CHAPTER 6: DEVELOPMENT OF BREAKDOWN CODES AND BREAKDOWN MAINTENANCE PROTOCOLS

6.1 Introduction:

Effective performance of systems is critical to the organization and hindrance to this phenomenon is the actual availability of the systems. When availability performance is inadequate, engineers need to develop methodology for prioritizing the availability improvement efforts. These efforts include actions that reduce the occurrence of system failures, improvements on the execution of machinery maintenance, and/or add redundancy to the system (Cassady C. R. et al, 2004). Uninterrupted utilization of plant and machinery is always required for gaining the maximum benefit of mechanization which always results in better production. The impact of plant and machinery breakdown duration affects the process productivity. It is always necessary for plant managers, to predict the duration of plant downtime to enable develop suitable contingency plans to reduce the impact of downtime (Edwards D.J., et al, 2001). Many authors have developed models and maintenance improvement programme to overcome the above issues. Even though efforts have been made to develop different types of maintenance strategies for enhancing the performance of machinery, nothing has been done to actually streamline Breakdown Maintenance Activities (BMA) (Rapinder S, 2000). Fonseca et al, (2001) adds that in the fields of reliability and maintainability studies, only a small number of researchers have seriously addressed the issue of handling uncertainties especially related with failure data of systems.

The studies conducted within mining industry on its critical machinery reveals that when the size and complexity of mining machinery continue to increase, the implications of machinery failure become ever more critical. As Unplanned failures / breakdowns will result in significantly three to four times higher costs than a planned maintenance or repair, the priority to be given to reduce the duration of failures. Failures on larger machinery always lead to major losses to the production. The reliability of machinery during the failure maintenance is dependent on the factor of how at every time of repair it is executed in a planned or unplanned way and also it is essential that the quality of repair will be influenced by the increased understanding of the nature of the failures and failure pattern of plant and machinery (Barabady J, 2005).

Plant and machinery breakdown in any manufacturing/construction process derails the entire production and project line. There will be a negative effect on profitability due to frequent breakdowns and might lead to a severity like losing a large business order or a big manufacturing lot/completed work being rejected. Cost of breakdown is not just the cost of component and labor input used for rectifying the machine. In fact, it is a great loss to the productivity and subsequent revenue loss. Frequent breakdowns as well, impact the precision output of machine which leads to poor quality output and further contributes to indirect loss to the organization. A well planned breakdown maintenance practice has become a need of the hour.

As a result of operating conditions there is always a wear and tear of the machinery and the breakdowns are inevitable. Breakdowns bring a state of unproductivity to the environment and create an atmosphere of restlessness to the team who are associated with it.

Since these breakdown maintenance tasks are always reactive due the reason it interrupts the production, there is biggest level of concern amongst the crew who are associated with the machines. For the operator it gives him loss of morale until it becomes operational, as he needs to wait idle as well answer to the queries of the end users. For the owner or the contractor of the machine these breakdowns are loss of revenue and keep them under pressure until it is back to operation. The end users of the machines are at a chaotic situation as the planned progress of activities pertaining to this plant or machinery totally becomes hampered due to this and non-functioning becomes the result. The client of the project applies pressure to the entire crew for the breakdowns and its relative causes. As a result of all of the above, there is state of ambiguity and restlessness with the entire team.

It will be the primary objective for the entire team, as to how quickly the machine or the system can be returned to service. Even if the machine functions at least to the minimum acceptable level, it is judged to be effective to the end users. Most of the breakdown maintenance has two importance factors which lead to its high recurring cost, namely; poor planning and incomplete repair. The limitation of breakdown maintenance is that most of the repairs are poorly planned, and the concentration is always reactive, that is, only to attend to the obvious symptoms of failure and not on the root cause. These are happening due to the time constraints imposed by production and plant management as well as minimal utilization of manpower and maintenance resources. Breakdown or reactive maintenance costs three to four times more than the same repair when it is well planned.

The failure data of the target organization reveals that that disruption of the construction activities due to machinery break downs accounts to only to an extent of 2 % to 3 % of the total working hours of the system. In spite of being a small percentage, the revenue lost due to these breakdowns/failures to the construction process is fairly high as the inter dependency rate of machinery and the cost effect of breakdowns per hour is very high with the construction machinery. A well-structured preventive maintenance procedure is followed to ensure that the system works satisfactorily without any interruptions. In spite of these measures, breakdown on the construction machineries are inevitable due to the working environment, climatic conditions, operative efficiency, missed preventive maintenance schedules, damage caused to machines during accidents etc. To identify the critical breakdown factors which are to be further developed as breakdown codes, previous breakdown data are investigated. The records from different sites are consolidated for this study.

6.2 Breakdown Main and Sub Codes Identification (BMC and BSC) through Cause Effect Analysis Diagrams

The past breakdown records of the firm is the input for the analysis. Figure 6.1 is the flow chart of the process of examining the breakdown maintenance record. The effective execution of the breakdown maintenance process depends on the uninterrupted, unambiguous, effective execution of breakdown maintenance function. The various failure contributors/breakdown factors, which influence the breakdowns on the plant and machinery, are listed based on their occurrence. These breakdown factors contribute to the breakdown down hours and duration and to the general overall breakdown percentage of the target organization's plant and machinery. The fish bone diagrams (Ishikawa diagrams) are constructed to identify the factors responsible for different types of breakdowns in the construction machinery. Based on their occurrences, these factors are given specific codes called Breakdown Main Codes (BMC). The Break down sub codes (BSC) are identified from the sub parameters of each BMC.

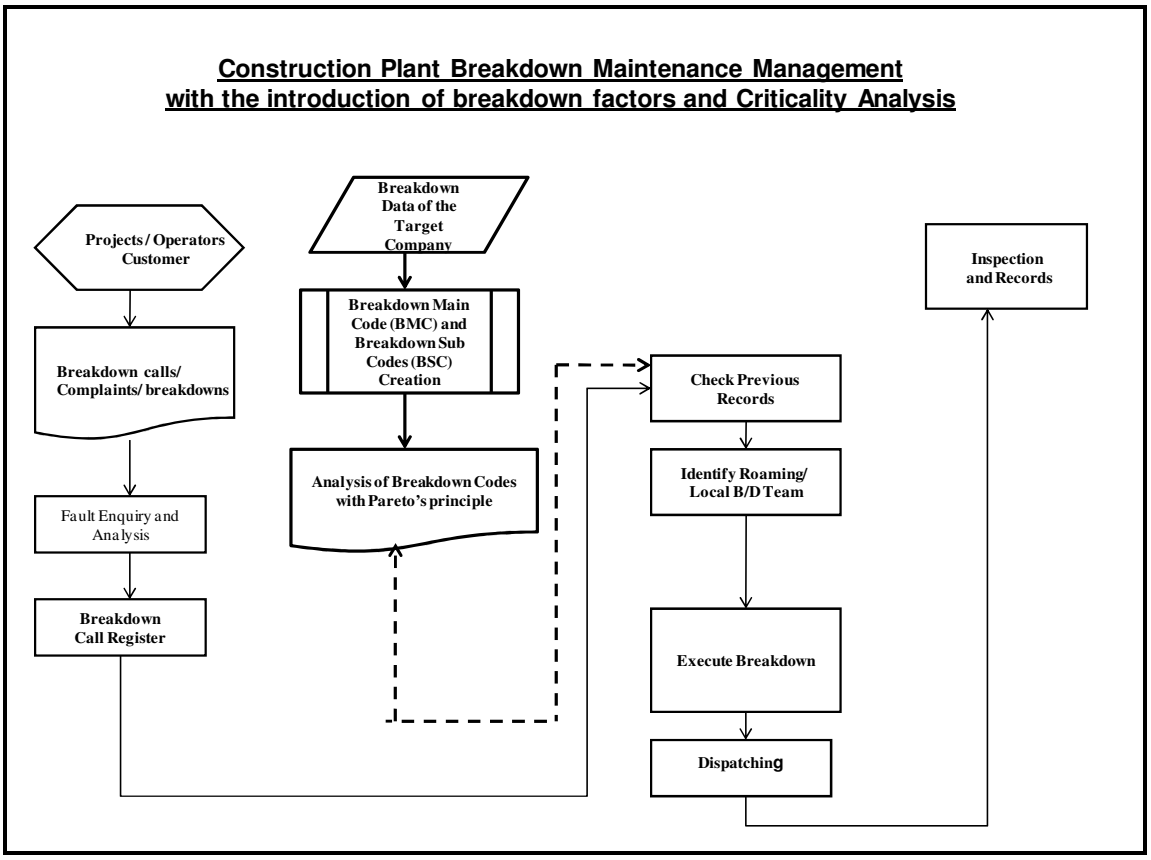

Figure 6.1 Breakdown Process with records analysis

The last five year breakdown records for the wheel loader and dumper are further examined and classified into various categories of failures, namely: Engine Failures, (Mechanical Failure), Transmission Failures, Propeller Shaft Failures, Differential Failures, Axle/Wheel Failures, Steering Failures, Hydraulic Failures, and Electrical Failures.

A systematic examination on various breakdowns is performed and is classified into one of the above categories of failures based on the major factors which contribute to these failures and tabulated in Table 6.1 and 6.2. The order of frequency of breakdowns on both the machinery varied generally while wheel loader accounted for more frequent failures on the wheel assembly where the dumper had more frequent failures accounted on the engine side. Since both machines are critical in nature for the analysis, all the failures on these machinery are considered to be critical and a detailed analysis on breakdown codes for this machinery were to be performed.

Table 6.1 Analysis of failures on systems of Wheel Loader (2007 - 2011)

Wheel Loader - Analysis of Type of Failures Based on the Occurrence (2007 - 2011)								
Sl. No.	Types of Failures	2007	2008	2009	2010	2011	Total	Average
1	Wheel Assembly	6	11	27	24	16	84	16.80
2	Hydraulic	0	2	3	3	9	17	3.40
3	Electrical	0	3	8	0	4	15	3.00
4	Engine	1	0	2	4	3	10	2.00
5	Axle Drive	0	1	3	0	1	5	1.00
6	Differential	0	0	1	1	1	3	0.60
7	Steering	0	1	0	1	1	3	0.60
8	Transmission	1	0	0	1	0	2	0.40
9	Propeller Shaft	1	0	0	0	0	1	0.20

Table 6.2 Analysis of Failures on systems of Dumper (2007 - 2011)

Dumper - Analysis of Type of Failures Based on the Occurrence (2007 - 2011)								
Sl. No.	Types of Failures	2007	2008	2009	2010	2011	Total	Average
1	Engine	6	10	8	4	7	35	7.00
2	Electrical	1	7	1	2	4	15	3.00
3	Clutch	4	2	6	2	0	14	2.80
4	Propeller Shaft	2	3	3	1	4	13	2.60
5	Gear Box	1	1	2	7	0	11	2.20
6	Wheel	7	0	0	0	3	10	2.00
7	Hydraulic	1	1	2	0	4	8	1.60
8	Drop Box	0	1	1	2	2	6	1.20
9	Steering	1	1	0	1	1	4	0.80
10	Differential	0	0	0	1	1	2	0.40

A Cause Effect Analysis (CEA) diagram which is a Rout Cause Analysis (RCA) tool that helps to identify, sort, and display possible causes of a specific problem or quality characteristic is used in understanding various possible factors that could contribute to the different types of failures which can occur in the machine system/component and is shown in figure 6.2. It is useful for identifying and organizing the known or possible causes of quality, or the lapse/gaps in it. The structure provided by the diagram helps team members think in a very systematic way.

RCA is one of the common terminologies found in the reliability literature, as a tool to be used to brainstorm and identify the causes of problems to avoid future occurrence of failure of process/product reliability and maintainability issues (Madu, 2005). It graphically illustrates the relationship between a given outcome and all the factors that influence the outcome. These types of diagrams are also called as "Ishikawa diagram" because it was invented by Kaoru Ishikawa, or a "fishbone diagram" because of the way it looks. Constructing a Cause-and-Effect Diagram is necessitated when there is a need to identify the possible root causes, the basic reasons, for a specific effect, problem, or condition. It is also used in sorting out and relating the interactions among the factors affecting a particular process or effect. It also finds its use while analyzing existing problems so that corrective action can be taken.

The basic plant / machinery failure may happen due to any of the component or multiples of components failures. As mentioned in above tables, the failures can be due to engine, electrical, transmission, gear box, propeller, wheel, axle, hydraulic, steering or other related component failures. The outcome of the CEA provides an insight into the possible break down factors in the component systems of the machinery. These breakdown factors reveal their relationships with the various components and their impact on the overall performance of the machine.

To effectively categorize the breakdowns causes in relation with their components, various codes namely Breakdown Main Codes (BMC) and Breakdown Sub Codes (BSC) were developed to various components based on the reasons available/identified through the CEA. To identify the BSC's from BMC second level CEA is performed on the identified BMC as shown in figure 6.3. The BSCs are developed based on the various breakdown data, logical discussions, and on the breakdown knowledge of the maintenance crew.

For example in the case of the Wheel Loader, breakdown for duration of 150 hours has been recorded for the breakdown factor on the engine, which was analyzed as due to the "Engine Oil, Coolant mixing". CEA diagram is used to study this problem as shown in figure 6.3. This breakdown is attributed to the following factors: performance of the engine, and also due to the coolant oil mixing with the engine oil. This results in reduction in volume of cooling oil, or/hence excess smoke from the engine and also creates more adverse effects due to wear and tear on the engine. From the figure 6.3, the cause of the engine failure and the

cause of oil related failures are examined. As the breakdown of the wheel loader is due to the factor of engine oil and coolant oil mixing and this would have led to the excessive consumption of coolant oil in the engine and hence the best fit attribute from figure 6.3 is Coolant Excessive Consumed. This factor is identified as the Breakdown Main Code (BMC). Now to find out various follow on effects of this excessive coolant oil consumption, the Cause and effect diagram is drafted as shown in figure 6.4 to understand the effects of this cause which reveal various sub effects of this main code and will help us in understanding the nature of the breakdown in detail. These are called as the Breakdown Sub Codes and termed as BSC. The similar fish bone diagrams are constructed for each type of primary failure to arrive at the BMCs and BSCs. The identified BMC's are further scrutinized to examine their level of participation in the breakdown of the selected machines. Subsequently these BMC's and BSC's are subjected to a Pareto Analysis.

