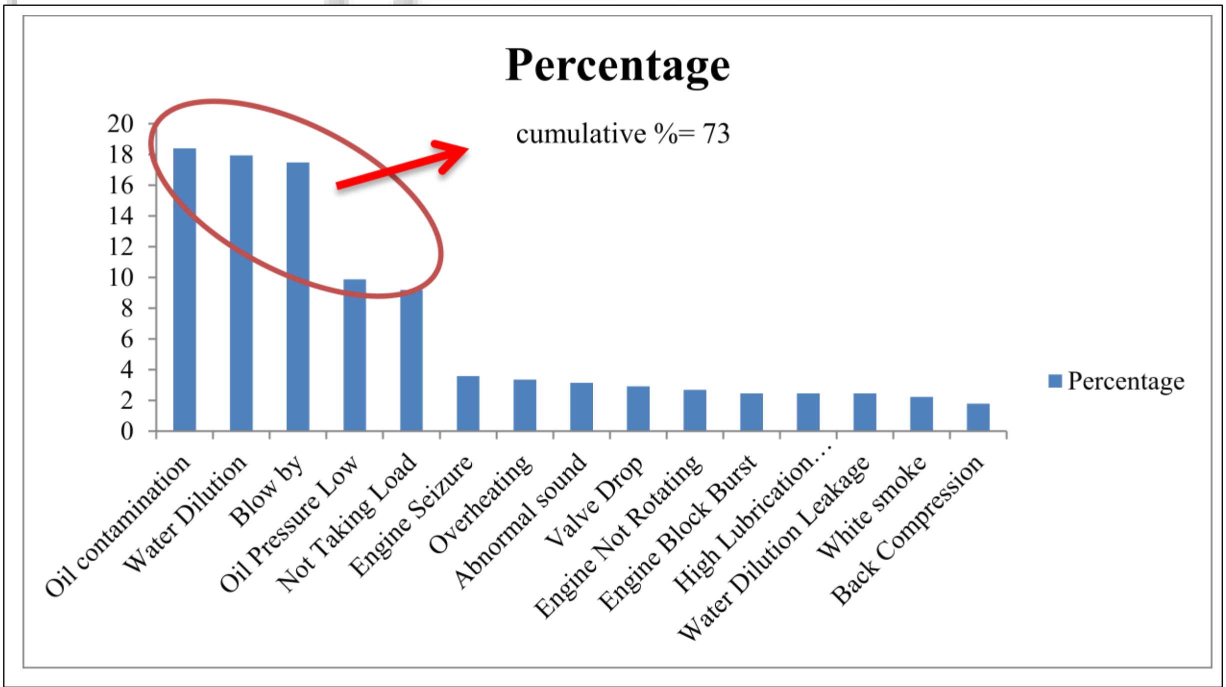
Table. 1: Number of hours for all 3 models after which the new engines have failed

MODEL	0-2000	2000-4000	4000-6000	6000-8000	8000-10000	10000-12000
MODEL-C	90	53	27	13	7	2
MODEL-T	12	8	4	4	1	0
MODEL-K	11	6	2	5	1	0

Table. 2 : Number of hours for all 3 models after which the O/H engines have failed.

Nature Of Breakdown	2010	2011	2012	Percentage
Water Dilution	26	24	30	17.94
Abnormal sound	4	3	7	3.14
Blow by	24	25	29	17.49
Engine Block Burst	3	4	4	2.47
Not Taking Load	15	13	13	9.19
Oil Pressure Low	13	14	17	9.87
Oil contamination	30	23	29	18.39
Engine Not Rotating	4	3	5	2.69
High Lubrication Consumption	3	4	4	2.47
Overheating	3	5	7	3.36
Back Compression	2	3	3	1.79
Engine Seizure	4	5	7	3.59
Valve Drop	3	4	6	2.91
White smoke	3	3	4	2.24
Water Dilution Leakage	3	4	4	2.47
TOTAL	140	137	169	

Table. 3: Different causes of engine failure during the period (2010-2012)



The above figure shows the cumulative percentage of the various important causes due to which the majority of the failure occurs.

A. Data Collected on Spare Parts

Different causes of engine failures results in different repair and maintenance activities. Below are listed the different spare parts used in various engine failure. The data is only

All rights reserved by *www.ijsrd.com*

as accurate as provided from the workshop records. However, it gives a fairly workable idea of the quantity of the spare parts used.