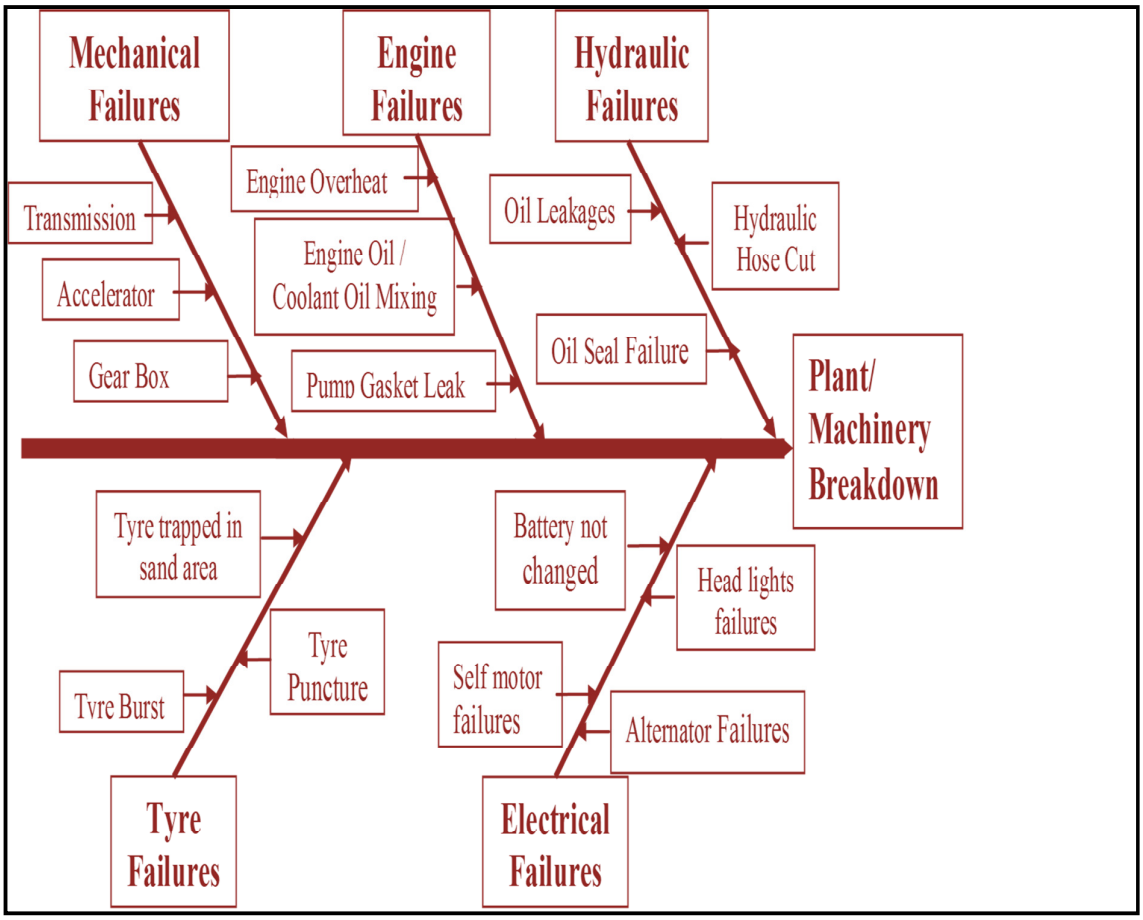

Figure 6.2 CEA Diagram - Basic Failures in Construction Machinery

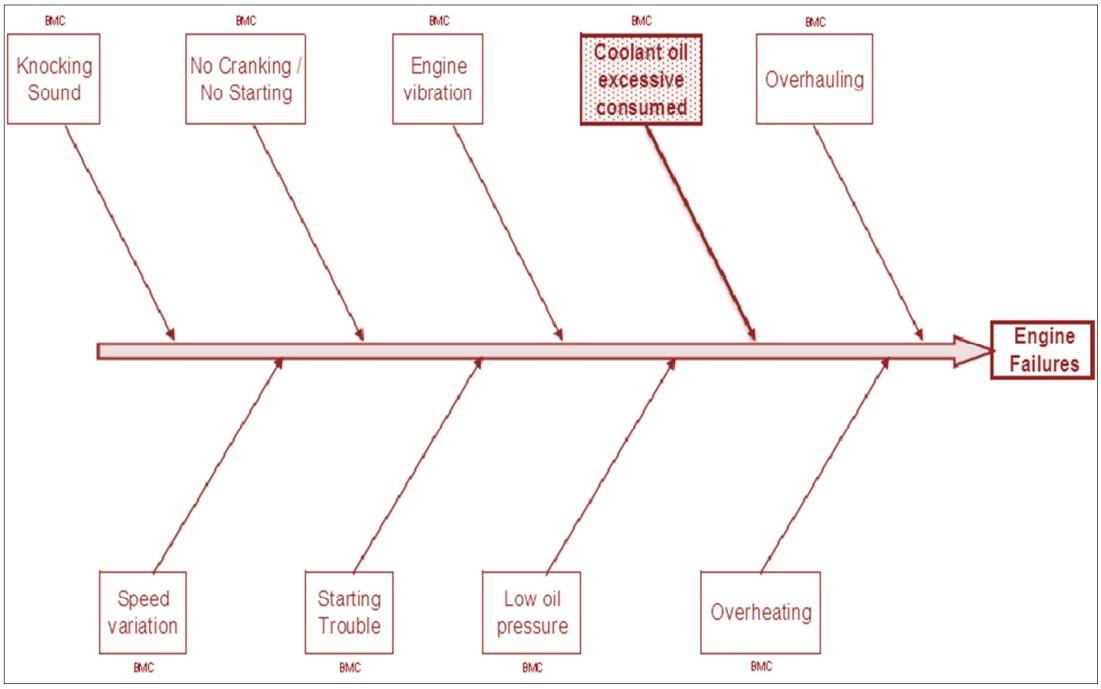

Figure 6.3 Basic Engine Failures - BMC Identification

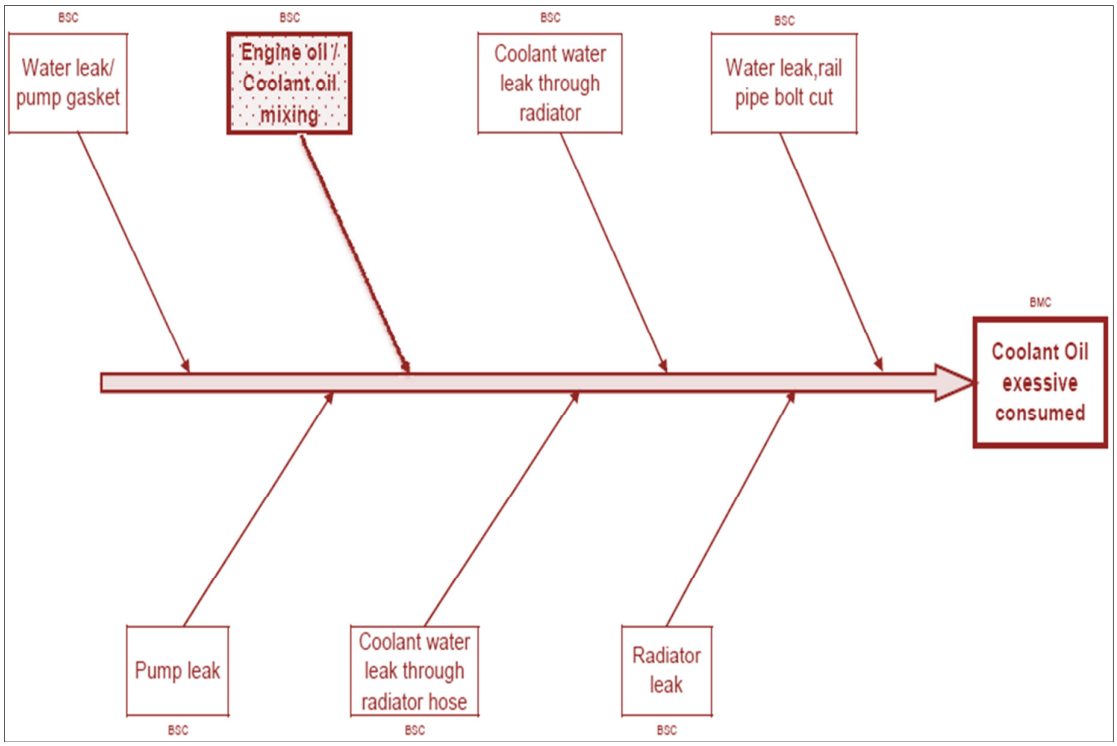

Figure 6.4 BSC Analysis from BMC

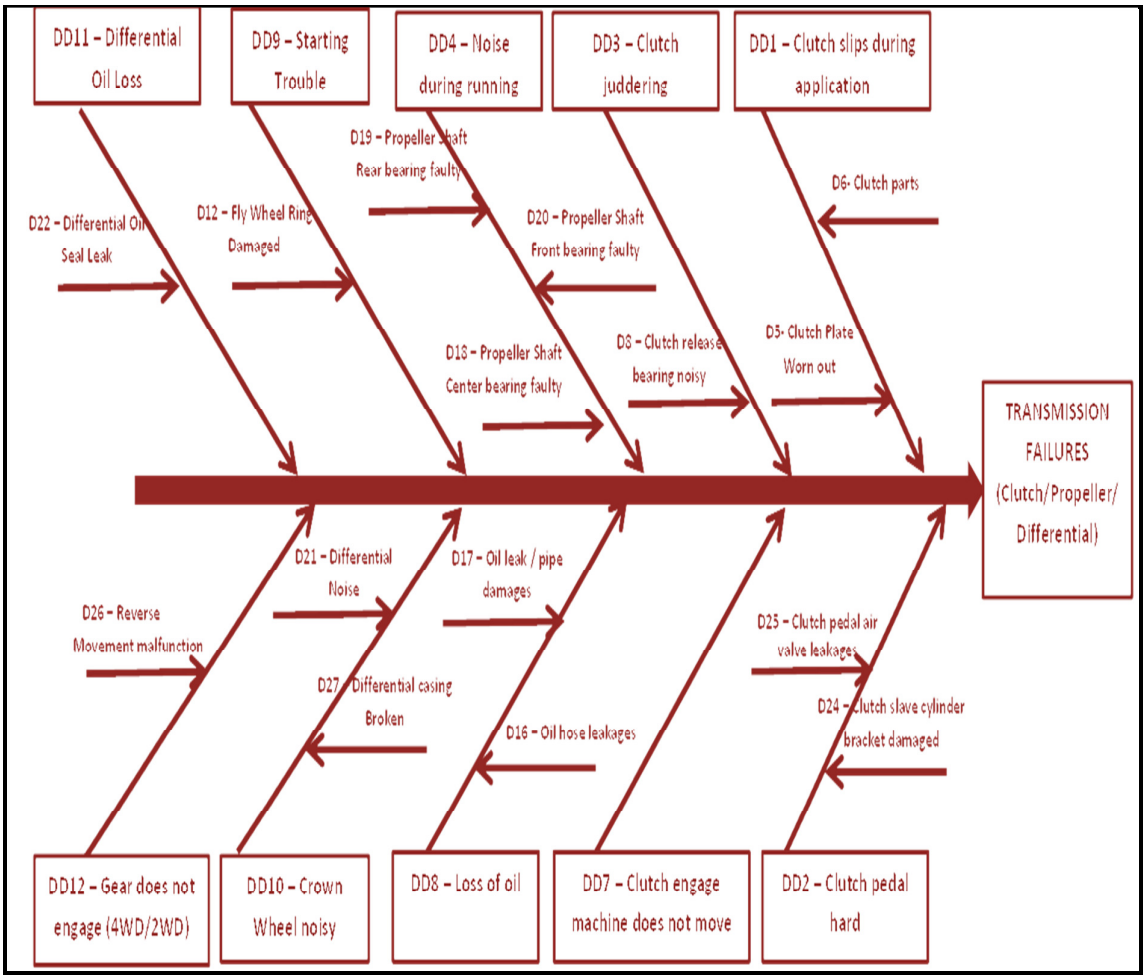

Figure 6.5 CEA Diagram for Transmission Failures

Figure 6.5 indicates the CEA diagram developed for identifying various transmission failures happening with the heavy machinery. The main causes and the sub causes indicate the identification of BMCs and BSCs for this failure patterns.

Similar CEA diagrams are developed for the various failures happening with the construction machinery with the main nodes representing the BMC and the sub nodes representing the BSC and the results of various BMC and BSC are listed in table 6.3.

Table 6.3 List of Breakdown Main Code (BMC) and Breakdown Sub Code (BSC)

BREAKDOWN ANALYSIS					
SL. NO	Breakdown Main Code (BMC)	FAULT DESCRIPTION	Breakdown Sub Code (BSC)	FAILURE DESCRIPTION	SOLUTION
1	AA1	ENGINE MAJOR OVERHAULING	A6	ENGINE CYLINDER HEAD GASKET FAILURE	GASKET CHANGED
2	AA2	ENGINE OVER HEATING	A5	TEMPERATURE INCREASED	TEMPERATURE SWITCH CHANGED
			A17	WATER LEAK - WATER PUMP CHANGE	WATER PUMP CHANGE
			A19	ENGINE FAN BELT CUT	ENGINE FAN BELT CHANGED
			A24	ENGINE OVER HEAT / RADIATOR LEAK / ENGINE SEIZURE	ENGINE OVERHAULING WORK
			A39	FAN RADIATOR PULLY LOCK BROKEN	FAN RADIATOR PULLY LOCK CHANGED
			A42	FAN LEAF BROKEN - RADIATOR	FAN LEAF CHANGED - RADIATOR
			A43	ENGINE OVER HEAT	RADIATOR SERVICED
			A44	RADIATOR FAN PULLY BROKEN SIEZED / FAN BELT CUT	RADIATOR FAN CLUTCH/ FAN BELT CHANGED
			A59	RADIATOR CHOKED	RADIATOR CORE CHANGED
3	AA3	COOLANT OIL EXCESSIVE CONSUMED	A2	COOL WATER LEAK - RADIATOR TOR TANK	RADIATOR TOP TANK
			A3	COOL WATER LEAK - RADIATOR HOSE	RADIATOR HOSE
			A7	RADIATOR SERVICE	COOLANT TANK WATER LEAK RADIATOR SERVICE
			A27	WATER LEAK RAIL PIPE BOLT CUT / REPAIR	WATER RAIL PIPE BOLT CHANGED
			A28	WATER LEAK / PUMP GASKET	WATER PUMP GASKET CHANGED
			A37	OIL PUMP PROBLEM	OIL PUMP KIT CHANGED
4	AA4	ENGINE LOW OIL PRESSURE	A1	ENGINE OVERHAULING WORK	RADIATOR TOP TANK
			A8	OIL PUMP LEAK	PUMP KIT CHANGED
			A38	ENGINE OIL / COOLANT OIL MIXING	OIL COLLER SERVICED
			A45	ENGINE OIL / FUEL MIXING	INJECTOR AND FUEL PUMP CALIBRATED
			A50	ENGINE LOW OIL PRESSURE - SENSORS / SWITCH / METER / OIL VISCOS	OIL VISCOSITY CHECKED
			A51	ENGINE OIL AND WATER MIXING - LINER "O" RING CUT - ENGINE WORK	ENGINE MAJOR OVERHAULING
			A53	ENGINE LOW OIL PRESSURE IN GAUGE	ENGINE OVERHAULING WORK
5	AA5	ENGINE OIL EXCESSIVE CONSUMED	A4	OIL SEAL LEAK - REAR END - FLY WHEEL SIDE	OIL SEAL CHANGED
			A16	OIL LEAK - COVER PACKING	COVER PACKING CHANGED
			A18	OIL LEAK - FILTER BODY	FILTER BODY ASSY CHANGED
			A26	OIL LEAK - TIMING COVER SEAL OR CRANK SEAL	TIMING COVER SEAL CHANGED
			A31	OIL LEAK COOLER BODY	COOLER BODY WELDED
			A32	OIL LEAK	COMPRESSOR UNIT - HOSE CHANGED
			A46	OIL SEPARATOR HOSE CUT / COMPRESSOR UNIT	OIL SEPARATOR HOSE CHANGED

BREAKDOWN ANALYSIS					
SL. NO	**Breakdown Main Code (BMC)**	**FAULT DESCRIPTION**	**Breakdown Sub Code (BSC)**	**FAILURE DESCRIPTION**	**SOLUTION**
6	AA6	ENGINE VIBRATION	A9	ENGINE MOUNTING FRONT R	ENGINE MOUNTING FRONT R CHANGED
			A10	ENGINE MOUNTING FRONT L	ENGINE MOUNTING FRONT L CHANGED
			A12	ENGINE MOUNTING REAR L1	ENGINE MOUNTING REAR L1 CHANGED
7	AA7	ENGINE KNOCKING NOISE	A33	COMPRESSOR SEPARATOR CHOQED AND RELEIF VALVE LEAK	AIR SEPARATOR CHANGED
8	AA8	ENGINE SPEED VARIATION	A30	AIR RELEIF VALVE MALFUNCTION - COMPERSSOR	AIR RELEIF VALVE KIT CHANGED
			A35	ACCELERATOR CABLE CUT	ACCELERATOR CABLE CHANGED
			A36	ENGINE RPM SUDDENLY RAISED	ECB BOARD CHANGED
			A40	ENGINE STOPS WHILE RUNNING	FUEL CONTROL RELAY CHANGED
			A54	ENIGNE RPM NOT RAISED - CAM SHAFT SENSOR PROBLEM	CAM SHAFT SENSOR CHANGED
			A55	ACCELERATOR SPRING CUT	ACCELERATOR SPRING CHANGED
9	AA9	IMPROPPER COLOUR OF EXHAUST	-	-	-
10	AA10	ENGINE STARTING TROUBLE	A41	ENGINE OVER CRANKING LOW ALTERNATOR DISPLAY ON LCD	FUEL LINE CHECKED, FUEL FILTER CHANGED
11	AA11	ENGINE DOES NOT CRANK AND NO STARTING	A34	ENGINE - COMPRESSOR COUPLING BROKEN	COUPLING CHANGED
			A49	ENGINE NOISE	FAN RADIATOR PULLY LOCK CHANGED
12	AA12	ENGINE CRANKS AND NO STARTING	-	-	-
13	BB1	FIP, INJECTOR CALIBRATION	B1	FUEL PUMP FAILURES	FUEL PUMP CALIBRATED
			B15	ENGINE OVER HEATED AUTOMATIC TRIP	INJECTORS CHANGED / THOROUGHLY FLUSHED
14	BB2	ENGINE KNOCKING SOUND	B1	FUEL PUMP PROBLEM	FUEL PUMP CALIBRATED
15	BB3	ENGINE CRANKS NO START	B1	FUEL PUMP PROBLEM	FUEL PUMP CALIBRATED
			B9	ENGINE STARTING TROUBLE - HAND PRIMER MALFUNCTION	HAND PRIMER CHANGED
			B20	STARTING TROUBLE - FUEL LIFT PUMP NOT WORKING	FUEL LIFT PUMP CHANGED
16	BB4	ENGINE HARD TO START	B1	FUEL PUMP PROBLEM	FUEL PUMP CALIBRATED
			B16	ENGINE NOT CRANKING	INJECTOR SERVICED FUEL LINE CHECKED
			B17	ENGINE OVER CRANKING / FUEL LINE FEED PUMP PROBLEM	FUEL LINE CHECKED AND FEED PUMP CHANGED
17	BB5	ENGINE SPEED VARIATION	B2	INJECTOR PROBLEM	INJECTOR CALIBRATED
			B18	LOW ALTERNATOR PROBLEM	FUEL LINE / INJECTOR / PUMP RECHARGED
18	BB6	ENGINE VIBRATION	B2	INJECTOR PROBLEM	INJECTOR CALIBRATED
19	BB7	ENGINE EMITS WHITE SMOKE	B1	FUEL PUMP PROBLEM	FUEL PUMP CALIBRATED
			B2	INJECTOR PROBLEM	INJECTOR CALIBRATED

BREAKDOWN ANALYSIS					
SL. NO	Breakdown Main Code (BMC)	FAULT DESCRIPTION	Breakdown Sub Code (BSC)	FAILURE DESCRIPTION	SOLUTION
20	BB8	LACK OF POWER	B1	FUEL PUMP FAULTS	FUEL PUMP CALIBRATED
			B2	INJECTOR FAULTS	INJECTOR CALIBRATED
21	BB9	EXCESSIVE FUEL CONSUMPTION	B1	FUEL PUMP FAULTS	FUEL PUMP CALIBRATED
			B2	INJECTOR FAULTS	INJECTOR CALIBRATED
			B7	FUEL INLET PIPE LEAK	FUEL INLET PIPE CHANGED
22	CC1	GRINDING NOISE WHILE ENGAGING GEAR	C1	GEAR BOX ABNORMAL SOUND DURING GEAR SHIFT	GEAR BOX OVERHAULING WORK
			C3	GEAR BOX MAJOR OVER HAULING	GEAR BOX MAJOR OVER HAULING
23	CC2	GEAR BOX NOISY WHILE MOVEMENT	C14	GEAR BOX SOUND	TOP GEAR SHAFT CHANGED
			C20	GEAR BELT TENSIONER BROKEN / ROLLER COMPACTOR	GEAR BELT TENSIONER CHANGED
			C22	REVERSE GEAR NOT ENGAGED / RELAY SWITCH FAULTY	REVERSE GEAR RELAY SWITCH CHANGED
24	CC3	GEAR BOX KNOCKING WHILE ENGAGING CLUTCH OR DURING LOAD CHANGE	-	-	-
25	CC4	GEAR SHIFT DIFFICULTIES	C2	GEAR SHIFTING CABLE CUT	GEAR SHIFTING CABLE CHANGED
26	CC5	MACHINE DRIVES BUT LACKS POWER IN ALL GEARS	-	-	-
27	CC6	MACHINE DOES NOT DRIVE IN ANY GEAR	C7	GEAR ENGAGE PROBLEM	GEAR BOX TOP COVER OVER HAULING
			C18	CHAIN CUT / ROLLER	ROLLER CHAIN CHANGED
28	CC7	MACHINE DOES NOT ACHIEVE MAXIMUM SPEED WHILE TRAVELLING IN THE HIGHWAY	-	-	-
29	CC8	EXCESSIVE OIL CONSUMPTION	C10	OIL LEAK TOP COVER SEAL	TOP COVER OIL SEAL CHANGED
			C17	OIL LEAK	OIL LEAK PACKING CHANGED
30	CC9	MACHINE CAN TRAVEL WHEN PARKING BRAKE IS APPLIED	-	-	-
31	CC10	AUTO SHIFT DOES NOT WORK	-	-	-
32	CC11	GEAR ENGINE PROBLEM	C19	GEAR ENGINE PROBLEM	ENGINE OVERHAULING
			C23	ROLLER BEARING DAMAGE	ROLLER BEARING CHANGED
33	CC12	GEAR CANNOT ENGAGE	-	-	-
34	DD1	CLUTCH SLIPPING WHEN CLUTCH APPLY	D5	CLUTCH PLATE WORNOUT	CLUTCH PLATE CHANGED
			D6	CLUTCH PARTS (Clutch Plate/Pressure Plate/Pressure Bearing/Release Bearing/Fork/Pilot Bearing)	CLUTCH KIT CHANGED
35	DD2	CLUTCH PEDAL HARD	D24	CLUTCH SLAVE CYLINDER BRAKET DAMAGE	CLUTCH SLAVE CYLINDER BRAKET CHANGED
			D25	CLUTCH PEDAL AIR VALVE LEAK	VALVE CHANGED
36	DD3	CLUTCH JUDDERING	D8	CLUTCH RELEASE BEARING SOUND	CLUTCH RELEASE BEARING CHANGED
37	DD4	NOISE WHILE TRAVELLING	D18	PROPELLOR SHAFT BEARING CENTRE PROBLEM	PROPELLER SHAFT BEARING CENTRE CHANGED
			D19	PROPELLER SHAFT BEARING REAR FAULT	PROPELLER SHAFT BEARING REAR CHANGED
			D20	PROPELLER SHAFT BEARING FRONT FAULT	PROPELLER SHAFT BEARING FRONT CHANGED

BREAKDOWN ANALYSIS					
SL. NO	**Breakdown Main Code (BMC)**	**FAULT DESCRIPTION**	**Breakdown Sub Code (BSC)**	**FAILURE DESCRIPTION**	**SOLUTION**
38	DD5	MECHINE NOT ACHIEVING FULL SPEED WHILE TRAVELLING ON ROAD	-	-	-
39	DD6	TRANSMISSION RANGE NOT CONTROLLED WITH SPEED LEVER	-	-	-
40	DD7	CLUTCH ENGAGE - MACHINE NO MOVEMENT	-	-	-
41	DD8	LOSS OF OIL	D16	OIL LEAK HOSE	OIL LEAK HOSE CHANGED
			D17	OIL LEAK PIPE DAMAGE	PIPE CHANGED
42	DD9	STARTING TROUBLE	D12	PLY WHEEL RING DAMAGE	PLY WHEEL RING CHANGED
43	DD10	CROWN WHEEL NOISE	D21	DIFFERENTIAL SOUND	DIFFERENTIAL OVER HAULING
			D27	DIFFERENTIAL CASING BROKEN	DIFFERENTIAL CASING CHANGED
44	DD11	DIFFERENTIAL OIL LOSS	D22	DIFFERENTIAL PINION OIL SEAL LEAK	DIFFERENTIAL PINION OIL SEAL CHANGED
45	DD12	GEAR CANNOT ENGAGE 4WD/2WD/ AT REVERSE	D26	REVERSE MOVEMENT FAULTS	TRANSMISSION UNIT OVERHAULING
50	EE1	BRAKE IS INEFFECTIVE	E5	PARKING BREAK VALVE KIT LEAK	PARKING BREAK VALVE KIT LEAK CHANGED
			E7	FRONT WHEEL R/BRAKE LINING LOW	FRONT WHEEL R/BRAKE RELINING
			E8	FRONT WHEEL L/BRAKE LINING LOW	FRONT WHEEL L/BRAKE RELINING
			E20	BRAKE SWITCH NOT WORKING	BRAKE SWITCH CHANGED
			E26	PARKING BRAKE CABLE CUT	PARKING BRAKE CABLE CHANGED
51	EE2	BRAKE CANNOT BE RELASED	-	-	-
52	EE3	WHEEL PULLING ONE SIDE WHILE APPLY BRAKE	-	-	-
53	EE4	NOISE DEVELOPED WHILE APPLYING BRAKE	-	-	-
54	EE5	LOSS OF BRAKE OIL	E13	BRAKE OIL LEAK	OIL LEAK BRAKE HOSE CHANGED
55	EE6	BRAKE RELEASE TOO SLOW	-	-	-
56	EE7	BRAKES DOES NOT APPLY	-	-	-
57	EE8	BRAKES DOES NOT RELEASE	-	-	-
58	EE9	BRAKES GRAB	-	-	-
59	EE10	UNEVEN BRAKE	E16	BRAKE WHEEL CYLINDER LEAK	BRAKE WHEEL CYLINDER LEAK KIT CHANGED
60	EE11	AIR PRESSURE ABNORMAL	-	-	-
61	EE12	AIR PRESSURE DROPS QUICKLY DURING ENGINE STOPPAGE AND BRAKES RELEASE	E14	AIR LEAK	AIR LEAK HOSE CHANGED
62	EE13	AIR PRESSURE DROPS QUICKLY DURING ENGINE STOPPAGE AND BRAKES FULLY APPLIED	-	-	-
63	EE14	COMPRESSOR KNOCKS CONTINUOUSLY	-	-	-
64	EE15	EXCESSIVE OIL OR WATER IN BRAKE SYSTEM	-	-	-
65	EE16	OPERATING FORCE OF BRAKE PEDAL TOO LIGHT	E2	BRAKE BOOSTER LEAK	BRAKE BOOSTER LEAK KIT CHANGED
			E3	BRAKE MASTER CYLINDER LEAK	BRAKE MASTER CYLINDER ASSY CHANGED
66	EE17	OPERATING FORCE OF BRAKE PEDAL TOO HEAVY	E4	BRAKE PEDAL SPRING CUT	BRAKE PEDAL SPRING CHANGED
			E28	BRAKE VALVE NOT FUNCTIONING	BRAKE VALVE ASSEMBLY CHANGED