1) Water Dilution :

Liner Cylinder, Piston, Ring Liner, Seal, Main Bearing, Gasket Head , Gasket Body, Thrust, Washer, "O" Ring, Connection Oil Supply, Oil Hose, Slinger, Element With "O" Ring, Plunger , Spring, Value Ex, Value Intake, Collet, Pin Injector, Pin Roll, Roller Injector, Repair Kit, Ring Set, Drives Acc With Compressor, Injector Assembly., Screw, Big Seal, Bolt, Diaphragm, Plate Cover, Rocker, Clamp, Sleeve, Breather, Grommet, Ball Check Valve, Connecting Rod, Hose Rubber Drain, Cap Injector, Repair Fitter etc.

2) Abnormal sound :

Liner Cylinder, Ring Liner, Seal, Main Bearing, Ring Nut, Piston Kit, Gasket Head, Gasket Body, Connection Oil Supply, Hose, Plunger, :O: Ring, Spring, Element With "O" Ring, Pin Injector, Roller Injector, Pin Roller, Repair Kit Ring Set, Filter, Acc Drive With Comp, Thrust, Oil Assy., Grommet, Hose Turbo Section, Nozzle.

3) Blow by

Liner Cylinder, Piston Kit, Crankshaft, Gasket Head, Gasket Body, Oil Pump, Tub Water Transfer, Oil Filter Element, Water Pump, Value Exhaust, Value Intake, Collect, Spring, "O" Ring, Air Compressor, Cap Injector Screw**.**

4) Not taking load

Cylinder Head, Cam Follower, Pin Value, Pin Injector, Pin Roller, Roller, Value Exhaust, Valve Intake, Injector, Thrust, Coupling, Rocker Assembly, Cap Filter, Screw, Spring, Repair Kit(Turbo Charger), Water Pump, Liner Cylinder, Piston, Ring Liner, etc.

5) Oil contamination/oil pressure low

Liner Cylinder, Piston, Ring Liner, "O" Ring, Gear Cover, Set Upper Engine Gasket, Set Lower Engine Gasket, Sleeve, Crankshaft, Front Main Bearing, Hose Real, Vibrational Damper .Main Bearing, Camshaft, After Cooler, Hose Plain, Cap Timer Cover, Spring, Value Exhaust, Value Intake, Collect, Seal Value, Injector Assembly, Water Pump, Connecting Rod, etc.

6) Engine not rotating

Liner Cylinder, Piston, Ring Liner, Main Bearing, Seal, Dowell Ring, Gasket Head, Gasket Body, Thrust, Washer, Spring, "O" Ring, Plunger, Hose, Turbo Supply Hose, etc.

7) High lubrication consumption

Linear Cylinder, Piston, Ring Liner, Main Bearing, Ring Set, Gasket Head, Gasket Body, Slinger, "O" Ring, Plunger, Spring, Value Exhaust, Value Intake, Collect, Spring Value, Injector Assy., Crankshaft, Pin Injector, Pin Roller, Rocker Assembly, etc.

8) Over heating

Liner Cylinder, Piston, Ring Liner, Seal Kit, Piston, Gasket Head, Gasket Body, Thrust, Washer, Cap Filter, Screw, "O" Ring, Slinger, Main Bearing, Plunger, Spring, Connection Oil Supply, Element With "O" Ring, Plastic Coupling, Elbow, Hose Turbo Supply, Elbow Turbo Charger, Flange, Plastic Nozzle, Valve Exhaust, Valve Intake, Collect, Pin Value, Pin Injector, Pin Roller, Repair Kit Of Turbocharger, Seal, Spring, Water Pump, etc.

9) Back compression

Liner Kit, Seal O Ring Kit, Hose, Piston Kit, Head Gasket Kit, Central& Lower, Gas Kit, Rear St Gasket Kit, Front St Gasket Kit, Oil Cooler Lines Gasket, After Cooler Gasket, Gasket (Injector Adaptor O-Ring), Ring Set, Seal (Head), Seal Breather, Valve Ex, Valve In, Insert Ex, Insert In, Lock (Collect), Guide, Regulator, Injector Assembly, Filter Hose, Bearing.

10) Enigine seizure

Cylinder Liner, Piston Kit, Spring, Crankshaft, Value Exhaust, Value Intake, Collet, Gasket Head, Gasket Body, "O" Ring, Pump Oil, Injectors, Nozzles, Repair Kit (Turbocharger), Seal Kit, Oil Cooler, Front Structure Gasket, Rear Structure Gasket, Oil Filter, Washers, Plugs, Lock Nuts, Central and Lower Structure etc.

11) Valve drop

Liner Kit, Seal O Ring Kit, Hose, Piston Kit, Head Gasket Kit, Central& Lower, Gas. Kit, Rear St Gasket Kit, Front St Gasket Kit, Oil Cooler Lines Gasket, After Cooler Gasket, Gasket (Injector Adaptor O-Ring), Ring Set, Seal (Head), Seal Breather, Valve Ex, Valve In, Insert Ex, Insert In, Lock (Collet), Guide, Regulator, Injector Assembly, Spring, Cross Head, Guide, Piston Head, Cylinder, Bearing, Filter.

12) White smoke

Liner Kit, Seal O Ring Kit, Hose, Piston Kit, Head Gasket Kit, Central& Lower Gas Kit, Rear St Gasket Kit, Front St Gasket Kit, Oil Cooler Lines Gasket, After Cooler Gasket, Gasket (Injector Adaptor O-Ring), Ring Set, Seal (Head), Seal Breather, Valve Exhaust, Valve Intake, Insert Exhaust, Insert Intake, Lock (Collet), Injector Assembly Head, "O" Ring, Bearing Hose Filter.

13) Water dilution leakage

Liner Cylinder, Piston Kit, Main Bearing, Thrust, Gasket Head, Gasket Body, Piston Ring, Connecting Rod, Oil Pump, Grommet, Bolt, Nut, Injector, Turbo Charger, Valve Intake, Valve Exhaust, Collet, Spring, Nozzle, Filter, Water Pump etc.

In certain cases of engines failure, such as those occurring as a consequence of Engine Block Burst are subjected to Survey Off Grounding rather than any repair as the repair and maintenance costs are subsequently high.

III. CLASSIFICATION OF SPARE PARTS

In the previous section we have had an idea of the different spare parts used. In this section we have classified the spare parts after through research into three categories as per usage of the respective items.

A. Mandatory Items

These parts are replaced whenever fault arises in the engine and engine is to be disassembled for any kind of repair or maintenance activity whatsoever.

Liner Kit, Seal O Ring Kit, Hose, Piston Kit, Head Gasket Kit, Central& Lower Gas Kit, Rear Structure Gasket Kit, Front Structure Gasket Kit, Oil Cooler Lines Gasket, After Cooler Gasket, Gasket (Injector Adaptor O-Ring), Ring Set, Seal (Head), Seal Breather, Valve Exhaust, Valve Intake, Insert Exhaust, Insert Intake, Lock (Collet), Guide, Regulator, Injector Assembly, Compressor Spring, Plunger, Turbo Repair Kit, Hose(Compressor), Hose Breather,

All rights reserved by *www.ijsrd.com*

Breather Assembly, Clamp Breather By Pass, Hose Breather By Pass, Filter Oil, Filter Fuel, Ring Kit, Primary Fuel Filter, Water Pump, Seat (Compressor Head), Washer (Head Spring), Washer Air Cooler.

B. Non Mandatory Items:

Studying the failure patterns of these spare parts from the maintenance records of past five years, it has been found that the reliability of these components is around 60-70%.
Bearing Main Standard, Bearing Connecting Rod Standard, Lock Piston (Snap Ring), Plate (Thrust Camshaft), Cover, Oil Pan, Connecting Rod Bolt, Gear Air Comp, Pin Piston, Push Rod Valve, Lifter Assembly, Fan Pulley, Nut, Spring Lifter, Hub Fan, Seal O Ring, Plug(Drain Plug Oil Pan), Bridge (Intake) Rocker Lever, Plate Thrust (Crank Shaft), Piston Assembly (Air Compressor), Spring Head (Retainer Top &Bolt), Damper Vibration, Bolt Oil Pan Filter, Bolt Vibrational Dumper, Diode (Shut Down Coil), Line Assembly (Nozzle Pipe), Adapter, Impeller Water Pump, Elbow, Seal(Fuel Pump), Screw, Flywheel Bolt, Bearing Oil Pump, Spring Head(Retainer Top & Bolt), Seal (Turbo To After Cooler), Exhaust Manifold (Real & Front), Exhaust Manifold (Center), Priming Pump (Feed Pump), Solenoid (Shut Down Coil).