BREAKDOWN ANALYSIS					
SL. NO	Breakdown Main Code (BMC)	FAULT DESCRIPTION	Breakdown Sub Code (BSC)	FAILURE DESCRIPTION	SOLUTION
67	FF1	MACHINE DEVELOPS EXCESS VIBRATION	-	-	-
68	FF2	EXCESSIVE NOISE	-	-	-
69	FF3	BODY/CHASSIS LEVEL UNEVEN	-	-	-
70	GG1	WHEEL WOBBLING WHILE RUNNING ON ROAD	-	-	-
71	GG2	WHEEL VIBRATION WHILE RUNNING ON ROAD	-	-	-
72	GG3	UN EVEN TYRE WEAR	G6	TYRE PUNCTURE REAR OUTER LHS	TYRE PUNCTURE RECTIFIED
73	GG4	TYRE ONE SIDE WEAR TOE IN	-	-	-
74	GG5	TYRE ONE SIDE WEAR TOE OUT	G29	TYRE BURST	TYRE NEW CHANGE - FRONT
75	GG6	WHEEL HUBS LUBRICANT LEAKAGE	G18	WHEEL HUB OIL SEAL REAR INNER LEAK	WHEEL HUB OIL SEAL REAR INNER CHANGED
76	GG7	SPEED TOO SLOW (TYRE AIR LOSS)	G1	TYRE PUNCTURE FRONT RIGHT	TYRE PUNCTURE RECTIFIED
			G2	TYRE PUNCTURE FRONT LEFT	TYRE PUNCTURE RECTIFIED
			G3	TYRE PUNCTURE REAR INNER RHS	TYRE PUNCTURE RECTIFIED
			G4	TYRE PUNCTURE REAR OUTER RHS	TYRE PUNCTURE RECTIFIED
			G5	TYRE PUNCTURE REAR OUTER LHS	TYRE PUNCTURE RECTIFIED
			G6	TYRE PUNCTURE REAR OUTER LHS	TYRE PUNCTURE RECTIFIED
77	GG8	WHEEL EXCESIVE NOISE WHILE BRAKE	-	-	-
78	HH1	EXCESIVE PLAY IN THE STEERING	H15	STEERING UNIVERSAL AND BUSH WORNOUT	STEERING UNIVERSAL AND BUSH CHANGED
79	HH2	HARD STEERING	H12	STEERING HARD	STEERING PUMP KIT CHANGED AND KING PIN LUBRICATED
80	HH3	STEERING WANDERING	-	-	-
81	HH4	STEERING PULL ONE SIDE DURING DRIVING	-	-	-
82	HH5	STEERING VIBRATION WHILE RUNNING 90KM AND ABOVE	H13	STEERING PUMP / WHEEL TURNING AREA NOT COVERED	STEERING PUMP CALIBRATED AND STOPPER BOLT ADJUSTEI
83	HH6	LOSS OF STEERING OIL	-	-	-
84	HH7	OVERHEATING OF STEERING OIL	-	-	-
85	HH8	STEERING PUMP PRESSURE REDUCED	-	-	-
86	HH9	STEERING WHEEL IS SLUGGISH	H14	STEERING CYLINDER OIL LEAK	STEERING CYLINDER OIL LEAK KIT CHANGED
87	HH10	STEERING WHEEL MOVES UNSTEADY	-	-	-
88	II1	SUSPENSION SYSTEM FAILURE	-	-	-
89	II2	WHEEL WOBBLING	I10	WHEEL WOBBLING	KING PIN PLY ADJUSTED
90	II3	TYRE UNEVEN WEAR	-	-	-
91	II4	WHEEL PULLING ONESIDE	-	-	-
92	II5	MACHINE NOT MOVING	I16	REAR AXLE BROKEN	REAR AXLE CHANGED
93	JJ1	STARTING TROUBLE	J1	STARTING TROUBLE	ALTERNATOR ASSY CHANGED
			J2	SELF STARTER FAULTS	SELF STARTER ASSY CHANGED
			J10	ENGINE NOT STARTED	IGNITION SWITCH CHANGED
			J13	ALTERNATOR FAILURES	CARBON BRUSH CHANGED
			J14	ALTERNATOR FAILURES	ARMATURE CHANGED
			J15	ALTERNATOR FAILURES	FIELD COIL CHANGED
			J23	STARTING TROUBLE / EMERGENCY SWITCH NOT RELEASED	EMERGENCY SWITCH CHANGED
			J35	STARTING TROUBLE - SHUTDOWN MODULE PROBLEM	SHUTDOWN MODULE BOARD CHANGED

BREAKDOWN ANALYSIS					
SL. NO	Breakdown Main Code (BMC)	FAULT DESCRIPTION	Breakdown Sub Code (BSC)	FAILURE DESCRIPTION	SOLUTION
94	JJ2	ENGINE NOT CRANCKING WILL NOT START	J3	STARTING TROUBLE	BATTERY CHANGED
			J6	BATTERY NOT RECHARGED	ALTERNATOR REGULATOR CHANGED
			J32	STARTING TROUBLE - TIMING RELAY PROBLEM	TIMING RELAY CHANGED
95	JJ3	ENGINE CRACKING WILL NOT START	J4	STARTING TROUBLE SOLENOID SWITCH PROBLEM	IGNITION SOLENOID SWITCH CHANGED
			J26	SOLENOID WIRE LOOSE CONTACT	SOLENOID WIRE CHANGED
			J31	SELF STARTED PROBLEM	SELF STARTER OVERHAULING/PISTON/BRUSH / HOLDER
			J34	ENGINE OVER CRANKING NOT STARTED	ELECTRONIC CONTROL BOARD CHANGED
96	JJ4	ENTIRE ELECTRICAL FUNCTIONS DOES NOT WORK	J19	SENSOR CONTROL BOARD PROBLEM	SENSOR CONTROL BOARD CHANGED
			J33	ON-OFF SWITCH PROBLEM	ON-OFF SWITCH CHANGED
			J37	TELYS BOARD PROBLEM	TELYS BOARD CHANGED
			J38	FUSE BOX BROKEN	FUSE BOX CHANGED
			J40	PANEL BOARD MAIN BRAKER DEFECTS	PANEL BOARD MAIN BRAKER CHANGED
97	JJ5	SPEED VARIATION (ELECTRONIC CONTROL SENSORS)	J9	ENGINE NOT STOPPED SOLENOID SWITCH ASSY	SOLENOID SWITCH ASSY CHANGED
			J17	LOW ALTERNATOR PROBLEM DISPLAYED ON LCD AVR BOARD	AVR BOARD ASSY CHANGED
			J27	LOW VOLTAGE PROBLEM	AVR BOARD CHANGED
98	JJ6	EXCESSIVE NOISE DEVELOPED (ENGINE / GENSET)	J20	VOLTAGE DROPPED	GENSET REWINDING WORK
			J29	GENSET BEARING NOISE / VOLTANGE FLUCTUATION	BEARING REWINDING
99	JJ7	VOLTAGE DROPS/ FLUCTUATION	J16	VOLTAGE DROP - AVR BOARD PROBLEM	AVR BOARD CHANGED
			J18	VOLTAGE FLUCTUATION	GENSET REWINDING AND BEARING, RECTIFIER AND AVR CH
			J28	LOW ALTERNATOR PROBLEM	AVR BOARD CHANGED
100	JJ8	ELECTRICAL PROBLEM - WIRING / CIRCUIT NOT FUNCTIONING	J5	STEERING COLUMN SWITCH BROKEN	STEERING COLUMN SWITCH BROKEN CHANGED
			J8	HEAD LIGHT NOT WORKING	HEAD LIGHT SEALED BEAM CHANGED
			J21	ACTUATOR PROBLEM	ACTUATOR CHANGED
			J22	PTO SWITCH NOT WORKING	PTO/ SWITCH AND SOLENOID CHANGED
			J24	REVERSE AND FORWARD PROBLEMS	SWITCH RELAY CHANGED
			J25	REVERSE PROBLEM / REVERSE SWITCH/Loose Contacts	REVERSE SWITCH CHANGED
			J36	A/C FAN MOTOR NOT WORKING	A/C FAN CLUTCH CHANGED
			J39	REEL GUARD / SWITCH NOT WORKING	REEL GUARD / SWITCH / ASSY CHANGED
101	KK1	EXHAUST SYSTEM LEAK	K4	EXHAUST LEAK	SILENCER WELDING WORK
			K8	Exhaust leak	SILENCER MUFFER CHANGED
102	KK2	AIR CONDITIONING SYSTEM FAILURE	K7	A/C SYSTEM NOT WORKING	A/C REPAIR - CONDENSOR / VALVE REPAIR
103	KK3	DENTING / PAINTING WORK	-	-	-
104	LL1	LACK OF POWER IN ALL HYDRAULIC FUNCTIONS	L1	HYDRAULIK PUMP PROBLEM	HYDRAULIK PUMP CALIBRATED
			L3	OIL LEAK CONTROL VALVE - HYD OIL	CONTROL VALVE CALIBRATED
			L7	HYD STEERING PUMP L/R ROTATION HARD	HYD STEERING PUMP CALIBRATED
105	LL2	ALL HYDRULIC RAMS SLOW TO OPERATE	L9	FRONT OUTRIGGER JACK/LH AUTOMATICALLY DOWN	FRONT OUTRIGGER JACK/LH SEAL CHANGED
			L12	FRONT LOADED ARM CYLINDER SEAL LEAK	FRONT LOADED ARM CYLINDER SEAL KIT CHANGED
			L13	FRONT BUCKET AUTOMATICALLY LOWERS DURING OPERATION	FRONT BUCKET SEAL KIT CHANGED
106	LL3	HYDRUALIC OIL BECOMES TOO HOT	-	-	-
107	LL4	POOR PERFORMANCE /SLOW OPERATING SPEED AND LOW STALL SPEED	L5	CONTROL VALVE NOT WORKING	CONTROL VALVE CALIBRATION WORK
			L8	HYD WINCH OIL LEAK	HYD WINCH OIL LEAK SEAL KIT CHANGED
108	LL5	RAM CREEP	L4	OIL LEAK TELESCOPIC CYLINDER SEAL / SCORING	TELESCOPIC CYLINDER SEAL KIT CHANGED
			L6	REAR JACK OIL LEAK	REAR JACK OIL SEAL KIT CHANGED
109	LL6	HYDRUALIC OIL LOSS - LEAKING SECTION - SEALS, "O" RING, KITS	L2	HYRDAULIC HOSE CUT	NEW HOSE CHANGED
			L14	OIL LEAK HYD TANK LEVEL TUBE BROKEN	HYD TANK LEVEL GUAGE TUBE CHANGED
			L15	SWING MOTOR BRAKE PROBLEM	SWING MOTOR BRAKE LINING AND SWITCH CHANGED
			L16	SWING ROTOR OIL LEAK	SEAL KIT CHANGEED
			L18	BOOM INNER CYLINDER HOSE LEAK	BOOM INNER CYLINDER HOSE AND SEALS CHANGED
			L21	OIL LEAK / FILTER BODY	FILTER BODY AND "O" RING CHANGED
110	LL7	ELECTRICAL DETERRENT - DOES NOT HOLD	L20	HYDRAULICK TEMPERATURE INCREASED	HYDRAULICK TEMPERATURE / PRESSURE GAUGE / SWITCH
111	LL8	MECHANICAL DETERRENT - DOES NOT HOLD	L11	REAR BACHOE CYL UNION BROKEN	REAR BACHOE CYL UNION CHANGED
112	LL9	ELECTRONICS DETERRENT - DOES NOT HOLD	-	-	-

6.3 Pareto Analysis on Breakdown Codes of Construction Machinery

6.3.1 Introduction:

Regardless of the naming origins, Dr. Juran's “vital few and trivial many” observation (the principle that 20 % of a set is generally responsible for 80 % of a related result), became known as Pareto's Principle or the 80/20 Rule. Pareto analysis is a statistical technique in decision making that is used for selection of a limited number of tasks that produce significant overall effect. It uses the Pareto principle - the concept that by doing 20 % of work we can generate 80% of the advantage of doing the entire job. Or in terms of quality improvement, a large majority of problems (80 %) are produced by a few key causes (20 %).

Pareto analysis is a formal technique which will be useful where many possible courses of action are competing for attention. In essence, the problem-solver estimates the benefit delivered by each action, then selects a number of the most effective / prioritized actions that deliver a total benefit reasonably close to the maximal possible one. Pareto analysis is a creative way of looking at causes of problems because it helps stimulate thinking and organize thoughts. However, it can be limited by its exclusion of possibly important problems which may be small initially, but which grow with time.

6.3.2 Construction of Pareto Chart

A Pareto chart is a special type of bar chart where the values being plotted are arranged in descending order. The graph is accompanied by a line graph which shows the cumulative totals of each category, left to right. The left vertical axis is the frequency of occurrence, but it can alternatively represent cost or other important unit of measure. The right vertical axis is the cumulative percentage of the total number of occurrences, total cost, or total of the particular unit of measure. Because the reasons are in decreasing order, the cumulative function is a concave function. The purpose is to highlight the most important among a (typically large) set of factors. In quality control, the Pareto chart often represents the most common sources of defects, the highest occurring type of defect, or the most frequent reasons for customer complaints.

A Pareto chart provides facts needed for setting priorities. It organizes and displays information to show the relative importance of various problems or causes of problems. It is essentially a special form of a vertical bar chart that puts items in order (from the highest to

the lowest) relative to some measurable effect of interest: frequency, cost, time. The chart is based on the Pareto principle, which states that when several factors affect a situation, a few factors will account for most of the impact. The Pareto principle describes a phenomenon in which 80 % of variation observed in everyday processes can be explained by a mere 20 % of the causes of that variation.

Placing the items in descending order of frequency makes it easy to discern those problems that are of greatest importance or those causes that appear to account for most of the variation. Thus, a Pareto chart helps teams to focus their efforts where they can have the greatest potential impact. Steps to identify the important causes using Pareto Analysis:

Step 1: To arrange the table listing the causes and their frequency as a percentage.
Step 2: To arrange the rows in the decreasing order of importance of the causes (the most important cause first)
Step 3: To add a column to the table to indicate cumulative percentage
Step 4: To plot causes on x- and cumulative percentage on y-axis
Step 5: To join the above points to form a curve
Step 6: To plot (on the same graph) a bar graph with causes on x- and percent frequency on y-axis
Step 7: A line at 80% on y-axis parallel to x-axis is drawn. This line is dropped at the point of intersection with the curve on x-axis. This point on the x-axis separates the important causes (on the left) and trivial causes (on the right)
Step 8: To note the records of causes which are on the 80% range

6.3.3 Pareto Chart in identifying the Criticality Analysis of Breakdown Main Codes

According to Peter F Knights (2001), Pareto histograms or Pareto analysis processes are commonly used to determine the maintenance priorities by logically ranking machinery failure codes according to their relative cost or downtime contribution. The Pareto's chart is drawn using the data collected to identify the significant few and insignificant many. The examples of following verily justify the usage of this technique for the construction machinery breakdown management:

- 20 % of inventory on hand occupies 80 % of warehouse space.

- 80 % of inventory line items (Stock Keeping Units or SKUs) come from 20 % of vendors.
- 80 % of revenues are the result of sales made by 20 % of sales staff.
- 20 % of workers may cause 80 % of problems,
- 20 % of personnel may deliver 80 % of entire production.

The formula appears to work in both directions.

The Pareto's law is used as an effective tool for machinery maintenance management in the areas of breakdown maintenance analysis, maintenance expenditure analysis, routine preventive maintenance, critical analysis of maintenance lags, defect analysis on components, unsafe practice analysis and accident analysis. Syed H H. et al, (2012) conducted studies in a Long wall mine where the principles of Pareto Analysis were used to identify the failure rates on the sub systems, where many sub systems were working together. The identification of the most critical system which was causing failures amongst many other subsystems helped the researchers to propose solutions and improvements.

If we consider breakdown maintenance execution itself as a conventional production process, effective execution of the process depends on the uninterrupted, unambiguous, effective execution of breakdown maintenance function. The past breakdown records of the firm is the input for this study. The various breakdown contributors/factors, which influence the breakdowns on the plant and machinery, are listed based on their occurrence. These breakdown factors only contribute to the breakdown hours and to the general overall breakdown percentage of the target organization's plant and machinery. The fish bone diagrams (CEA Tools) are shown in section 6.2 is used to identify the factors responsible for different types of breakdowns in the construction plant, with the knowledge base available with the maintenance crew. Based on the occurrences, Breakdown Main Codes (BMC) and the relative Breakdown sub codes (BSC) which are the sub causes of the main codes reasons, as identified from the sub parameters for each BMC in the previous sections.

We use these inputs into the Pareto's model and intend to study the effect of critical breakdown codes on to the group of Breakdown Main Codes (BMC) which contribute to 80 % of the breakdowns and with that we identify the critical BMC's and the subsequent BSC's.

These BSC's which are part of the critical BMC's are verified with FMEA tools. This list is further examined to identify the symptoms and the reasons which cause these breakdowns and these symptoms and reasons are further analysed with other tools namely FTA or the fault tree analysis. The significant breakdown contributing factors based on their criticality are identified for the benefit of the organization as a whole.

The focus of this tool is to identify the most contributing breakdown factors (80 % of breakdowns) on the construction machinery namely dumpers and wheel loaders, but are limited in numbers. With detailed study of these breakdown codes a proper system of breakdown maintenance management is formulated. Basically this Pareto analysis helps to understand the most contributing and significant breakdown factors. We select these factors and identify the sub factors as well. Thus significant factors based on their criticality are identified for the benefit of the organization as a whole.

The figure 6.6 include the Breakdown Main codes at the first column (Breakdown Codes), their relative actual breakdown hours as the next column (Hours), the actual breakdown percentage due to these codes (Percentage), the cumulative percentage of these codes (CP) and a base level of 80 % (Base) on other columns. The bar graph is drawn with breakdown hours on the y axis and the breakdown codes on the x axis. The parabolic curve of 80 % very clearly helps us to identify the significant causes which are limited in number to the majority duration of the failures.

Dumper Breakdowns 2007				
Breakdown Codes	Hours	Percentage	Cumulative Percentage (CP)	Base
AA1	325	25%	25%	80%
EE1	252.5	19%	44%	80%
LL6	240	18%	62%	80%
DD1	124	9%	71%	80%
AA3	116	9%	80%	80%
DD4	65	5%	85%	80%
AA4	40	3%	88%	80%
EE17	37	3%	91%	80%
BB1	35	3%	93%	80%
HH9	25	2%	95%	80%
EE16	17	1%	96%	80%
JJ1	15	1%	97%	80%
DD2	10	1%	98%	80%
AA5	8	1%	99%	80%
CC6	6	0%	99%	80%
EE12	6	0%	100%	80%
EE16	3.5	0%	100%	80%

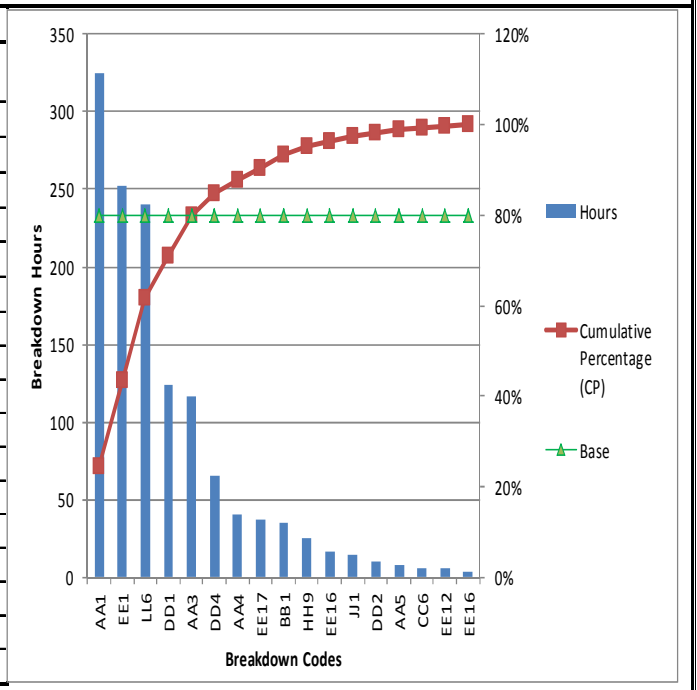

Figure 6.6 Pareto Analyses for Dumper BMC – 2007

Dumper Breakdowns 2008				
Breakdown Codes	Hours	Percentage	Cumulative Percentage (CP)	Base
AA4	262	26%	26%	80%
DD4	222	22%	48%	80%
DD1	128	13%	61%	80%
AA1	78	8%	69%	80%
JJ3	61	6%	75%	80%
CC1	48	5%	80%	80%
AA	40	4%	84%	80%
AA6	40	4%	88%	80%
JJ8	38	4%	92%	80%
HH1	30	3%	95%	80%
JJ1	14	1%	96%	80%
CC6	11	1%	97%	80%
AA8	8	1%	98%	80%
BB3	7	1%	99%	80%
JJ2	6	1%	99%	80%
LL6	4	0%	100%	80%
AA5	3	0%	100%	80%

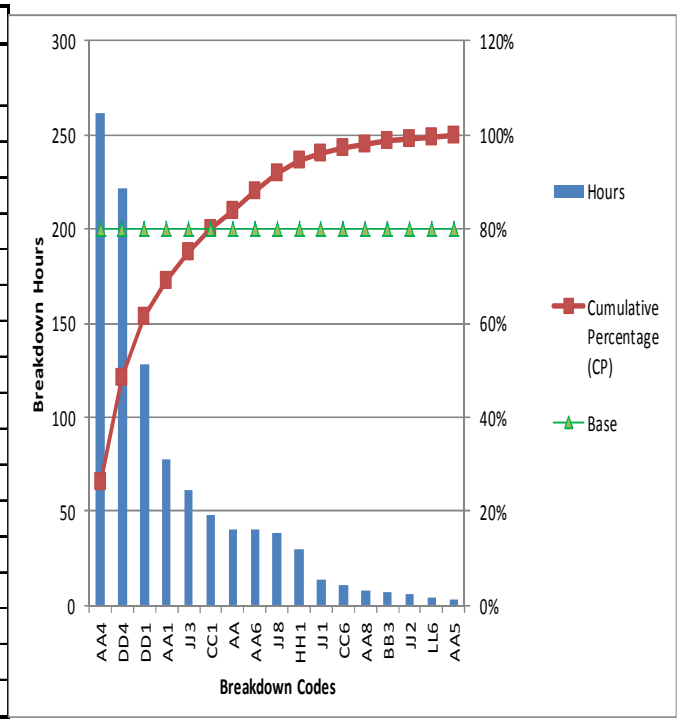

Figure 6.7 Pareto Analyses for Dumper BMC – 2008

Dumper Breakdowns 2009				
Breakdown Codes	Hours	Percentage	Cumulative Percentage (CP)	Base
DD1	195	36%	36%	80%
AA1	115	21%	56%	80%
CC1	70	13%	69%	80%
CC8	36	7%	76%	80%
DD4	36	7%	82%	80%
BB1	30	5%	88%	80%
AA4	24	4%	92%	80%
AA3	9	2%	94%	80%
LL1	8	1%	95%	80%
BB3	6	1%	96%	80%
DD3	6	1%	97%	80%
JJ1	6	1%	99%	80%
AA8	4	1%	99%	80%
LL6	4	1%	100%	80%