C. Insurance Items

The probably of failure of these items is 0.1. These are very costly spare parts. In many cases failure of more than on one these parts in a single engine can lead to Survey Off Grounding of the said engine.

Crankshaft, Cam Shaft, Compressor Assembly, Cylinder Head Assembly, Turbocharger, Cooler, Flywheel, Connecting Rod, Oil Pump Assembly, Rocker Arm.

It can roughly said that 20% of the total spare parts used are Mandatory Items, while 70% are Non- Mandatory Items and 10% of the total spare parts are Insurance Items.

IV. RELIABILITY ANALYSIS

Using the data from Table.1 and Table.2, we have calculated the Reliability of all the three engine models for both old and new engines. Reliasoft's Weibull++ software has been used to good effect for estimating the Shape Parameter β and Characteristic Life α. The Two-Parameter Weibull Distribution, which has been used to calculate Reliability.

A. Reliability Estimation of New Engines

PARAMETERS	MODEL-C	MODEL-T	MODEL-K
β	2.91	4.24	1.91
α (Hours)	9274	14502	8335
MTTF (Hours)	8272	12780	7395

Table. 4: lists the Shape Parameter, Characteristic Life and Mean Time To Failure (MTTF) of Model-C, Model-T and Model-K respectively

For all three engines, the value of Shape Parameter is distinctly greater than 1, which indicates that all of them have crossed the expected life span and had reached their Wear-Out or Burn-Out period [5]. Investigations revealed that damage and subsequent replacement of those spare parts listed under Insurance items primarily appeared in these cases. Therefore if repair and maintenance activities are invoked prior to their failure, any time after Characteristics Life (At least 37% of the total components survive this point) and before MTTF, there is a high possibility of minimising or altogether avoiding the use of spare parts listed under Insurance items.

B. Reliability Estimation of Overhauled Engines

PARAMETERS	MODEL-C	MODEL-T	MODEL-K
β	1.31	1.01	1.32
α (Hours)	3279	3064	3513
MTTF (Hours)	3022	3120	3232

Table. 5: Calculation of different parameters using Reliasoft's Weibull++ for all models Overhauled Engine.

The number of previous Overhauls an Engine has had plays a crucial factor in the repair activities it undergoes. For example, if an Engine has undergone more than 2 overhauls already, and it damages any of its Insurance Item, it is highly likelihood that the component would not be replaced due to high investment, low yield ratio. That said experienced personnel attending to these engines further suggested that in certain cases, for overhauled engines specially, even when multiple Non-Mandatory items fail in a single engine Survey Off Grounding happens to be the 'go to' response.

V. IMPLEMENTATION OF RELIABILITY ANALYSIS

The estimated Reliability of various engine models observed in Table.4 and Table.5 was closely studied and under the direction of the Operations Manager at the workshop, on the basis of this data, a predictive or preventive Maintenance plan was worked out. After 6 months of operating under this scheme, failure data was observed. The next section throws further light into the matter.

VI. RESULTS AND DISCUSSION

After implementing the Predictive Maintenance (P.M.) the failure data for the next 6 months is tabulated below.

MODEL	0-2000	2000-4000	4000-6000	6000-8000	8000-10000	10000-12000	12000-14000	14000-16000	16000-18000
MODEL-C	1	0	1	5	3	2	4	1	1
MODEL-T	0	0	0	1	1	1	4	4	3
MODEL-K	0	1	1	2	1	1	0	1	0

Table. 6: Number of hours for all 3 models after which the New engines have failed after application of P.M

All rights reserved by *www.ijsrd.com*

MODEL	0-2000	2000-4000	4000-6000	6000-8000	8000-10000	10000-12000
MODEL-C	9	7	6	8	4	1
MODEL-T	2	1	1	1	1	0
MODEL-K	1	1	0	1	1	0

Table. 7: Number of hours for all 3 models after which the O/H engines have failed after application of P.M

From Table.6 and Table.7 we can see that a total of 84 engines had failed during this period. 39 of them were new engines and 45 were Overhauled engines.