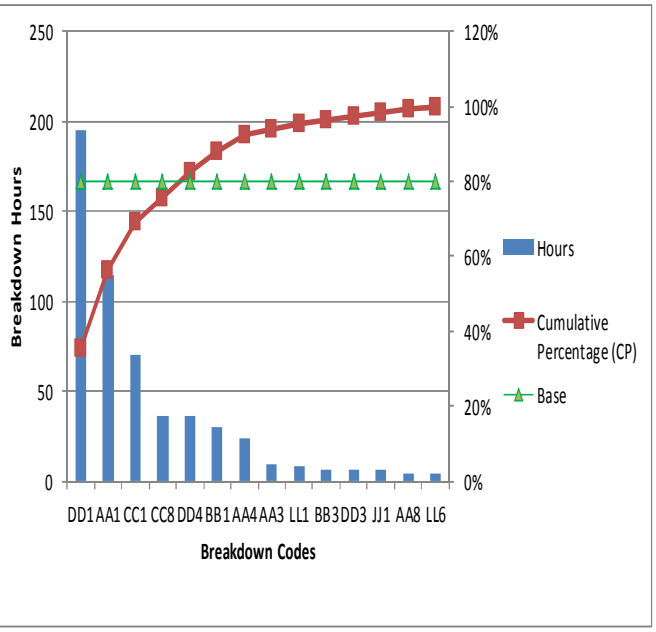

Figure 6.8 Pareto Analyses for Dumper BMC – 2009

Dumper Breakdowns 2010				
Breakdown Codes	Hours	Percentage	Cumulative Percentage (CP)	Base
AA5	390	24%	24%	80%
CC2	346	21%	45%	80%
DD10	260	16%	61%	80%
CC1	240	15%	75%	80%
AA1	197	12%	87%	80%
HH5	120	7%	94%	80%
CC11	50	3%	97%	80%
CC6	18	1%	99%	80%
DD5	13.5	1%	99%	80%
JJ1	10	1%	100%	80%

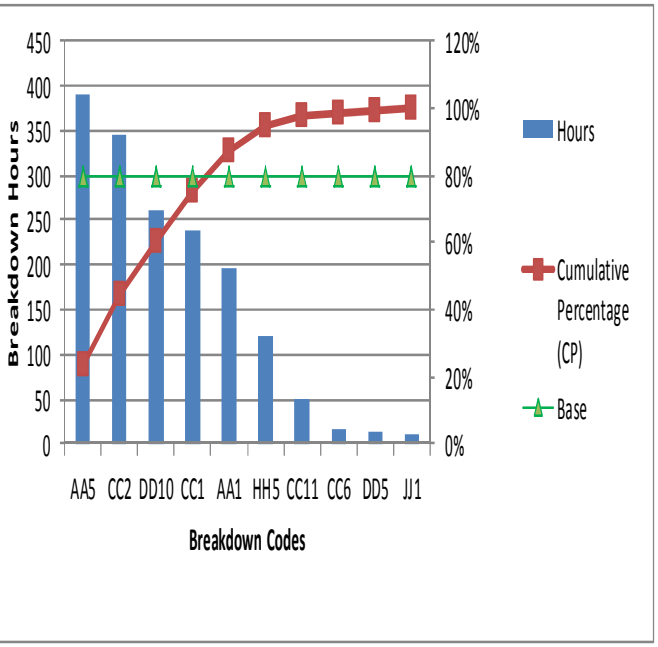

Figure 6.9 Pareto Analyses for Dumper BMC - 2010

Dumper Breakdowns 2011				
Breakdown Codes	Hours	Percentage	Cumulative Percentage (CP)	Base
JJ3	204	25%	25%	80%
EE16	196	24%	48%	80%
DD1	159	19%	68%	80%
AA11	72	9%	76%	80%
BB1	30	4%	80%	80%
JJ1	26	3%	83%	80%
LL5	25	3%	86%	80%
BB3	23	3%	89%	80%
CC6	20	2%	91%	80%
LL1	20	2%	94%	80%
HH2	18	2%	96%	80%
DD3	16	2%	98%	80%
CC2	5	1%	98%	80%
JJ2	5	1%	99%	80%
LL6	5	1%	100%	80%
BB8	3	0%	100%	80%

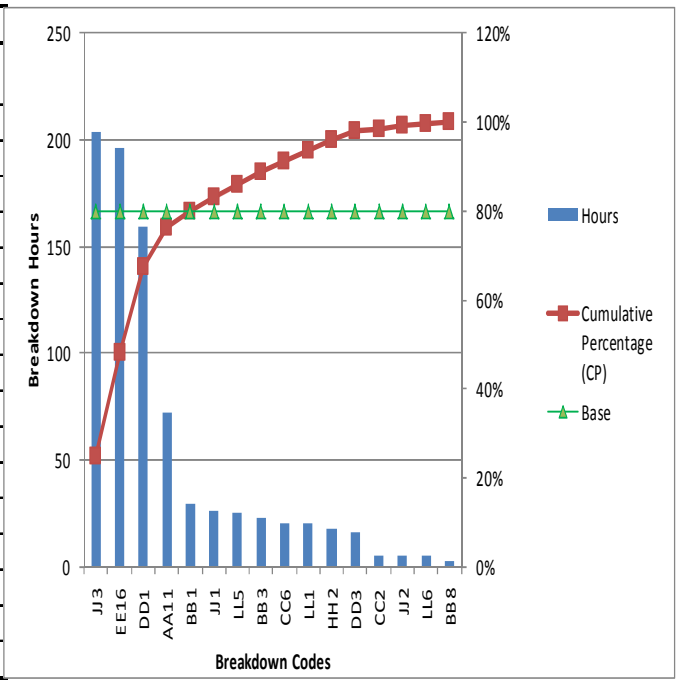

Figure 6.10 Pareto Analyses for Dumper BMC - 2011

The critical BMC's pertaining to Pareto study reveal the fact that the following codes only attribute to 80% or more breakdowns to the dumpers.

Table 6.4 Critical BMC for Dumper from Pareto Analyses

2007	2008	2009	2010	2011
AA1, AA3	**AA1,** AA4	**AA1**	AA5	AA11
	CC1	**CC1**, CC8	**CC1**, CC2	
DD1	**DD1,** DD4	**DD1**	DD10	**DD1**
EE1				EE16
	JJ3			**JJ3**
LL6				

Similarly the Pareto Charts are constructed for the Wheel loaders in the same manner.

Wheel Loader 2007

Breakdown Codes	Hours (hrs)	Percentage	Cumulative Percentage (CP)	Base
DD4	60.5	63%	63%	80%
GG7	26	27%	90%	80%
AA3	6	6%	96%	80%
CC8	4	4%	100%	80%

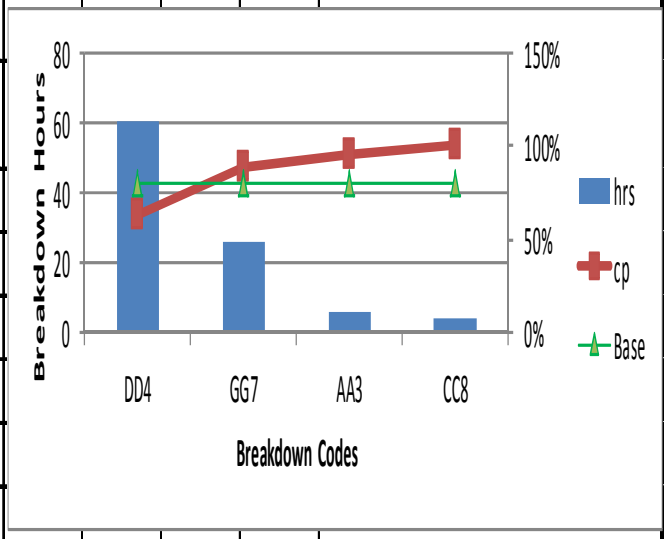

Figure 6.11 Pareto Analyses for Wheel Loader BMC – 2007

Wheel Loader 2008

Breakdown Codes	Hours (hrs)	Percentage	Cumulative Percentage (CP)	Base
DD12	480	82%	82%	80%
GG7	28.5	5%	86%	80%
JJ2	24	4%	91%	80%
HH2	20	3%	94%	80%
JJ8	14	2%	96%	80%
GG5	11.5	2%	98%	80%
LL6	10	2%	100%	80%

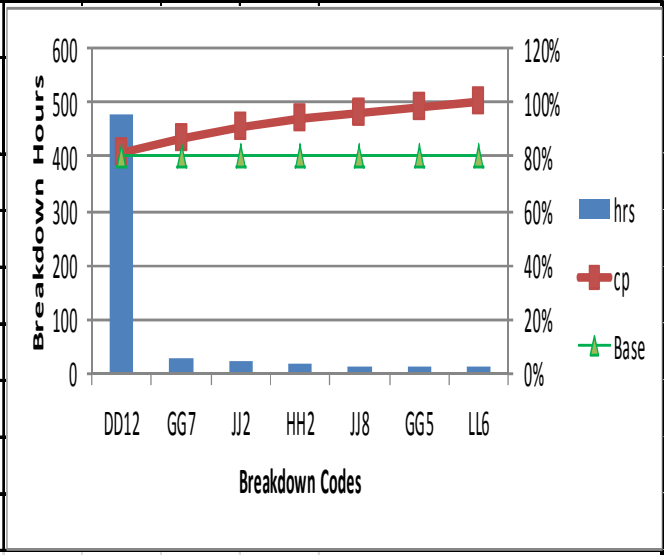

Figure 6.12 Pareto Analyses for Wheel Loader BMC - 2008

Wheel Loader 2009				
Breakdown Codes	Hours (hrs)	Percentage	Cumulative Percentage (CP)	Base
EE1	297	35%	35%	80%
EE16	180	21%	56%	80%
AA2	103	12%	68%	80%
GG7	99	12%	80%	80%
JJ1	75	9%	89%	80%
LL6	28	3%	92%	80%
GG6	20	2%	94%	80%
JJ8	19	2%	96%	80%
JJ3	17	2%	98%	80%
DD8	6	1%	99%	80%
JJ4	4	0%	100%	80%
AA8	3	0%	100%	80%

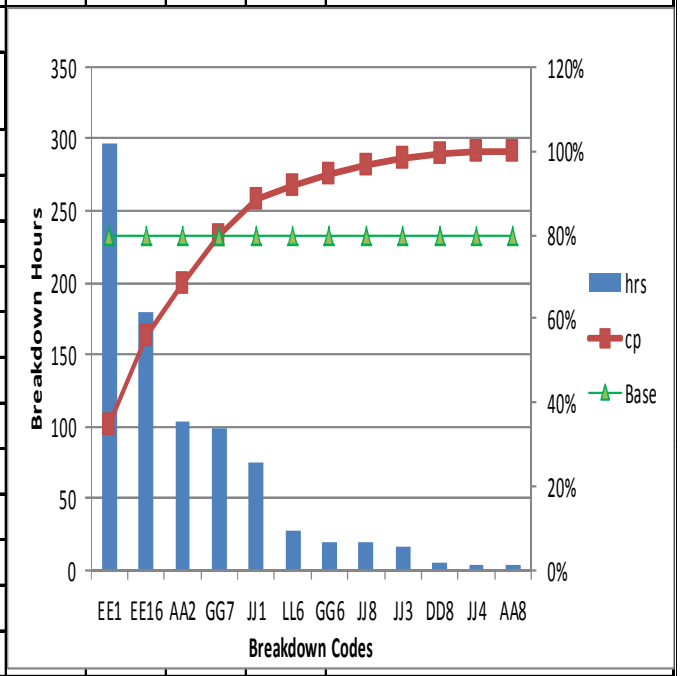

Figure 6.13 Pareto Analyses for Wheel Loader BMC – 2009

Wheel Loader 2010				
Breakdown Codes	Hours (hrs)	Percentage	Cumulative Percentage (CP)	Base
DD11	330	45%	45%	80%
AA3	150	21%	66%	80%
GG7	112	15%	81%	80%
JJ1	70	10%	91%	80%
BB2	40	5%	96%	80%
LL6	16	2%	99%	80%
BB3	7	1%	100%	80%
JJ2	3	0%	100%	80%

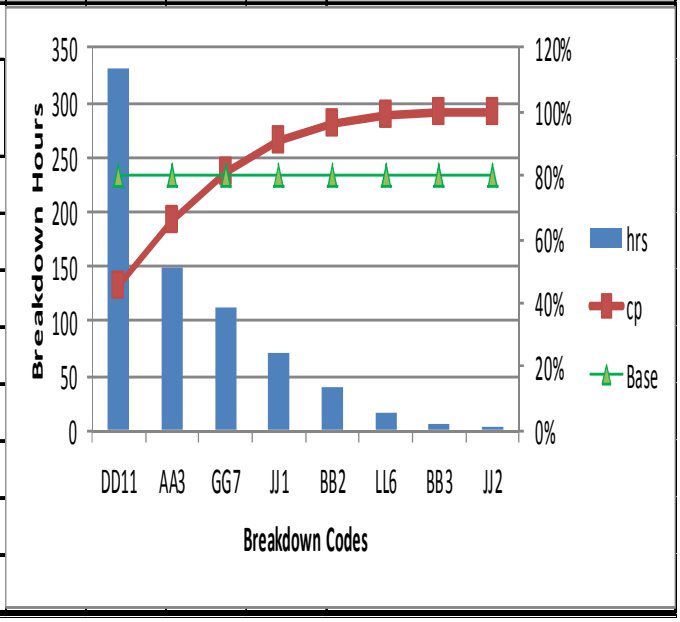

Figure 6.14 Pareto Analyses for Wheel Loader BMC - 2010

Wheel Loader 2011				
Breakdown Codes	Hours (hrs)	Percentage	Cumulative Percentage (CP)	Base
AA1	190	25%	25%	80%
DD10	180	23%	48%	80%
EE16	80	10%	59%	80%
GG7	75	10%	69%	80%
LL6	67.5	9%	77%	80%
LL2	58	8%	85%	80%
JJ3	41	5%	90%	80%
LL1	38	5%	95%	80%
AA3	23.5	3%	98%	80%
JJ1	5	1%	99%	80%
AA2	4	1%	99%	80%
JJ8	4	1%	100%	80%

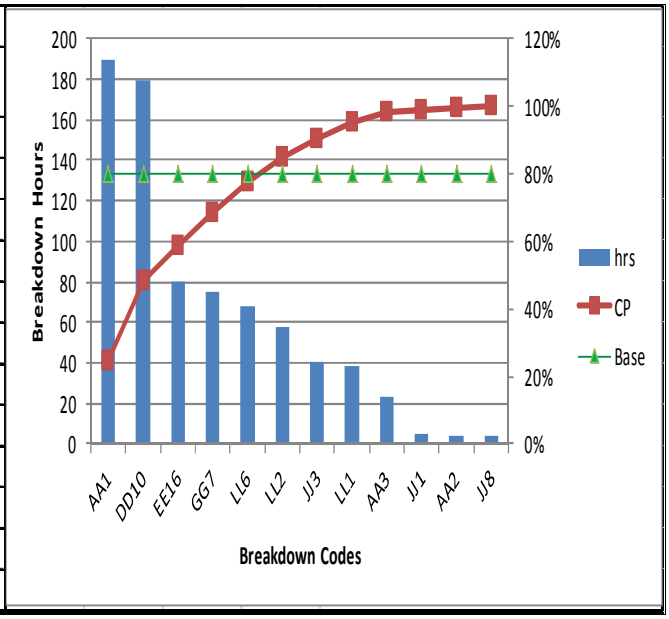

Figure 6.15 Pareto Analyses for Wheel Loader BMC - 2011

The critical BMC's pertaining to Pareto study reveal the fact that the following codes only attribute to 80% or more breakdowns to the wheel loaders.

Table 6.5 Critical BMC for Wheel Loaders from Pareto Analyses

2007	2008	2009	2010	2011
		AA2	AA3	AA1
DD4	DD12		DD11	DD10
		EE1, **EE16**		**EE16**
		GG7	**GG7**	**GG7**
				LL6

The identified BMCs and BSCs ranked using Pareto analysis are listed in table 6.6 and table 6.7. The first column indicates the BMC followed by the total number of breakdown cumulative percentage over a period of 5 years it has contributed. All possible BSCs which could contribute to these breakdowns are also listed in the column 2 onwards. A study on these tables also reveals the factor that certain BSCs account for failure of both the machinery considered for the analysis. One reason for this could be that these considered machinery fall under earthmoving machinery and of heavy lifting/earth moving/material handling nature of machines and are used to load/unload and transport materials.

Table 6.6 Cumulative Effect Analysis of BMC with BSC for Wheel Loader

BMC (No of failures)	Related BSCs influencing the BMC (no of occurrences of the failure mode in bracket)					
Wheel Loader						
AA_1(1)	A_6(1)					
AA_2(12)	A_{43}(12)					
AA_3(21)	A_{38}(21)					
DD_{10}(1)	D_{21}(1)					
DD_{11}(45)	D_{22}(45)					
DD_{12} (82)	D_{26}(82)					
DD_4 (63)	D_{18}(63)					
EE_1 (35)	E_5(2)	E_7(1)	E_8(33)			
EE_{16}(22)	E_2(21)	E_3(1)				
GG_7 (74)	G_1(14)	G_2(18)	G_3(22)	G_4(15)	G_5(4)	G_6(1)
LL_6 (5)	L_2 (5)					

Table 6.7 Cumulative Effect Analysis of BMC with BSC for Dumper

Dumper						
AA_1(7)	A_6(7)					
AA_3(1)	A_{37}(1)					
AA_4(1)	A_1(1)					
AA_5(2)	A_4(1)	A_{31}(1)				
AA_{11}(3)	A_6(2)	A_{48}(1)				
BB_1(1)	B_1(1)					
CC_1(6)	C_1(3)	C_3(3)				
CC_2(3)	C_{14}(3)					
CC_8(1)	C_{10}(1)					
DD_1(14)	D_5(3)	D_6(10)	D_7(1)			
DD_4 (3)	D_{20}(2)	D_{18} (1)				
DD_{10} (1)	DD_{21} (1)					
EE_1 (3)	E_8(2)	E_{26}(1)				
EE_{16}(3)	E_2(1)	E_3(2)				
JJ_3(4)	J_4(2)	J_{31}(2)				
LL_6(1)	L_{16}(1)					

Based on these studies of Pareto Analysis the critical contributing breakdown codes namely BMC and their relative sub codes, BSC's are identified and tabulated as above. The total

number of initially arrived BMC codes (62 nos.), which were the causes of various breakdowns of the components on Wheel Loaders and Dumpers for the year (2007 to 2011) and have been reduced to 27 with the Pareto Analysis. The results are tabulated below as table 6.8. Similar analysis were performed with all the nine machinery under this study and listed in Appendix E and the resultant BMC and BSC codes from this study are listed in table 6.9.

Table 6.8 Effect of Reduction in BMC with Pareto Analysis

Pareto Analysis on the BMCs			
S.No	Equipment	BMC Contributor for 100% Breakdown (identified)	Critical BMC identified based on Pareto Analysis
1	WHEEL LOADER	26	11
2	DUMPER	36	16
TOTAL BMC		**62**	**27**

Table 6.9 Details of Codes reduced from Pareto Analysis for machinery

BMC Contributors for 100% Breakdowns	Criticality Effect - Reduced BMC Contributors for 80% Breakdowns	Description of Breakdown Main Code
AA1	AA1	ENGINE MAJOR OVERHAULING
AA2	AA2	ENGINE OVER HEATING
AA3	AA3	COOLANT OIL EXCESSIVE CONSUMED
AA4	AA4	ENGINE LOW OIL PRESSURE
AA5	AA5	ENGINE OIL EXCESSIVE CONSUMED
AA6		ENGINE VIBRATION
AA7	AA7	ENGINE KNOCKING NOISE
AA8	AA8	ENGINE SPEED VARIATION
AA9		IMPROPER COLOUR OF EXHAUST
AA11	AA11	ENGINE NOT CRANKING WILL NOT START
BB1	BB1	FUEL INJECTION PUMP - INJECTOR CALIBRATION
BB2		ENGINE KNOCKING SOUND
BB3	BB3	ENGINE CRANKS BUT DIDN'T START
BB4	BB4	ENGINE HARD TO START
BB5		ENGINE SPEED VARIATION
BB6	BB6	ENGINE VIBRATION
BB7	BB7	ENGINE EMITS WHITE SMOKE
BB8	BB8	LACK OF POWER
BB9		EXCESSIVE FUEL CONSUMPTION
CC1	CC1	GRINDING NOISE WHEN CHANGING GEAR
CC11	CC11	GEAR ENGINE PROBLEM
CC2	CC2	GEAR BOX NOISING WHILE TRAVELLING
CC4		GEAR SHIFT DIFFICULTIES
CC6	CC6	MACHINE DOES NOT DRIVE IN ANY GEAR
CC8	CC8	EXCESSIVE OIL CONSUMPTION
DD1	DD1	CLUTCH SLIPPING WHEN CLUTCH APPLIED
DD2		CLUTCH PEDAL HARD
DD3		CLUTCH JUDDERING
DD4	DD4	NOISE WHILE TRAVELLING
DD6	DD6	TRANSMISSION RANGE NOT CONTROLLED WITH SPEED LEVER
DD8		LOSS OF OIL
DD9	DD9	STARTING TROUBLE
DD10	DD10	CROWN WHEEL NOISE
DD11	DD11	DIFFERENTIAL OIL LOSS
DD12	DD12	GEAR CANNOT ENGAGE 4WD/2WD/ REVERSE
EE1	EE1	BRAKE IS INEFFECTIVE
EE12		AIR PRESSURE DROPS DURING ENGINE STOP/BRAKES RELEASE
EE16	EE16	OPERATING FORCE OF BRAKE PEDAL IS TOO LIGHT
EE17	EE17	OPERATING FORCE OF BRAKE PEDAL IS TOO HEAVY
GG3	GG3	UN EVEN TYRE WEAR
GG4		TYRE ONE SIDE WEAR TOE IN
GG5		TYRE ONE SIDE WEAR TOE OUT
GG6		WHEEL HUBS LUBIRICATION LEAKAGE
GG7	GG7	SPEED LOW (TYRE AIR LOSS)
GG8		WHEEL EXCESSIVE NOISE WHILE BRAKING
HH1		EXCESSIVE PLAY IN THE STEERING
HH2	HH2	HARD STEERING
HH5		STEERING VIBRATION WHILE RUNNING 90KM AND ABOVE
HH8	HH8	STEERING PUMP PRESSURE REDUCED
HH9		STEERING WHEEL IS SLUGGISH
II3		TYRE UNEVEN WEAR
JJ1	JJ1	STARTING TROUBLE
JJ2		ENGINE NOT CRANKING WILL NOT START
JJ3	JJ3	ENGINE CRANKING BUT NO START
JJ4	JJ4	ENTIRE ELECTRICAL FUNCTIONS DOES NOT WORK
JJ5		SPEED VARIATION (ELECTRONIC CONTROL SENSORS)
JJ6	JJ6	EXCESSIVE NOISE DEVELOP (ENGINE / GENSET)
JJ7		VOLTAGE FLUCTUATION / DROPPED
JJ8	JJ8	ELECTRICAL PROBLEM - WIRING / CIRCUIT NOT FUNCTIONING
KK1	KK1	EXHAUST SYSTEM LEAK
KK2		AIR CONDITIONING SYSTEM FAILURE
LL1	LL1	LACK OF POWER IN ALL HYDRAULIC FUNCTIONS
LL2	LL2	ALL HYDRULIC RAMS SLOW TO OPERATE
LL4	LL4	SLOW OPERATING SPEED/LOW MAXIMUM STALL SPEED
LL5	LL5	RAM CREEP
LL6	LL6	HYDRUALIC OIL LOSS - LEAKING SECTION - SEALS, "O" RING , KITS
LL7		ELECTRICAL DETERRENT WILL NOT HOLD
LL8	LL8	MECHANICAL DETERRENT WILL NOT HOLD

6.4 Failure Mode Effect Analysis (FMEA) for Critical Breakdown Sub Codes

FMEA, the Failure Mode Effect Analysis method is the reliability analysis tool which takes the task of identifying the possible failures and faults in a system and is helpful in evaluating the consequence of the same on the operations and functioning of the system (Hung and Sung, 2011). As an analysis technique FMEA facilitates the identification of potential problems in the design or process by examining the effects of lower level failures. Theoreticians have supported using failure mode and effects analysis (FMEA) as the technique for identifying and rectifying failures in achieving continuous quality improvement and newer techniques and newer techniques like TFMEA (Total Failure Mode Effect Analysis) facilitates the spontaneous formation of teams to provide solutions so as to prevent the recurrence of failures within the company (S.R. Devadasan et al. 2003). Keeter W, (2006) also emphasized the utilization of Failure Modes and Effects Analysis (FMEA) or Machinery Functional analysis methods to generate useful failure codes for breakdowns or failures happening to the plant and machinery.

As stated by Hunt J.E. et al (1995), FMEA constitutes investigation and assessment of the effects of all the possible failure modes on a system. With FMEA results, actions and provisions are made to reduce the likelihood of the problem occurrence and mitigating the relative risk, in case of occurrence of the failures. The FMEA team determines, by failure mode effect analysis, the effect of each failure and identifies single failure points that are critical. The approach involves statistical data collection especially related with the frequency of subcomponent failures and their likelihood of non-detectability and severity it imposes on system performance. The results of the analysis help managers and engineers to identify the failure modes, their causes and correct them during the stages of design and production. There need not be one to one failure mode to causes and it may vary one to many (Stamatis D H, 1995). It may also rank each failure according to the criticality of a failure effect and its probability of occurring.

The Breakdown Sub Codes (BSC) which is developed from the critical BMC's should be verified and ascertained properly that they are the true representative codes and a dependency rate on the same can be established. The Failure Mode Effect Analysis is performed on these selected BSC's to find out how influential these codes with respective to the various sub

components with which they are associated and also to ascertain their severity effect on local and system level. This exercise helps us to know that if these sub components which are associated with the selected BSC failure cause, are not having higher severity ratings with the failure, then the selection of these BSC's as the critical BSC's will not be a true statement. Hence the selected BSC's and their relative components severity ratings were ascertained with FMEA Analysis. The following sample BSC's are selected for analysis:

- A38 – Engine Oil / Coolant Oil Mixing
- A43 – Engine Overheat
- A37 – Oil Pump Problem
- L 13 – Front Bucket lowers automatically during operation
- L 05 – Control Valve Not Working
- J 14 – Alternator Problem

Table 6.10 FMEA for Engine Oil and Coolant Oil Mixing

Failure Mode and Effect Analysis (BSC A38 : Engine oil and Coolant Oil Mixing)					
Component	Function	Failure mode	Failure effect		Effect rate
			Local	System	
Oil Cooler	To maintain oil temperature	Oil cooler gasket/ 'o' ring damage	Coolant oil color changed	Oil viscosity and oil film thickness reduced	Low
Inter cooler	To maintain oil temperature / control friction	Inter cooler damage	Coolant oil color changed	Lubrication not attained properly	Low
Water pump	To maintain engine temperature	Water pump seal cut	Engine oil level increased	Radiator pressure reduced / Cooling function improper	Low
		Water pump gasket weak			High
Cylinder head assy	It houses the Inlet and Exhaust valve arrangements and continuous coolant route throughout the engine	Engine cylinder head gasket faults	Compression reduced and starting trouble with smoke emission	Combustion and stoke system failure	High
		Engine cylinder head crack / water gallery	Coolant continuous route function failure / very high temperature developed	Engine cooling system failure / performance reduced	Very high
Cylinder liner	The cylinder liners receives combustion heat through the piston and rings and transmit the heat to the coolant	Engine liner crack	Emitting smoke with excessive sound	Engine efficiency reduced	Very high
		Liner "O" ring cut	Cooling pressure reduced / oil pressure and film coating reduced	Engine performance decreased	Medium
Engine block	It houses the engine parts and oil/ coolant route throughout the engine	Block crack - coolant or oil route	Engine compression reduced / Excessive smoke with noise developed	Engine cooling system failure / quick damages	High

Table 6.10 details the FMEA development for the sub code A38. A38 is the BSC denoting the Engine Oil and Coolant Oil Mixing. The performance of the engine is very much dependent on the engine oil. The engine oil's purity level is important for the lubrication of the engine internal parts and any contamination will reduce the performance of the engine. This also results changes in volume of cooling oil, or/hence excess smoke from the engine and also creates more adverse effects due to wear and tear on the engine. The parts which are associated with this failure effect include cylinder head assembly, cylinder liner, water pump, engine block, oil cooler and the inter cooler. When we analyze the severity rating of this component due to this sub code, the rating is very high and high respectively for two each of the four components, while low for two of the components. This justifies that the sub code BSC A38, is very critical in nature for the performance of the engine and should be considered for further analysis on breakdown maintenance.

Table 6.11 FMEA for Front Bucket Automatic Lowering During Operation

Failure Mode and Effect Analysis (BSC L13 : Front bucket automatically lowered during operation)					
Component	Function	Failure mode	Failure effect		Effect rate
			Local	System	
Operating Control valve	To control pressure and oil flow regulation function	Seals and "o" rings	Hydraulic oil leaks	Oil level and pressure reduced	Medium
		Spool, pins & valves	Oil leaks and pressure released	Operation & control unstable	High
Bucket cylinder	Convert fluid power to mechanical force and linear motion. Its main operation is pull & push operation	Ram, seals & hoses	Engine oil pressure reduced/ sound developed	Engine oil lubrication system failure and engine seized	Very high
		Gland and nuts	Cylinder movements too slow	Bucket operation failure	Medium
Solenoid switch	Its function is to control the flow oil to hydraulic ram cylinders	Switch and contacts	Switch not working	Bucket tilting and pull & push operating failure	Very High

Table 6.11 details the FMEA development for the sub code L13. This BSC is related to the automatic lowering of the front bucket of the wheel loader, dumper and other earth moving machinery. The front bucket is an important component which performs the tilling/collection operation of the machine and has sharp edged teeth in front. The automatic lowering of front bucket during operation will lead to serious safety hazards and untoward happenings on the machine. The operator will not have enough control on it or he will be seriously disturbed

while performing his operation of this machine. The related components which initiate this failure or affected due to this failure include hydraulic cylinder, solenoid valve and the control valve. The severity ratings of malfunctioning of the components are estimated to be very high for two of the components and high for one of the components. Hence this BSC Code L13 is a valid code and should be considered for further analysis.

Similar sample analysis is performed for codes A43 – Engine Overheat; BSC A37 – Oil Pump Problems (Engine Low Oil Pressure); BSC L05 – Control valve not working (Slow Operational Speed) and BSC J14 – Alternator Problems (Starting Trouble) and the results are listed in the following tables 6.12 to 6.15.

Table 6.12 FMEA for Engine Overheating

Failure Mode and Effect Analysis (BSC A43 : Engine overheat)					
Component	Function	Failure mode	Failure effect		Effect rate
			Local	System	
Radiator fan / clutch	It can push the air through the radiator core or pull it through. It must cool the coolant and reduce the engine temperature.	Fan leaf broken	Fan rotation misaligned and noise developed	Air flow system failure / radiator coolant temperature not cooled	High
		Clutch condenser	Condenser failure/ clutch not functioning on right time	Air flow system failure	Medium
Water pump	It circulates the coolant oil throughout the engine and radiator	Water pump bearing/Impeller seized	Engine coolant oil level decreased/sound developed	Cooling function will not working properly	High
		Water pump gasket/ seal leak			High
Radiator	One top & bottom tanks vertically connected with core tubes to circulate the coolant from the top to bottom of the tank.	Radiator tanks / cap leak	Coolant level Insufficient	Engine was not able to withstand the working temperature	High
		Radiator core choked	Coolant flow route blocked / too heat developed	Engine cooling system failure / performance reduced	Very High
Fan belt	Radiator fan located at the front of the water pump and driven by a belt and pulley connected to the engines crank shaft.	Belt cut	Coolant circulation stopped	Engine temperature raised and system failure	Very High
Thermostat	Its function is to block the flow of coolant to the radiator until the engine has reached the operating temperature.	Thermostat valve stuck	Thermo valve not open	Thermostat function failed	Very High

Table 6.13 FMEA for Oil Pump Problem (Engine Low Oil Pressure)

Failure Mode and Effect Analysis (BSC - A37 : Oil pump problem- Engine low oil pressure)					
Component	Function	Failure mode	Failure effect		Effect rate
			Local	System	
Gear/rotor assy	To move the oil throughout the engine under pressure. This libricates and helps cool the engine.	Teeth broken/ wornout	Engine oil pressure reduced	Oil lubrication system failure and performance reduced	High
		blade wornout/ broken	Intermident oil supply	Oil lubrication system performance reduced	High
Pump drive shaft	Engine oil pump gears and blades driven by a drive shaft and connected with camshaft drive gear	Drive shaft broken / cotter pin broken	Engine oil pressure reduced/ sound developed	Engine oil lubrication system failure and engine seized	Very high
Stainer	Its funtion is to filter the flow of engine oil to the engine	carbon deposited on strainer wire mesh	Engine oil not able to pumping	lubrication system pressure reduced	High
Sump	Collect the oil (gallery) and sedimented	Oil accumulated low (operating level) due to cabon deposited and choked	Coolant circualtion stopped	Engine temperature raised and system failure	Very High

Table 6.14 FMEA for Control Valve not working - Slow Operating Speed

Failure Mode and Effect Analysis (BSC L05 : Control Valve not working - slow operational speed)					
Component	**Function**	**Failure Mode**	**Failure Effect**		**Effect Rate**
			Local	**System**	
Control Valve Assembly	To control the pressure and the oil flow regulations of the machine system	Seals and 'O' Rings	Hydraulic Oil leakages	Pressure and Oil level reduced	Medium
		Switch Assembly	Electronic Voltage supply short circuited	Operating functional failure	High
Spool and levers	It is fitted with the control valves to control and regulate the flow of medium and to further control the operation of the systems.	Lever	With contact points worn out, the circuit is not closed	Low level performance of hydraulic lever	Medium
		Spool and 'O' Rings	Oil leakages / oil level reduced	Pressure and Oil level reduced	Medium

Table 6.15 FMEA for Alternator Problem - Starting Trouble

Failure Mode and Effect Analysis (BSC J14 : Alternator problem - Starting trouble)					
Component	Function	Failure Mode	Failure Effect		Effect Rate
			Local	System	
Rotor	The rotor assy consists of a rotor shaft, a winding around an iron core, two pole pieces and slip rings.The rotor is pressed into the core. At the front end it is connected with fan and pulley	Slip rings	Slip ring damage	EMF dropped	High
		Field coils with windings	Short circuit	Current charging failure	High
Stator	The stator is fitted between the front & rear the housing. Three windings around the stator frame are arranged in layers in each of the slots of the frame. At the other end the stator is fitted with the rectifier.	Winding layers	Short circuit	EMF dropped and system performance failure	Very high
Regulator with carbon brush	Its main function is regulation and unification of the current and voltage	Regulator assembly	Regulator not working	Unifying the current & voltage system failure	Very high
		Carbon brush holders	Carbon detoriated	Current and Voltage cut off system failure.	Medium
Rectifier with diodes	The rectifier assembly consists of six diodes.Its main funtion is conversion of Alternating Current (AC) to Direct Current (DC).	Diodes not functioning	Rectifier and diodes melted	AC and DC convertion system failure	High
Fan and pulley assy	The pulley drives the rotor through an engine accessory drive belt.The fan behind the alternator pulley pulls in air through vents at the rear side of the alternator to cool the diodes.	Fan leaf and pulley broken	Pulley drive belt cut and rectifier diodes heated	Rectifier diodes melted and current producing system failure.	Medium
Housing	Bearings supporting the rotor assembly are mounted in the front & rear housing.	Bearings and housing broken	Rotor shaft rotation misaligned	Voltage dropped and short circuited on the stator	High

6.4.1 Importance of FMEA

- FMEA provides a procedure for identifying the root causes of failures and further developing effective corrective actions
- FMEA is useful for the identification of reliability/safety of the critical components in a system
- As a tool it facilitates greater tips for the investigations for the design alternatives at all stages of the design
- Also provides insight on to other maintainability, safety, testability, and logistic analyses

Although the FMEA is an essential reliability task, it also provides information for other purposes. The use of the FMEA is called for in maintainability, safety analysis, survivability and vulnerability, logistics support analysis, maintenance plan analysis, and for failure detection and isolation subsystem design.

The consolidated details are as listed in table 6.16 provides the severity ratings of these Breakdown Sub Codes and justifies further analysis of these codes as the severity ratings are on very high scale.

Table 6.16 Consolidated FMEA details for Sub Codes

FAILURE MODE EFFECT ANALYSIS (FMEA) SUBCODE (BSC) AND AFFECTED COMPONENTS SEVERITY RATING - ANALYSIS								
Sl.No	Sub Code	FMEA No.	Component	Severity Rating				Severity Percentage
				Very High(4)	High (3)	Medium (2)	Low (1)	
1	A38	F1	Cylinder Head Assembly	4				100%
2			Cylinder Liner	4				100%
3			Water pump		3			75%
4			Engine block		3			75%
5			Oil Cooler				1	25%
6			Inter Cooler				1	25%
Average (A)								67%
1	A43	F2	Radiator	4				100%
2			Fan belt	4				100%
3			Thermostat	4				100%
4			Water pump		3			75%
5			Radiator fan assembly		3			75%
6			Radiator clutch			2		50%
Average (B)								83.33%
1	A37	F3	Pump drive shaft	4				100%
2			Sump	4				100%
3			Strainer		3			75%
4			Gear / Rotor Assembly		3			75%
Average (C)								88%
1	L13	F4	Hyd. Cylinder	4				100%
2			Solenoid	4				100%
3			Control valve assembly		3			75%
Average (D)								92%
1	L05	F5	Control valve assembly		3			75%
2			Spool percentage levers assembly			2		50%
Average (E)								63%
1	J14	F6	Stator	4				100%
2			Regulator	4				100%
3			Rotor		3			75%
4			Rectifier		3			75%
5			Housing assy		3			75%
6			Fan & Pulley assembly			2		50%
Average (F)								80%
Total Average (A+B+C+D+E+F)								87.33%

6.5 Fault Tree Analysis for arriving Breakdown Symptom and Reason Codes

Fault Tree Analysis (FTA) is one of the most widely used methods in system reliability and failure probability analysis for identifying the root cause of failures. A fault tree is a graphical representation of a logical structure representing undesired events and their causes. It is a reliability tool used to analyze the probabilities associated with various failure causes and their effects on system performance (Sharma R K, 2010). The logical structure is created by using logic gates and represent undesired events by using basic events. Reliability parameters are assigned to the basic events.

The technique is widely used in system reliability studies. Fault tree analysis offers the ability to focus on an event of importance, such as a highly critical safety issue, and work to minimize its occurrence or consequence. The probability of the above events can be determined by using mathematical techniques. The resulting fault tree diagram is a graphical representation of the chain of events in the system or process, built using events and logical gate configurations / tree structures. Fault Tree Analysis is acknowledged as a key tool for safety and failure studies. It is unique and indispensable in analyzing risks and determining various combinations of hardware, software, and human error failures that result in a specified risk or system failure.

Fault tree analysis is useful both in designing new products/services and in dealing with identified problems in existing products/services. In the quality planning process, the analysis can be used to optimize process features and goals and to design for critical factors and human error. As part of process improvement, it can be used to identify root causes of troubles and to design remedies and countermeasures. Fault tree analysis also help with the diagnosis of the failure symptoms (modes) by illustrating which combinations of events could lead to the observed failure symptoms and this principle is used in the failure and failure root cause analysis (Nutter, D.W, 2001).

Our study uses this technique in determining the breakdown symptom and root cause factors namely Breakdown Symptom Codes (BSyC) and Breakdown Reason Codes (BRC). The BSC's which are subject to the analysis of FMEA are taken as inputs and subsequently the Fault Tree Analysis is performed on to them to identify the logical reasoning to

problems/failures and to determine the symptoms and reasons for the same. Basically the root cause of the specific breakdown is known as the BRC and the symptoms of this root causes are the symptom codes namely BSyC. The resultant BSyC and BRC are prepared for all the critical BMC and BSC's. Figure 6.16 is the detailed FTA developed for the Breakdown Sub Code - Engine Oil and Coolant Oil Mixing. The issues on engine performance and the oil related problems are analyzed and the causes of these two malfunctions are identified and listed as breakdown symptoms. The symptoms will lead to the identification of the root cause of the problem which is further identified as the breakdown reason. Table 6.17 details the list Breakdown Symptom Codes and Breakdown Reason Codes identified from figure 6.16. Similar sample analysis of breakdown codes and the relative BSyC and BRC identification are detailed in figure 6.17 and figure 6.18.