Nature Of Breakdown	Number of Failures	Percentage	Decrease in Percentage
Water Dilution	16	19.05	
Abnormal sound	4	4.76	
Blow by	14	16.67	0.82
Engine Block Burst	0	0	2.47
Not Taking Load	8	9.52	
Oil Pressure Low	11	13.10	
Oil contamination	13	15.48	2.91
Engine Not Rotating	4	4.76	
High Lubrication Consumption	1	1.19	1.28
Overheating	1	1.19	2.17
Back Compression	3	3.57	
Engine Seizure	0	0	3.59
Valve Drop	3	3.57	
White smoke	2	2.38	
Water Dilution Leakage	4	4.76	
TOTAL	84		

Table. 8 : Different causes of engine failure and their respective percentages after predictive maintenance

VII. Discussion

From Table.8 it is quite evident that certain causes of engine failure have been minimized and a few others have been totally abolished during the in which Reliability based preventive maintenance was applied. They can be summarized as follows.

Engine Block Burst and Engine Seizure were totally absent during this period. This highlighted a visible drop of 2.47% and 3.47% respectively, in these cases, compared to the period previously when breakdown maintenance was applied. As already stated, in certain cases of Engine Block Burst, the engine was left for Survey Off Grounding. However, when repair was possible high cost spare parts (Insurance Items) were consumed. Similarly Engine Seizure required a change of Crank Shaft, among other mandatory and Non-Mandatory Items. Thus, the percentage decrease in both these types of failure can be directly translated, not only into savings in spare parts listed under Insurance Items but also extend the life of the engine by omitting cases of severe Engine Block Burst.

Failures occurring from Oil Contamination and Overheating decreased by a noticeable 2.91% and 2.71%. Marginal decrease in percentage of failures occurring due to High Lubrication Consumption and Blow By were also noticed. Put together it would result in a saving of around 4-5% spare parts listed under Non-Mandatory Items.

VIII. Conclusion

Small and medium scale production and maintenance outlets, in which breakdown maintenance is still in vogue, might be missing out on the benefits of reliability analysis. In this investigative project we have shown that by an effective implementation of Reliability Centered Maintenance strategy we can forecast the failure of any equipment. To add to that its implementation can result in avoiding certain fatal engine failure such as Engine Block Burst, and certain high cost spare parts categorized as Insurance Items and 4-5% of Non-Mandatory spare parts can be saved. It would also be quite logical to say that the life of the engines also extends a few extra hours by application of preventive or predictive maintenance based on reliability analysis. The project is still under study and long term results by applying Diagnostic maintenance and Condition based monitoring, is a huge area to that can be explored to make the process more optimized.

References

[1] Barabady J., Kumar, U., 2008. Reliability Analysis of mining equipment: A case study of a crushing plant at Jajaram Bauxite Mine in Iran. Reliability Engineering and System Safety 93, p. 647-653.

[2] Mandal S.K., 1996. Evaluation of reliability index of longwall equipment systems for production contingency. Min Technol 78(897), p. 138–40.

[3] Kumar U., Huang, Y. 1993. Reliability analysis of a mine production system: a case study. In: Proceedings of the annual reliability and maintainability symposium, USA, 1993 p. 167–72.

[4] Barabady J., 2005. Reliability and maintainability analysis of crushing plants in Jajaram Bauxite Mine of Iran. In: Proceedings of the annual reliability and maintainability symposium, USA, 2005 p. 109–15.

[5] Deka C., Chattopadhayaya, S., 2013. A comparative reliability analysis of Bulldozers arriving at a workshop in Eastern India: A case study. IOSR Journal of

Mechanical and Civil Engineering. Vol.10, Issue 2, p. 47-52.
[6] Moubray J., 1991. Reliability–centered Maintenance. Oxford: Butterworth Heinemann.
[7] Patton Jr. J.D., Feldmann H.C., 1997, Service Parts Handbook, The Solomon Press, New York.
[8] Bleuel W.H., Patton Jr. J.D., 1994, Service Management: Principles and Practices, 3rd edition, Instrumental Society Of America, USA.
[9] Orsburn D.K., 1991, Spares Management Handbook, McGraw-Hill, New York.
[10] Lawrenson, J. , 1986, Effective spares Management, International Journal of Physical Distribution and Materials Management, 16(5), 1986, p. 1-111.
[11] Lee W.B., Steinberg E., Service Parts Management: Principles and Practices, American Production and Inventory Control Society, Alexandria, VA, 1984.
[12] Jaarsveld W., Dekker R., 2011, Spare parts stock control for redundant systems using reliability centered maintenance data, Reliability Engineering and System Safety 96 (2011) p. 1576-1586.
[13] Wang W., Syntetos A.A. 2011, Spare parts demand: Linking Forecasting to Equipment Maintenance. Transportation Research Part E 47(2011), p. 1194-1209

All rights reserved by *www.ijsrd.com*