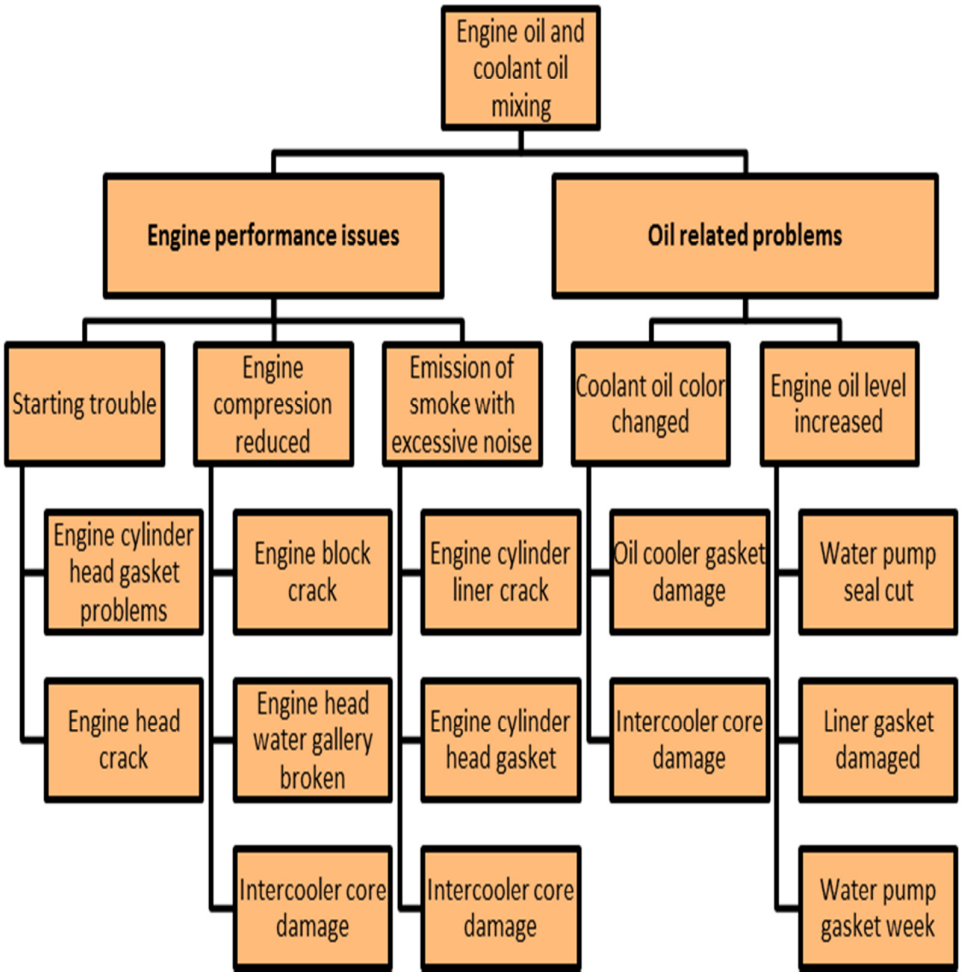

Figure 6.16 Fault Tree Analyses for BMC - Engine Oil and Coolant Oil Mixing

Table 6.17 Identified Symptom Codes and Reason Codes from FTA

Breakdown Sub Code		Breakdown Symptoms Code		Breakdown Reasons Code	
Code	Description	Code	Description	Code	Description
A38	Engine Oil and Coolant Oil Mixing	A38Sy1	Radiator Coolant Color changed	A38R1	Oil Cooler Gasket Damage
				A38R2	Inter Cooler Core Damage
		A38Sy2	Engine Oil level increased	A38R3	Water Pump Seal Cut
				A38R4	Engine Liner Gasket Damage
				A38R5	Water Pump Gasket Weak
		A38Sy3	Starting Trouble	A38R6	Engine Cylinder Head Gasket Cut
				A38R7	Engine Head Crack
		A38Sy4	Engine Compression reduced	A38R8	Engine Block Crack
				A38R9	Engine Head Water Gallery Broken
				A38R10	Inter Cooler Core Damage
		A38Sy5	Emitting Smoke with excessive noise	A38R11	Engine Cylinder/Liner Crack
				A38R12	Engine Cylinder Head Gasket
				A38R13	Inter Cooler Core Damage

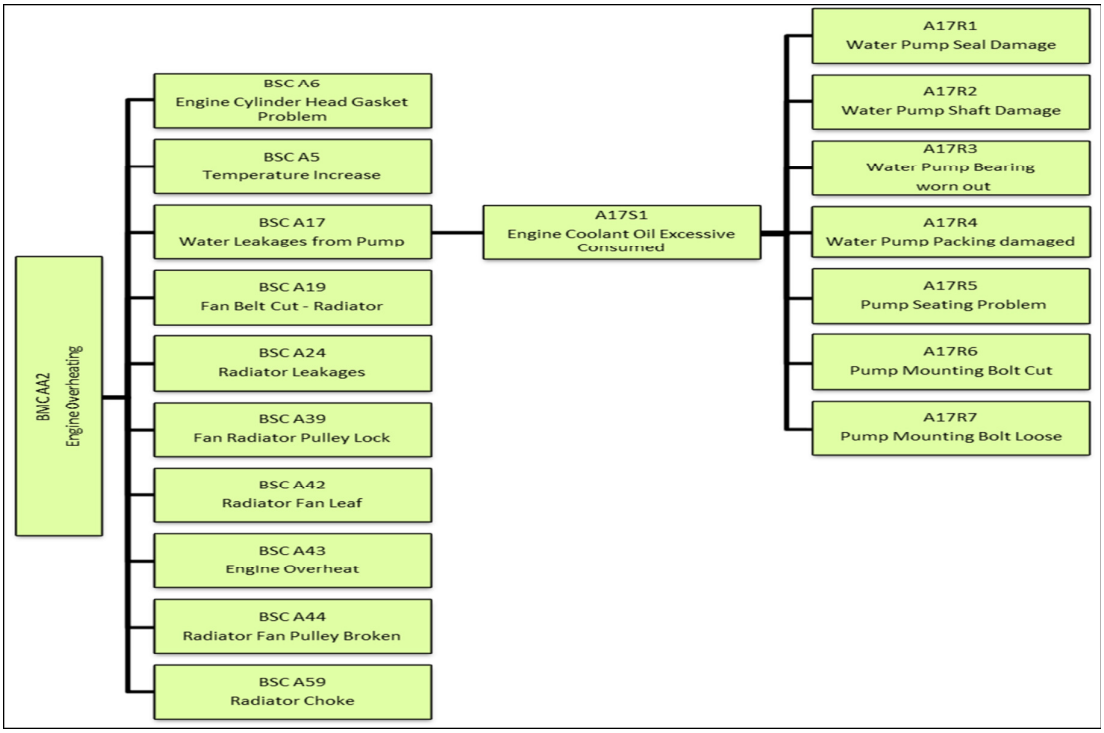

Figure 6.17 FTA Process for Engine Overheating (BMC) to Sub Codes, Symptom Codes and Reason Codes

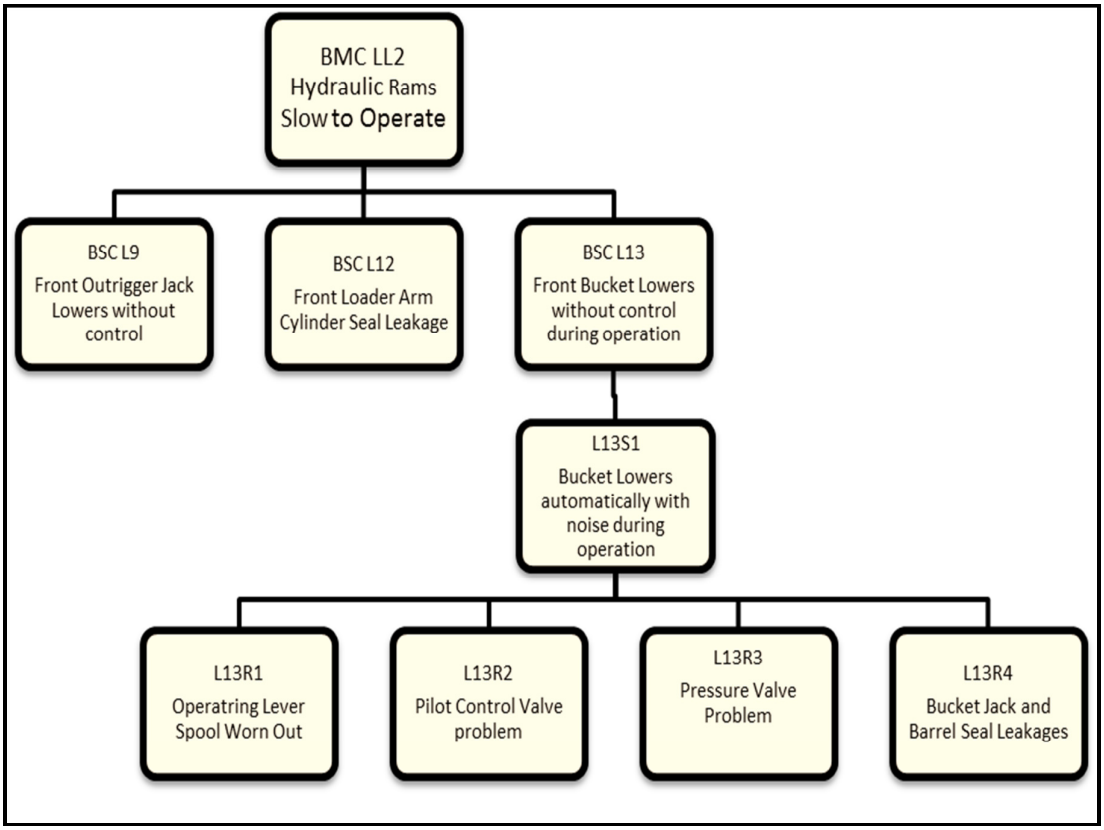

Figure 6.18 FTA Process for Hydraulic Ram Slow to Operate to Sub Code, Symptom Code and Reason Code

Similar analysis is performed to arrive at all the BSyC and BRC which are related to the critical BMC and BSC.

The above sections have detailed the identification of failure causes as breakdown codes in a systematic manner. The tools: CEA methods, Pareto Analysis Methods, FMEA Tools, FTA Tools have been used in this process. Sharma, R. K., et al. (2007) have used these techniques of RCA and FMEA methods for failure analysis. These tools have also been used by many researchers in the field of failure analysis.

The complete process of identifying the Breakdown Codes namely BMC, BSC, B SyC and BRC are listed as a flow process in figure 6.19.

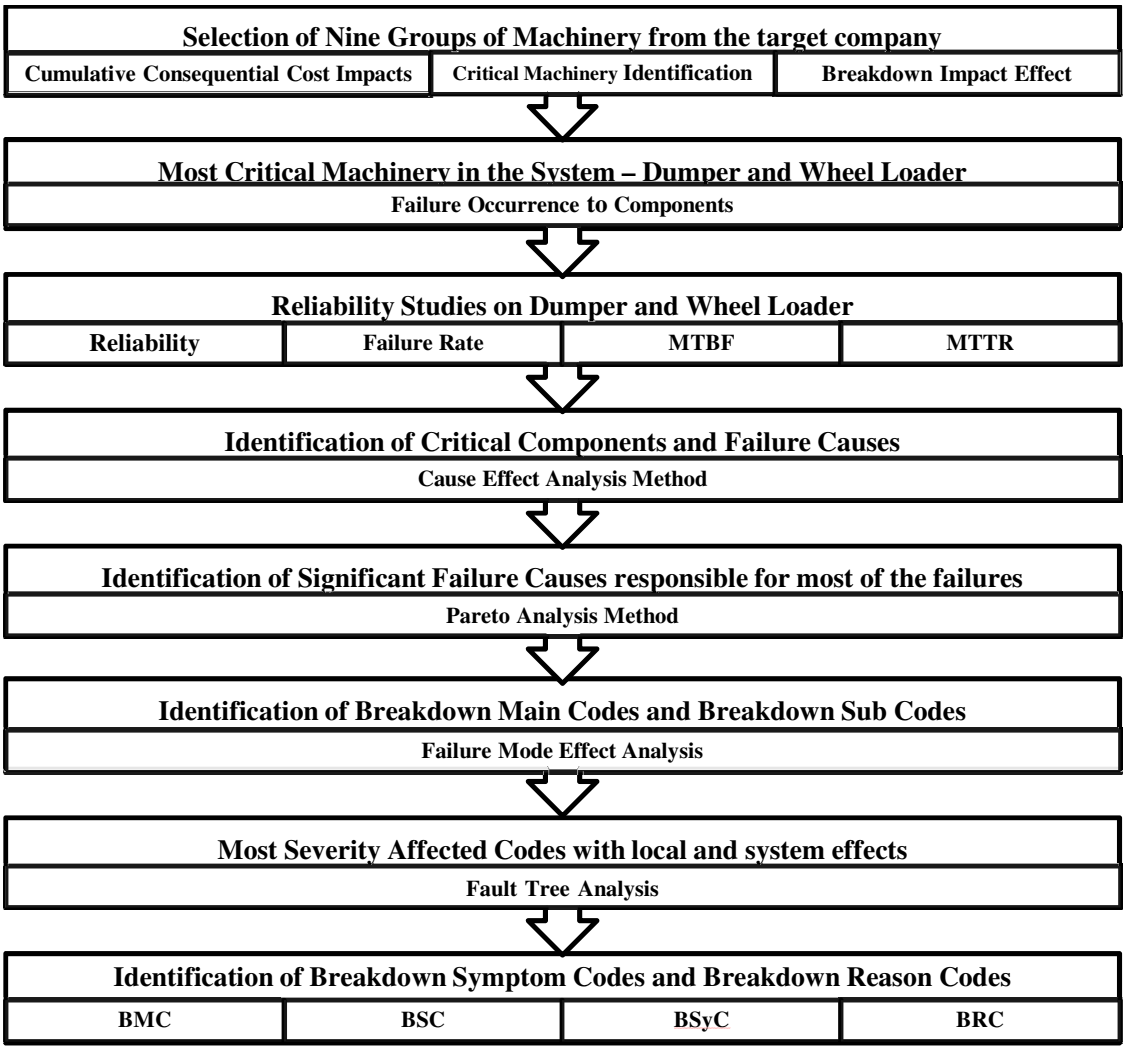

Figure 6.19 Complete Process of Identifying Breakdown Codes

6.6 Codes Listing and Summary

From the fault tree analysis tools, the various sub codes are further analyzed for the subsequent failure causes which are the reasons for the failures are analyzed. The symptoms which are prevalent prior to the any failure are listed as Breakdown Symptom Codes (BSyC) and the correct attribute or the reason of each symptom is considered as the reason code or Breakdown Reason Code and the table is listed in table 6.18 for all the components of the machinery.

Table 6.18 List of identified Breakdown Symptom Codes and Breakdown Reason Codes

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
A1	Engine overhauling work	A1S1	Knocking sound/ low oil pressure	A1R1	Cam shaft bush wear & tear
		A1S2	Oil pressure "0" level indicating on dash board	A1R2	Oil pump gear failure
		A1S3	Engine not cranking	A1R3	Push rod bent/ broken
		A1S4	Exessive sound	A1R4	Connecting rod bearing wear & tear
		A1S5	Engine over heat	A1R5	Coolant loss /execessive consumed
		A1S6	Engine oil and coolant mixed	A1R6	Engine liner crack/ o ring/seal malfunction
		A1S7	Coolant escaping from radiater/starting trouble	A1R7	Engine cylinder head gasket
		A1S8	Engine oversmoke	A1R8	Engine rings jammed/Turbo seal malfunction
		A1S9	Engine oil exessive consumed	A1R9	Engine oil exessive consumed
A2	Coolant water leak - Radiator Tank				
A3	Cooant water leak - radiator hose	A3 S1	Coolant excessive consumed	A3R1	Radiator cap / core
				A3R2	Radiator hoses leak
				A3R3	Radiator reservoir tank leak
				A3R4	Radiator hoses clip damaged
				A3R5	Water pump seal leak
		A3 S6	Coolant excessive consumed/engine over heat	A3R6	Water pump shaft
				A3R7	Engine block water dummy leak
A4	Oil seal leak - rear end; Fly wheel side	A4 S1	Oil consumed due to leakage	A4R1	Seal damamge
				A4R2	Seal seating cover wear & tear
				A4R3	Crank shaft rear end wear &tear
				A4R4	Oil filled in excess
				A4R5	Seating cover over tightened / loose
				A4R6	Seal hard due to over heating
				A4R7	Cransk shaft sleeve wear & tear
A5	Temperature increased	A5 S1	Temparature point indicating of dash board	A5R1	Spring/washer failure
		A5S2	Engine overheated but radiator not heated		
		A5S3	Temparature suddenly raised		
A6	Engine cylinder head gasket malfunction	A6S1	Engine starting trouble/over cranking	A6R1	Engine cylinder head gasket cut
		A6S2	Engine over smoke/fuel improper combustion	A6R2	Engine cylinder head gasket cut/bolt cut
		A6S3	Engine oil amd Warter mixing	A6R3	Engine cylinder Head and gasket crack
		A6S4	Engine not raising speed	A6R4	Engine cylinder head gasket cut and head facing problem
				A6R5	Engine head bolt cut
		A6S6	Engine over heated	A6R6	Engine head gasket malfunction

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
A7	Radiator service	A7S1	Engine coolant boiling water escaped from radi	A7R1	Radiator choked/ core blocked
		A7S2	Coolant excessive consumed daily	A7R2	Radiator top /bottom tank leak
				A7R3	Radiator core damaged
		A7S4	Engine overheated	A7R4	Radiator core fins blocked
A8	Oil pump leak	A8S1	Engine low oil pressure light indicating on fault display board/pressure meter indicating on red mark	A8R1	Gasket malfunction
				A8R2	O ring cut
				A8R3	Shaft cut/ wear & tear
				A8R4	Gear wear & tear
				A8R5	Pump strainer pipe crack
A9	Engine mounting front - Right	A9S1	Engine vibration	A9R1	Engine mounting bolt cut
				A9R2	Rubber Damaged
A10	Engine mounting front - Left	A10S1	Engine vibration	A10R1	Engine mounting rubber cracked
				A10R2	Engine mounting rubber bolt cut
A12	Engine Mounting Rear - L1				
A16	Oil leak - cover packing	A16S1	Engine oil excessive consumed	A16R1	Packing damage
				A16R2	Sump cover bolt loose
				A16R3	Oil seal damaged
A17	Water leak - water pump change	A16S4	Engine coolant excessive consumed / leak	A17R1	Other seals damaged
				A17R2	Water pump shaft
				A17R3	Bearing
				A17R4	Packing
				A17R5	Seating malfunction
				A17R6	Mounting Bolt malfunction
				A17R7	Mounting Bolt loose
A18	Oil leak - filter body				
A19	Engine fan belt cut	A19S1	Temparature suddenly raised	A19R1	Alternator bearing seized
		A19S2	Temparature red mark indicating on meter	A19R2	Radiator cover broken
		A19S3	Amps meter not worked on dash board	A19R3	Water pump bearing seized
		A19S4	Battery symbol light display on dash board	A19R4	Fan clutch not working
A24	Engine overheat / radiator leak / engine seizure	A24S1	Coolant excessive consumed / heat	A24R1	Thickness of copper coating reduced

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
A26	Oil leak - time cover seal or crank seal				
A27	Water leak rail pipe bolt cut / repair	A27S1	Coolant excessive consumed / heat	A27R1	Coolant pipe cut
				A27R2	Pipe sealant compound
				A27R3	Pipe crack
A28	Water leak / pump gasket	A28S1	Coolant excessive consumed / heat	A28R1	Gasket malfunction
				A28R2	Seal malfunction
				A28R3	Bearing seized
A30	Air relief valve malfunction - compressor	A30S1	Required output pressure not come	A30R1	Separator chocked
				A30R2	valve spring broken
				A30R3	Valve seal damaged
A31	Oil leak cooler body	A31S1	Engine oil excessive consumed	A31R1	Engine oil filter body 'O' ring damaged
				A31R4	Filter body seating not proper
				A31R5	Bolt washer damaged
		A31S2	Engine oil excessive consumed / pressure low	A31R2	Filter body O ring become hard
				A31R3	Filter body mounting bolt loose
A32	Oil leakages				
A33	Compressor separator choked and relief valve leak	A33S1	Compressor air and oil mixed	A33R1	Valve spring damaged
		A33S2	Output pressure low	A33R2	Valve seal and 'o'ring damaged
A34	Engine - compressor coupling broken	A34 S1	Engine running but compressed air not delivere	A34R1	To check engine mounting
		A34 S2	Compressor unit not functioning	A34R2	To check compressor mounting
				A34R3	Compressor housing bolt
A35	Accelerator cable Cut				
A36	Engine RPM raised suddently				
A37	Oil pump malfunction	A37S1	Engine oil low pressure indicating on board	A37R1	Gasket malfunction
		A37S2	Excessive noise coming from pump / pressure l	A37R2	Gear malfunction
		A37S3	Engine oil low pressure indicating on board / exceessive consumed	A37R3	Shaft cotter pin malfunction
		A37S4	Excessive oil consumed	A37R4	Leakage
A38	Engine oil - coolant oil mixing	A38S1	Radiator coolant color changed / low oil pressu	A38R1	Oil cooler O ring damaged
				A38R2	Oil cooler core damaged
		A38S3	Engine oil color changed / level increased	A38R3	Water pump seal damaged
				A38R4	Engine liner o ring damaged
		A38S5	Radiator coolant color changed / starting troubl	A38R5	Engine cylinder head gasket malfunction
		A38S6	Engine oil color changed / starting trouble	A38R6	Engine cylinder head crack

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
A39	Fan radiator pully lock broken	A39S1	Excessive sound developed in engine side / ove	A39R1	Lock broken
		A39S2	Excessive sound developed in engine	A39R2	Lock wear &tear
A40	Engine stops during running				
A41	Engine over cranking - Low alternator display				
A42	Fan leaf broken - radiator	A42S1	Suddenly getting noise	A42R1	Alternator bearing seized
				A42R2	Radiator cover broken
		A42S3	Belt cut - overheated	A42R3	Water pump bearing seized
		A42S4	Engine overheated on full speed	A42R4	Fan clutch not working
		A42S5	Excessive noise	A42R5	Fan bolt malfunction
		A42S6	Belt cut - overheated	A42R6	Belt over tight
A43	Engine overheat	A43S1	Coolant excessive consumed	A43R1	Radiator core leakage
				A43R2	Radiator hoses leakage
				A43R4	Radiator top / bottom tank leakage
		A43S3	Coolant excessive consumed / heat developed	A43R3	Radiator choked
		A43S6	Engine suddenly getting overheated	A43R5	Fan belt cut
		A43S7	Temperature meter indicating red mark / but coolant normal temperature	A43R6	Temperature switch malfunction / sensor
		A43S8	Engine overheated immediately	A43R7	Thermostat not functioning
		A43S9	Coolant excessive consumed / heated	A43R8	Water pump leak
A44	Radiator fan pully broken seized / fan belt cut	A44S1	Abnormal noise coming from engine side	A44R1	Bearing seized
				A44R2	Pulley wedge damaged
A45	Engine oil / fuel mixing	A45S1	Exhaust color changed (white smoke)	A45R1	Injector sealing washer malfunction
				A45R2	Injector barrel/plunger malfunction
		A45S3	Engine oil level increased / oil viscosity dropped	A45R3	Fuel pump hard malfunction
				A45R4	Fuel return line malfunction
		A45S5	Exhause color changed (white smoke) / level in	A45R5	Fuel pump malfunction
A46	Oil separator hose cut - compressor unit				
A49	Engine noise				
A50	Engine low oil pressure - sensors / switch / meter / oil	A50S1	Engine stopped intermittent due to low oil pressure - Display on board	A50R1	Oil pressure sensor switch short circuit
		A50S2	Engine not started	A50R2	cam shaft sensor terminal short circuit
		A50S3	Engine not started / suddenly stopped while run	A50R3	sensor switch - fused
		A50S4	Engine Pressure indicated as low	A50R4	oil pressure meter malfunction
		A50S5	Engine stops with vibrationh	A50R5	oil pressure meter line blocked
A51	Engine oil and water mixing / liner ó' ring cut				
A53	Engine low oil pressure	A53S1	Low oil pressure light indicated / showing mete	A53R1	cam shaft bush wear & tear
		A53S2	Low oil pressure light indicated / showing meter / noise developed	A53R2	Connecting rod bush wear & tear
A54	Engine RPM not raised due to cam shaft sensor malfunction				
A55	Accelerator spring cut				
A59	Radiator choke				

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
B1	Fuel pump malfunction	B1S1	Starting trouble /over cranking	B1R1	Cam shaft broken
		B1S2	engine not getting speed / White smoke	B1R2	Delivery valve and plunger barrel
		B1S3	Starting trouble /over cranking	B1R3	Governer malfunction
		B1S4	Abnormal sound	B1R4	Timer malfunction
		B1S5	Starting trouble /over cranking	B1R5	Fuel and water mixing due to improper fuel used
		B1S6	Engine not getting speed / sound variation	B1R6	Accelator rack broken
		B1S7	Pump seized / Starting trouble	B1R7	Oil lubrication line blocked
B2	Injector malfunction				
B7	Fuel inlet pipe leak				
B9	Engine starting trouble - hand primer troubles				
B15	Engine overheated and trips automatically				
B16	Engine not cranking				
B17	Engine over cranking - fuel feed pump malfunction				
B18	Low alternator malfunctions				
B20	Fuel lift pump not functioning				
C1	Gear Box abnormal noise during gear change				
C2	Cable cut during gear shifting				
C3	Gear box major overhauling				
C7	Gear engagement problems				
C10	Oil leak - torque cover seal				
C14	Gear box noisy				
C17	Oil leakages				
C18	Chain cut / roller	C18S1	Machine will not move	C18R1	Drum bearing seized
				C18R2	Chain tensioner wear and tear
				C18R3	Chain cover packing damaged / sand deposited with lubricant
				C18R4	Roller drive spracket cotter pin play
				C18R5	Hydraulic motor pump shaft cut
				C18R6	Roller drive sprocket teeth damaged
C19	Gear / Engine issues				
C20	Gear belt tensioner broken / roller compactor	C20S1	Machine will not move	C20R1	Tensioner mounting bolt cut
				C20R2	Tensioner cut
C22	Reverse gear not engaged / Relay switch				
C23	Roller bearing damages				
C24	Movement faults / chain roller stuck	C24S1	Machine will not move	C24R1	Bearing malfunction

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
D5	Clutch plate worn out	D5S1	Gear not enage / not moving	D5R1	Over load
		D5S2	Gear operation hard	D5R2	Recless operation
		D5S3	Machine not moving but gear engaged	D5R3	Release bearing jammed
D6	Clutch Parts (Clutch Plate / Pressure Plate / Pressure Bearing / Release Bearing / Fork / Pilot Bearing)	D6S1	Not getting pickup speed	D6R1	Over load operation
		D6S2	Not moving with any gear	D6R2	Continuously using clutch while operation & driving
				D6R3	Wrong operation
D8	Clutch release bearing noise				
D12	Flywheel ring damage	D12S1	Starting trouble / gear slippery sound	D12R1	Selfstarter bentex teeth damaged
				D12R2	Selfstarter bentex not released
D16	Oil leakages - hoses				
D17	Oil leakages - pipe damages				
D18	Propellor shaft bearing centre malfunction	D18S1	Girinding noise developped while driving	D18R1	Shaft yoke play
				D18R2	Lubrication not applied at proper intervals
D19	Propellor shaft bearing rear malfunction				
D20	Propellor shaft bearing front malfunction				
D21	Differential sound	D21S1	Humming noise developped	D21R1	Oil lost due to seal damage/bearing seizure
		D21S2	Grinding noise	D21R2	Sun/star gear malfunction
		D21S3	Excessive sound while vehicle movung	D21R3	Pinion play high - due to wear and tear
		D21S4	Excessive sound while brake apply	D21R4	Disc brake wear and tear
D22	Differential pinon oil seal leak	D22S1	Exessive oil consumed	D22R1	Breather choke
D24	Clutch slave cylinder bracket damages				
D25	Clutch pedal air valve leak				
D26	Reverse moving malfunction	D26S1	Gear not engaging	D26R1	Solenoid switch
				D26R2	Relay
				D26R3	Fuse
		D26S4	Excessive noise during reverse movement	D26R4	Reverse gear slip
		D26S5	Forward / reverse movement issues	D26R5	Reverse unit malfunction
D27	Differential casing broken				
E2	Brake booster leakages				
E3	Brake master cylinder leakages				
E4	Brake pedal spring cut				
E5	Parking brake cable cut				
E7	Front wheel rear brake low lining				

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
E13	Brake oil leak				
E14	Air leakages				
E16	Brake wheel cylinder leakages				
E20	Brake switch not functioning				
E26	Parking brake cable cut				
E28	Brake valve not functioning				
G1	Tyre puncture - front right				
G2	Tyre puncture - front left				
G3	Tyre puncture - rear inner RHS				
G4	Tyre puncture - rear outer LHS				
G5	Tyre puncture - rear inner RHS				
G6	Tyre puncture - rear outer RHS				
G18	Wheel hub oil seal - rear inner leak				
G29	Tyre burst				
H12	Steering hard	H12S1	Steering hard with exessive sound	H12R1	Hydraulic oil level low
		H12S2	Steering locked	H12R2	Pump failure
		H12S3	Steering hard with exessive sound (left & right	H12R3	Steering jack seal leak
H13	Steering pump malfunction - wheel turning area not covered				
H14	Steering cylinder oil leakages				
H15	Steering universal / bush worn out				
I10	Wheel wobbling				
I16	Rear Axle broken				
J1	Starting trouble	J1S1	Starting trouble/ Light indicating on dash board	J1R1	Regulater/rectifier short circuit due to bearing seizure
J2	Self starter malfunction	J2S1	Starting trouble	J2R1	Solenoid failure (bentex not released)
				J2R2	Ignition key stuck
J3	Starting troubles				
J4	Starting trouble - solenoid swtich	J4S1	Engine crank but will not start	J4R1	Solenoid heated due to engine over cranking
J5	Steering column switch broken				
J6	Battery discharged				
J8	Head light not working	J8S1	Bulb fused	J8R1	Switch malfunction
				J8R2	Fused
				J8R3	Mounting clamp loose
J9	Engine not stopping - solenoid switch assembly				
J10	Engine not starting				
J13	Alternator malfunction				

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
J14	Alternator malfunction	J14S1	Alternater not charged	J14R1	Alternater armature over heated due to rectifier failure
J15	Alternator malfunction				
J16	Voltage dropped - Auto Voltage Regulator				
J17	Low alternator displayed on AVR board				
J18	Voltage fluctuations				
J19	Sensor Control board malfuction				
J20	Voltage droppage	J20S1	Exessive sound / vibration	J20R1	Rotar bearing
				J20R2	Rotar balance improper
				J20R3	Alternater mounting broken
J21	Actuator malfunctions				
J22	Pressure Turn Over PTO Switch not working				
J23	Starting trouble / emergency switch not released				
J24	Reverse and forward movement issues				
J25	Reverse not working - reverse switch / loose contact	J25S1	Reverse gear not engaging / reverse not movin	J25R1	Switch short circuited (loose contact / water deposit)
				J25R2	Solenoid malfunction
				J25R3	Relay short circuited due to water deposited
J26	Solenoid wire loose contacts				
J27	Low voltage issues				
J28	Low alternator issues				
J29	Genset bearing noise / voltage fluctuation				
J31	Self starter malfunction	J31S1	Engine cranks but starting trouble	J31R1	Rear and front armature bush
				J31R2	Water inside due to Insulation rubber damage
		J31S3	Engine cranks but will not start /Noisy	J31R3	Ignition switch stuck
				J31R4	Compressed air not released before starting
J32	Starting trouble - timing relay				
J33	ON OFF Switch malfunction				
J34	Engine overcranking - doesn't start				
J35	Starting trouble - shut down module malfunction				
J36	AC Fan motor not functioning				
J37	Telys board malfunction				
J38	Fuse box broken				
J39	Reel guard / switch not working				
J40	Panel board main breaker defective				
K4	Exhaust leakages				
K7	Airconditioning systems not working				

BSC	Breakdown sub code details	BSyC	Breakdown symptom code details	BRC	Breakdown reason code details
K8	Exhaust leakages				
L1	Hydraulic Pump malfunctions				
L2	Hydraulic hose cut	L2S1	Exessive oil consumed / oil dropped	L2R1	Wrong operation and working place
				L2R2	Hose getting hard
				L2R3	Over load operation
L3	Oil leakages - hydraulic control valve				
L4	Oil leak - telescopic cylinder seal - scoring	L4S1	Telescopic jack autimaticaly downed while operaton and idle	L4R1	Oil seal damaged
				L4R2	Cylinder tube scoring / one side load operation
				L4R3	Telescopic return valve not working
				L4R4	Hydraulic oil change poor condition
L5	Control valve not working	L5S1	Hydraulic function failure	L5R1	Hydraulic oil pump not funtioning
L6	Rear jack oil leak	L6S1	Exessive oil consumed	L6R1	Oil seal (pressure seal)
				L6R2	Gland nut 'o' ring thread damaged
L7	Hydraulic steering pump Left/Right rotation hard	L7S1	Steering hard while right & left turn	L7R1	King pin kit seized
				L7R2	Jack cylinder seal / oil leak
				L7R3	Pump not funtioning (piston damaged)
L8	Hydraulic winch oil leakages				
L9	Front outrigger jack LH lowers automatically				
L11	Rear back hoe cylinder union broken	L11S1	Back hoe vibration while operation	L11R1	Bracket bolt lose / cotter pin cut
				L11R2	Bracket cut due to over load
L12	Front loader arm cylinder seal leak				
L13	Front bucket lowers down during operation	L13S1	Bucket automaticaly downed with sound while operation	L13R1	Operater lever spool
				L13R2	Pilot control valve
				L13R3	Pressure valve
				L13R4	Bucket jack seal kit / barrel
L14	Oil leakages - Hydraulic tank level tube broken				
L15	Swing motor brake malfunction				
L16	Swing rotor oil leakages	L16S1	Hyd oil exessive consumed	L16R1	Rotar seal
				L16R2	Hydraulic oil tank breather valve malfunction
L18	Boom inner cylinder hose leak				
L20	Hydraulic oil temperature increased				
L21	Oil leak / filter body				

In this chapter the systematic identification of breakdown failure codes namely Breakdown Main Code (BMC), Breakdown Sub Code (BSC), Breakdown Symptom Code (BSyC) and Breakdown Reason Code (BRC) have been done. The techniques used for this identification include various flow process tools, Cause Effect Analysis diagrams, Pareto Analysis, FMEA Tools and Fault Tree Analysis diagrams.

6.7 Evolving the Breakdown Maintenance Protocol (BMP)

6.7.1 Introduction

An effective system and tool which will keep the breakdown maintenance crew unambiguous and focused on the repair strategy is always essential for the construction plant, particularly in the United Arab Emirates where lots of construction is taking place. The systematic approach developed here is in line with the medical protocols, wherein a patient who has suffered with any breakdown of illness is attended by the paramedics and doctors with a very systematic approach which in other words is the Standard Operating Procedures (SOP) for any kind of human breakdowns.

6.7.2 Concept of Protocol

The different languages being used by people to communicate in the world, the different types of body languages they use, different types of understanding people have, the number of different machines they use, the number of ways in which they transmit data and the different software they use – all indicate one information to us, we would never be able to communicate worldwide if there were no 'standards' governing the way we communicate and the way our machines treat data. These standards are sets of rules.

There are rules governing how data can be transferred over networks, how they are compressed, how they are presented on the screen, how they can be understood and interpreted and so on. These set of rules are called protocols. It is often a known fact that people generally tend to work more competently if they have a step-by-step procedure/guidance. To meet this requirement of standardization, protocols are everywhere around us and are being developed constantly (Brakel J.W., 2005). There are many protocols, each one governing the way a certain technology works. For example, the Internet Protocol (IP) defines a set of rules governing the way computers use IP packets to send data over the Internet or any other IP-based network. It also defines addressing in IP. Likewise, we have other protocols:

- TCP: Transmission Control Protocol, used for the reliable transmission of data over a network.
- HTTP: Hypertext Transfer Protocol, used for transmitting and displaying information in the form of web pages on browsers.

- FTP: File Transfer Protocol, used for file transfer (uploading and downloading) over the Internet / SMTP: Simple Mail Transfer Protocol, used for email / Wi-Fi.
- Security Protocol

6.7.2.1 Medical/Patient Protocol

Most of protocols are originated with medical fields. A medical protocol is a series of steps (System of Procedures) followed by one or more medical professionals in a medical setting. A paramedic protocol is a type of standard operating procedure (SOP) which refers specifically to treatment of patients. A patient protocol deals specifically with patient care. In each medical specialty, experts can recommend the steps to be followed for a certain procedure or process, such as providing a clinical medical treatment. Other practitioners can duplicate those steps as effective practice of medicine.

The protocol consists of an evaluation (or diagnosis) part and a treatment part, to be performed in sequence (Frank van Harmelen et al, 2001). Protocols will govern all paramedics or other Emergency Medical Technicians (EMT) operating in a specific area regardless of which ambulance company or other health care provider employs them. Ambulance companies also have SOPs that govern their day-to-day functions, such as housekeeping or vehicle maintenance. Protocols help set standards of care and help paramedics make critical decisions in the field. Protocols also serve to ensure quality patient care.

6.7.2.2 Functioning of Medical Protocols

In the medical field, medics and paramedics work 25% more efficiently if a protocol indicates their function as to what to do, when to do and what is expected from them (P Clayton et al, 1995). The preliminary requirement for assessing critically a human- system based on the medical protocols is its ability to match the actions a physician performs in practice to the actions prescribed in a protocol (Robert et al, 2006). All Emergency Medical Services (EMS) protocols are developed based on the latest medical knowledge and best practices in the medical field. Some examples of protocols include what drugs paramedics are allowed to administer and under what conditions. A sample Medical Protocol during Human Blood or Body Fluid Exposure is displayed in Figure 6.20. (Source: University of Alberta, Canada)

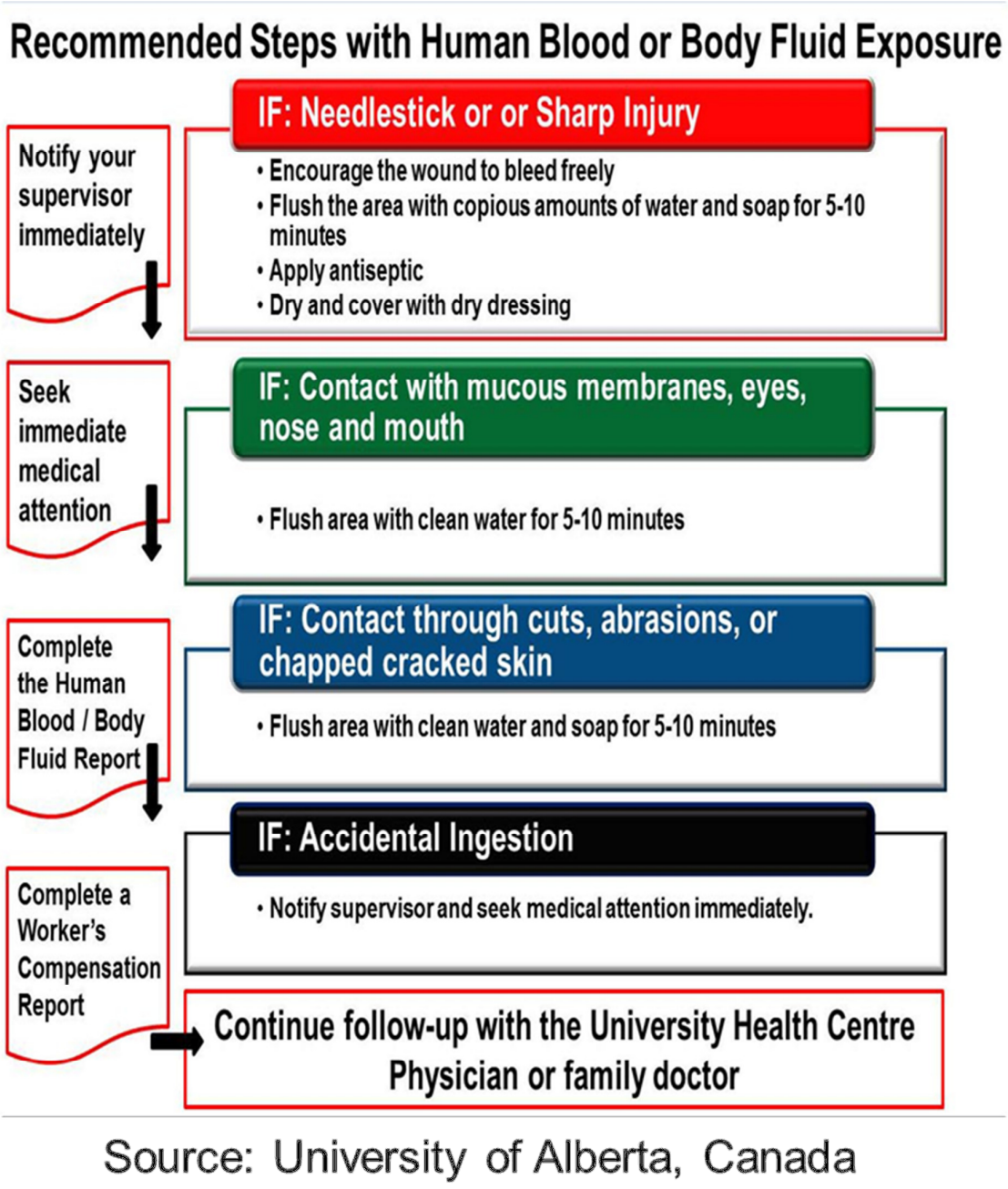

Figure 6.20 Medical Protocols - Flow Process

Protocols also help determine in what situations a paramedic may call for aero medical evacuation. Protocols cannot possibly resolve every situation. Often paramedics rely on what is known as "online medical direction." In certain situations, for example the administration of certain drugs, a paramedic must contact Medical Command (MEDCOM) for orders. The paramedic describes the patient's condition to the medical director, who is usually a licensed

physician, and based on the information, the physician directs the paramedic on what actions to take (Brady Emergency Care, 7th Ed).

6.7.3 Construction Machinery - Breakdown Maintenance Protocol (BMP)

As mentioned in the earlier sections, if a patient is under an emergency condition or broken down due to an illness, the first aid provider arrives at the spot and does the initial paramedical arrangements and informs the medical crew as per the patient protocol. Upon receiving the information either from the patient/patient's attendees/first aid provider, the hospital immediately prepares requisite specialist doctors, paramedical staff, medicines, theatres, anaesthetists, special instruments, blood, oxygen etc. so that upon arrival of the patient there is no ambiguity/waiting period and the immediate required predetermined treatment in response to the identified problem is executed.

We intend to use the similar principles in formulating a tool called 'Breakdown Maintenance Management Protocol' (BMP) which will keep the entire maintenance crew ready with the required resources including spare parts, work-front/space, technicians/crew, and all other essential items. With the BMP in place, a broken down plant, either at site or at the repair yard, when subjected to a breakdown/breakdown complaint, gets focused and immediate attention upon its inspection at site and arrival to the site/workshop, wherein a system of predetermined activities and procedures related to the particular type of breakdown are performed and the effective execution of breakdown maintenance process is ensured.

6.7.4 Functioning of BMP

Whenever any breakdown occurs at the construction project site or at factories, the maintenance crew will get a call from the user/operator/site. Upon analyzing the given breakdown information, the Breakdown maintenance Mechanic/Team checks the broader area of the breakdown as to which system is basically at fault and relate it to the main code of the breakdown (BMC) to which it aptly fits which will be generic. Further it is checked with the many available Breakdown sub codes (BSC) which are associated and related with the BMC and get the lead information on the specific area of the breakdown. It is further analyzed for the symptom codes (BSyC) which are the basic symptoms which existed during/on account of these breakdowns, and it will reveal the crew to the further closer reasoning of the problem from the system of symptom codes and get closer to the correct reason codes (BRC) which has attributed the breakdown. Each BRC is associated exactly

with a BMP which is the Breakdown Maintenance Protocol for every Breakdown Reason Code. The BMP provides required information and the focused attention/actions required for executing the particular breakdown effectively.

The BMP triggers all the crew who are at site and those at the central workshop 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. It will also indicate the time management/duration of works, skill levels of technicians, outsourcing requirements, material handling devices required etc.

This entire breakdown rectification process of combining the identification and diagnosing of the problem, relation study with the available breakdown codes, selecting the right BMP and effective utilization of the same to complete the breakdown process is termed as Breakdown Maintenance Management (BMM).

6.7.5 Structure of the BMP Ruler

The reliability and availability of a repairable system prominently involves detailed study on the maintenance issues pertaining to that system. The right kind of maintenance scheduling of all the machinery in the system can keep up high availability of the repairable systems, as well avoiding the damage of failure and reduces the wastages on cost (Zhang et al, 2002). The construction of BMP is to be made considering that this tool will be utilized even by the site mechanics whose education levels are purely to their experience levels pertaining to the limited number of machinery's they deal with. At the same time this tool will be used by the mechanical supervisors also for preparing the resource requirements and some time for getting the exact codes and the relative BMP's for the breakdowns/problems which are not attended by the site mechanics but only a reference is given as feedback from the end users/operatives of the machinery.

6.7.5.1 Input Parameters

The input parameters for the BMP Ruler are the various breakdown codes namely:

a) Breakdown Main Code

b) Breakdown Sub Code

c) Breakdown Symptom Code

d) Breakdown Reason Code

Further the ruler works with a set of BMP nos. which indicate the exact Protocol required with reference to specific Breakdown Reason Codes.

For the initial usage of BMP Ruler, the Codes Relations Chart, which will allow the user to familiarize with various levels of codes and their relationships with other levels of codes are used is listed in table 6.19.

Lists of Breakdown codes, which denote the exact phrase relationship of code with reference to various components and systems, are listed in tables 6.20, 6.21, 6.22, 6.23 and 6.24. The user after consistent usage of these facilities will get familiarized with the BMP Ruler.

6.7.5.2 Table of Breakdown Codes and Relation Chart

Table 6.19 Codes Relations Chart to be used with the BMP Ruler

BMC		BSC		BSyC		BRC		BMC		BSC		BSyC		BRC		BMC		BSC		BSyC		BRC	
1	AA1	1	A6	1	A6S1	1	A6R1	3	AA3	3	A7	29	A7S1	29	A7R1	5	AA5	5	A4	62	A4 S1	62	A4R1
				2	A6S2	2	A6R2					30	A7S2	30	A7R2							62	A4R2
				3	A6S3	3	A6R3							30	A7R3							62	A4R3
				4	A6S4	4	A6R4					31	A7S4	31	A7R4							62	A4R4
						4	A6R5			3	A27	32	A27S1	32	A27R1							62	A4R5
				5	A6S6	5	A6R6							32	A27R2							62	A4R6
2	AA2	2	A5	6	A5 S1	6	A5R1							32	A27R3							62	A4R7
				6	A5 S2					3	A28	33	A28S1	33	A28R1			5	A16	63	A16S1	63	A16R1
				6	A5 S3									33	A28R2							63	A16R2
		2	A17	7	A17S4	7	A17R1							33	A28R3							63	A16R3
						7	A17R2			3	A37	34	A37S1	34	A37R1			5	A18				
						7	A17R3					35	A37S2	35	A37R2			5	A26				
						7	A17R4					36	A37S3	36	A37R3			5	A31	64	A31S1	64	A31R1
						7	A17R5					37	A37S4	37	A37R4							64	A31R4
						7	A17R6	4	AA4	4	A1	38	A1 S1	38	A1R1							64	A31R5
						7	A17R7					39	A1 S2	39	A1R2					65	A31S2	65	A31R2
		2	A19	8	A19S1	8	A19R1					40	A1 S3	40	A1R3							65	A31R3
				9	A19S2	9	A19R2					41	A1 S4	41	A1R4			5	A32				
				10	A19S3	10	A19R3			4		42	A1 S5	42	A1R5			5	A46				
				11	A19S4	11	A19R4					43	A1 S6	43	A1R6	6	AA6	6	A9	66	A9S1	66	A9R1
		2	A24	12	A24S1	12	A24R1					44	A1 S7	44	A1R7							66	A9R2
		2	A39	13	A39S1	13	A39R1					45	A1 S8	45	A1R8			6	A10	67	A10S1	67	A10R1
				14	A39S2	14	A39R2					46	A1 S9	46	A1R9							67	A10R2
		2	A42	15	A42S1	15	A42R1			4	A8	47	A8S1	47	A8R1			6	A12				
						15	A42R2							47	A8R2	7	AA7	7	A33	68	A33S1	68	A33R1
				16	A42S3	16	A42R3			4				47	A8R3					69	A33S2	69	A33R2
				17	A42S4	17	A42R4							47	A8R4	8	AA8	8	A30	70	A30S1	70	A30R1
				18	A42S5	18	A42R5							47	A8R5							70	A30R2
				19	A42S6	19	A42R6			4	A38	48	A38S1	48	A38R1							70	A30R3
		2	A43	20	A43S1	20	A43R1							48	A38R2			8	A35				
						20	A43R2	4	AA4			49	A38S3	49	A38R3			8	A36				
						20	A43R4							49	A38R4			8	A40				
				21	A43S3	21	A43R3					50	A38S5	50	A38R5			8	A54				
				22	A43S6	22	A43R5					51	A38S6	51	A38R6			8	A55				
				23	A43S7	23	A43R6			4	A45	52	A45S1	52	A45R1	9	AA9		-				
				24	A43S8	24	A43R7							52	A45R2	10	AA10	10	A41				
				25	A43S9	25	A43R8					53	A45S3	53	A45R3	11	AA11	11	A34	71	A34S1	71	A34R1
		2	A44	26	A44S1	26	A44R1							53	A45R4					72	A34S2	72	A34R2
						26	A44R2					54	A45S5	54	A45R5							72	A34R3
		2	A59							4	A50	55	A50S1	55	A50R1			11	A49				
3	AA3	3	A2									56	A50S2	56	A50R2	12	AA12		-				
		3	A3	27	A3 S1	27	A3R1					57	A50S3	57	A50R3								
						27	A3R2					58	A50S4	58	A50R4								
						27	A3R3					59	A50S5	59	A50R5								
						27	A3R4			4	A51												
						27	A3R5			4	A53	60	A53S1	60	A53R1								
				28	A3S6	28	A3R6					61	A53S2	61	A53R2								
						28	A3R7																

BMC		BSC		BSyC		BRC		BMC		BSC		BSyC		BRC		BMC		BSC		BSyC		BRC	
13	BB1	13	B1	73	B1S1	73	B1R1	34	DD1	34	D5	83	D5S1	83	D5R1	60	EE16	60	E2				
				74	B1S2	74	B1R2					84	D5S2	84	D5R2			60	E3				
				75	B1S3	75	B1R3					85	D5S3	85	D5R3	61	EE17	61	E4				
				76	B1S4	76	B1R4			34	D6	86	D6S1	86	D6A1			61	E28				
				77	B1S5	77	B1R5					87	D6S2	87	D6A2	62	FF1		-				
				78	B1S6	78	B1R6							87	D6A3	63	FF2		-				
				79	B1S7	79	B1R7	35	DD2	35	D24					64	FF3		-				
		13	B15							35	D25					65	GG1		-				
14	BB2	14	B1					36	DD3	36	D8					66	GG2		-				
15	BB3	15	B1					37	DD4	37	D18	88	D18S1	88	D18R1	67	GG3	67	G6				
		15	B9											88	D18R2	68	GG4		-				
		15	B20							37	D19					69	GG5	69	G29				
16	BB4	16	B1							37	D20					70	GG6	70	G18				
		16	B16					38	DD6							71	GG7	71	G1				
		16	B17					39	DD7									71	G2				
17	BB5	17	B2					40	DD8	40	D16							71	G3				
		17	B18							40	D17							71	G4				
18	BB6	18	B2					41	DD9	41	D12	89	D12S1	89	D12R1			71	G5				
19	BB7	19	B1											89	D12R2			71	G6				
		19	B2					42	DD10	42	D21	90	D21S1	90	D21R1	72	GG8		-				
20	BB8	20	B1									91	D21S2	91	D21R2	73	HH1	73	H15				
		20	B2									92	D21S3	92	D21R3	74	HH2	74	H12	98	H12S1	98	H12R1
21	BB9	21	B1									93	D21S4	93	D21R4						H12S2	98	H12R2
		21	B2							42	D27										H12S3	98	H12R3
		21	B7					43	DD11	43	D22	94	D22S1	94	D22R1	75	HH3		-				
22	CC1	22	C1					44	DD12	44	D26	95	D26S1	95	D26R1	76	HH4		-				
		22	C3											95	D26R2	77	HH5	77	H13				
23	CC2	23	C14											95	D26R3	78	HH6		-				
		23	C20	80	C20S1	80	C20R1					96	D26S4	96	D26R4	79	HH7		-				
						80	C20R2					97	D26S5	97	D26R5	80	HH8		-				
		23	C22					45	EE1	45	E5					81	HH9	81	H14				
24	CC3		-							45	E7					82	HH10		-				
25	CC4	25	C2							45	E8					83	II1		-				
26	CC5		-							45	E20					84	II2	84	I10				
27	CC6	27	C7							45	E26					85	II3		-				
		27	C18	81	C18S1	81	C18R1	46	EE2		-					86	II4		-				
						81	C18R2	47	EE3		-					87	II5	87	I16				
						81	C18R3	48	EE4		-					88	JJ1	88	J1	99	J1S1	99	J1R1
						81	C18R4	49	EE5	49	E13							88	J2	100	J2S1	100	J2R2
						81	C18R5	50	EE6		-											100	J2R3
						81	C18R6	51	EE7		-							88	J10				
28	CC7		-					52	EE8		-							88	J13				
29	CC8	29	C10					53	EE9		-							88	J14	101	J14S1	101	J14R1
		29	C17					54	EE10	54	E16							88	J15				
30	CC9	30	-					55	EE11		-							88	J23				
31	CC10	31	-					56	EE12	56	E14							88	J35				
32	CC11	32	C19					57	EE13		-					89	JJ2	89	J3				
		32	C23					58	EE14		-							89	J6				
33	CC12	33	C24	82	C24S1	82	C24R1	59	EE15		-							89	J32				

BMC		BSC		BSyC		BRC		BMC		BSC		BSyC		BRC		BMC		BSC		BSyC		BRC	
90	JJ3	90	J4	102	J4S1	102	J4R1	95	JJ8	95	J5					101	LL3	101					
		90	J26							95	J8	106	J8S1	106	J8R1	102	LL4	102	L5	110	L5S1	110	L5R1
		90	J31	103	J31S1	103	J31R1							106	J8R2			102	L8				
						103	J31R2							106	J8R3	103	LL5	103	L4	111	L4S1	111	L4R1
				104	J31S3	104	J31R3			95	J21											111	L4R2
						104	J31R4			95	J22											111	L4R3
		90	J34							95	J24											111	L4R4
91	JJ4	91	J19							95	J25	107	J25S1	107	J25R1			103	L6	112	L6S1	112	L6R1
		91	J33											107	J25R2							112	L6R2
		91	J37											107	J25R3	104	LL6	104	L2	113	L2S1	113	L2R1
		91	J38							95	J36											113	L2R2
		91	J40							95	J39											113	L2R3
92	JJ5	92	J9					96	KK1	96	K4							104	L14				
		92	J17							96	K8							104	L15				
		92	J27					97	KK2	97	K7							104	L16	114	L16S1	114	L16R1
93	JJ6	93	J20	105	J20S1	105	J20R1	98	KK3	98												114	L16R2
						105	J20R2	99	LL1	99	L1							104	L18				
						105	J20R3			99	L3							104	L21				
		93	J29							99	L7	108	L7S1	108	L7R1	105	LL7	105	L20				
94	JJ7	94	J16											108	L7R2	106	LL8	106	L11	115	L11S1	115	L11R1
		94	J18											108	L7R3							115	L11R2
		94	J28					100	LL2	100	L9					107	LL9						
										100	L12												
										100	L13	109	L13S1	109	L13R1								
														109	L13R2								
														109	L13R3								
														109	L13R4								

Table 6.20 Breakdown Main Code List

BMC	Breakdown Main Code Details	BMC	Breakdown Main Code Details	BMC	Breakdown Main Code Details
AA1	ENGINE MAJOR OVERHAULING	DD4	NOISE WHILE TRAVELLING	HH1	EXCESSIVE PLAY IN THE STEERSING
AA2	ENGINE OVER HEATING	DD6	TRANSMISSION RANGE NOT CONTROLLED WITH SPEED LEVER	HH2	HARD STEERING
AA3	COOLANT OIL EXCESSIVE CONSUMED	DD7	CLUTCH ENGAGE BUT MACHINE NOT MOVING	HH3	STEERING WANDERING
AA4	ENGINE LOW OIL PRESSURE	DD8	LOSS OF OIL	HH4	STEERING PULL ONE SIDE DURING DRIVING
AA5	ENGINE OIL EXCESSIVE CONSUMED	DD9	STARTING TROUBLE	HH5	STEERING VIBRATION WHILE RUNNING 90KM AND ABOVE
AA6	ENGINE VIBRATION	DD10	CROWN WHEEL NOISE	HH6	LOSS OF STEERING OIL
AA7	ENGINE KNOCKING NOISE	DD11	DIFFERENTIAL OIL LOSS	HH7	OVERHEATING OF STEERING OIL
AA8	ENGINE SPEED VARIATION	DD12	GEAR CANNOT ENGAGE 4WD/2WD/ REVERSE	HH8	STEERING PUMP PRESSURE REDUCED
AA9	IMPROPER COLOUR OF EXHAUST	EE1	BRAKE IS INEFFECTIVE	HH9	STEERING WHEEL IS SLUGGISH
AA10	ENGINE STARTING TROUBLE	EE2	BRAKE CANNOT BE RELASED	HH10	STEERING WHEEL MOVES UNSTEADLY
AA11	ENGINE NOT CRANKING WILL NOT START	EE3	WHEEL PULLING ONESIDE WHILE APPLY BRAKE	II1	SUSPENSION SYSTEM FAILURE
AA12	ENGINE CRANKING WILL NOT START	EE4	NOISES DEVELOPED WHILE APPLY BRAKE	II2	WHEEL VOBBLING
BB1	FIP, INJECTOR CALIBRATION	EE5	LOSS OF BRAKE OIL	II3	TYRE UNEVEN WEAR
BB2	ENGINE KNOCKING SOUND	EE6	BRAKE RELEASE TOO SLOWLY	II4	WHEEL PULLING ONESIDE
BB3	ENGINE CRANKS BUT DIDN'T START	EE7	BRAKES DO NOT APPLY	II5	MACHINE NOT MOVING
BB4	ENGINE HARD TO START	EE8	BRAKES DO NOT RELEASE	JJ1	STARTING TROUBLE
BB5	ENGINE SPEED VARIATION	EE9	BRAKES GRAB	JJ2	ENGINE NOT CRANCKING WILL NOT START
BB6	ENGINE VIBRATION	EE10	UNEVEN BRAKE	JJ3	ENGINE CRACKING WILL NOT START
BB7	ENGINE EMITS WHITE SMOKE	EE11	AIR PRESSURE WILL NOT BE NORMAL	JJ4	ENTIRE ELECTRICAL FUNCTIONS DOES NOT WORK
BB8	LACK OF POWER	EE12	AIR PRESSURE DROPS DURING ENGINE STOP/BRAKES RELEASE	JJ5	SPEED VARIATION (ELECTRONIC CONTROL SENSORS)
BB9	EXCESSIVE FUEL CONSUMPTION	EE13	AIR PRESSURE DROP WHEN ENGINE STOPS/BRAKES APPLIED	JJ6	EXCESSIVE NOISE DEVELOP (ENGINE / GENSET)
CC1	GRINDING NOISE WHEN CHANGING GEAR	EE14	COMPRESSOR KNOCKS CONTINUOUSLY	JJ7	VOLTAGE FLUCTUATION / DROPPED
CC2	GEAR BOX NOISING WHILE TRAVELLING	EE15	EXCESSIVE OIL OR WATER IN BRAKE SYSTEM	JJ8	ELECTRICAL PROBLEM - WIRING / CIRCUIT NOT FUNCTIONING
CC3	GEAR BOX KNOCK WHEN CLUTCHING/LOAD CHANGE	EE16	OPERATING FORCE OF BRAKE PEDAL IS TOO LIGHT	KK1	EXHAUST SYSTEM LEAK
CC4	GEAR SHIFT DIFFICULTIES	EE17	OPERATING FORCE OF BRAKE PEDAL IS TOO HEAVY	KK2	AIR CONDITIONING SYSTEM FAILURE
CC5	MACHINE DRIVES BUT LACKS POWER IN ALL GEARS	FF1	MACHINE TO DEVELOP EXCESS VIBRATION	KK3	DENTING/PAINTING WORK
CC6	MACHINE DOES NOT DRIVE IN ANY GEAR	FF2	EXCESS NOISE	LL1	LACK OF POWER IN ALL HYDRAULIC FUNCTIONS
CC7	MAXIMUM SPEED NOT ACHIEVED ON THE HIGHWAY	FF3	BODY LEVEL UNEVEN	LL2	ALL HYDRULIC RAMS SLOW TO OPERATE
CC8	EXCESSIVE OIL CONSUMPTION	GG1	WHEEL WOBBLING WHILE RUNNING ON ROAD	LL3	HYDRUALIC OIL BECOMES TOO HOT
CC9	MACHINE CAN TRAVEL WHEN PARKING BRAKE IS APPLIED	GG2	WHEEL VIBRATION WHILE RUNNING ON ROAD	LL4	SLOW OPERATING SPEED/LOW MAXIMUM STALL SPEED
CC10	AUTO SHIFT DOES NOT WORK	GG3	UN EVEN TYRE WEAR	LL5	RAM CREEP
CC11	GEAR ENGINE PROBLEM	GG4	TYRE ONE SIDE WEAR TOE IN	LL6	HYDRUALIC OIL LOSS - LEAKING SECTION - SEALS, "O" RING , KITS
CC12	GEAR CANNOT ENGAGE	GG5	TYRE ONE SIDE WEAR TOE OUT	LL7	ELECTRICAL DETERRENT WILL NOT HOLD
DD1	CLUTCH SLIPPING WHEN CLUTCH APPLY	GG6	WHEEL HUBS LUBIRICATION LEAKAGE	LL8	MECHANICAL DETERRENT WILL NOT HOLD
DD2	CLUTCH PEDAL HARD	GG7	SPEED TOO SLOWLY (TYRE AIR LOSS)	LL9	ELECTRONIC DETERRENT WILL NOT HOLD
DD3	CLUTCH JUDDERING	GG8	WHEEL EXCESSIVE NOISE WHILE BRAKING		

Table 6.21 Breakdown Sub Code List

BSC	Breakdown Sub Code Details	BSC	Breakdown Sub Code Details	BSC	Breakdown Sub Code Details
A1	ENGINE OVERHAULING WORK	C3	GEAR BOX MAJOR OVER HAULING	J4	STARTING TROUBLE SOLENOID SWITCH PROBLEM
A2	COOL WATER LEAK - RADIATOR TOR TANK	C7	GEAR ENGAUGE PROBLEM	J5	STEERING COLUMN SWITCH BROKEN
A3	COOL WATER LEAK - RADIATOR HOSE	C10	OIL LEAK TOP COVER SEAL	J6	BATTERY NOT RECHARGED
A4	OIL SEAL LEAK - REAR END - FLY WHEEL SIDE	C14	GEAR BOX SOUND	J8	HEAD LIGHT NOT WORKING
A5	TEMPERATURE INCREASED	C17	OIL LEAK	J9	ENGINE NOT STOPPED SOLENOID SWITCH ASSY
A6	ENGINE CYLINDER HEAD GASKET PROBLEM	C18	CHAIN CUT / ROLLER	J10	ENGINE NOT STARTED
A7	RADIATOR SERVICE	C19	GEAR ENGINE PROBLEM	J13	ALTERNATOR PROBLEM
A8	OIL PUMP LEAK	C20	GEAR BELT TENSIONER BROKEN / ROLLER COMPACTOR	J14	ALTERNATOR PROBLEM
A9	ENGINE MOUNTING FRONT R	C22	REVERSE GEAR NOT ENGAGE / RELAY SWITCH PROBLEM	J15	ALTERNATOR PROBLEM
A10	ENGINE MOUNTING FRONT L	C23	ROLLER BEARING DAMAGE	J16	VOLTAGE DROP - AVR BOARD PROBLEM
A12	ENGINE MOUNTING REAR L1	C24	MOVEMENT FAULTS - CHAIN ROLLER STRUCK	J17	LOW ALTERNATOR PROBLEM DISPLAYED ON LCD AVR BOARD
A16	OIL LEAK - COVER PACKING	D5	CLUTCH PLATE WORNOUT	J18	VOLTAGE FLUCTUATION
A17	WATER LEAK - WATER PUMP CHANGE	D6	CLUTCH PARTS (CL.PLT / PR.PLT/ PR.BRG/RLS.BRG/FORK/PILOT BRG)	J19	SENSOR CONTROL BOARD PROBLEM
A18	OIL LEAK - FILTER BODY	D8	CLUTCH RELEASE BEARING SOUND	J20	VOLTAGE DROPPED
A19	ENGINE FAN BELT CUT	D12	PLY WHEEL RING DAMAGE	J21	ACTUATOR PROBLEM
A24	ENGINE OVER HEAT / RADIATOR LEAK / ENGINE CHEASED	D16	OIL LEAK HOSE	J22	PTO/ SWITCH NOT WORKING
A26	OIL LEAK - TIMING COVER SEAL OR CRANK SEAL	D17	OIL LEAK PIPE DAMAGE	J23	STARTING TROUBLE / EMERGENCY SWITCH NOT RELEASED
A27	WATER LEAK RAIL PIPE BOLT CUT / REPAIR	D18	PROPELLOR SHAFT BEARING CENTRE PROBLEM	J24	REVERSE AND FORWARD PROBLEM
A28	WATER LEAK / PUMP GASKET	D19	PROPELLOR SHAFT BEARING REAR PROBLEM	J25	REVERSE PROBLEM / REVERSE SWITCH/LOOSE CONTACTS
A30	AIR RELEIF VALVE PROBLEM - COMPERSSOR	D20	PROPELLOR SHAFT BEARING FRONT PROBLEM	J26	SOLENOID WIRE LOOSE CONTACT
A31	OIL LEAK COOLER BODY	D21	DIFFERENTIAL SOUND	J27	LOW VOLTAGE PROBLEM
A32	OIL LEAK	D22	DIFFERENTIAL PINION OIL SEAL LEAK	J28	LOW ALTERNATOR PROBLEM
A33	COMPRESSOR SEPARATOR CHOKED AND RELEIF VALVE LEAK	D24	CLUTCH SLAVE CYLINDER BRACKET DAMAGE	J29	GENSET BEARING NOISE / VOLTAGE FLUCTUATION
A34	ENGINE - COMPRESSOR COUPLING BROKEN	D25	CLUTCH PEDAL AIR VALVE LEAK	J31	SELF STARTED PROBLEM
A35	ACCELERATOR CABLE CUT	D26	REVERSE MOVING PROBLEM	J32	STARTING TROUBLE - TIMING RELAY PROBLEM
A36	ENGINE RPM SUDDENLY RAISED	D27	DIFFERENTIAL CASING BROKEN	J33	ON-OFF SWITCH PROBLEM
A37	OIL PUMP PROBLEM	E2	BRAKE BOOSTER LEAK	J34	ENGINE OVER CRANKING NOT STARTED
A38	ENGINE OIL, COLLENET OIL MIXING	E3	BRAKE MASTER CYLINDER LEAK	J35	STARTING TROUBLE - SHUTDOWN MODULE PROBLEM
A39	FAN RADIATOR PULLY LOCK BROKEN	E4	BRAKE PEDAL SPRING CUT	J36	A/C FAN MOTOR NOT WORKING
A40	ENGINE STOPS WHILE RUNNING	E5	PARKING BREAK VALVE KIT LEAK	J37	TELYS BOARD PROBLEM
A41	ENGINE OVER CRANKING LOW ALTERNATOR DISPLAY ON LCD	E7	FRONT WHEEL R/BRAKE LINING LOW	J38	FUSE BOX BROKEN
A42	FAN LEAF BROAKEN - RADIATOR	E13	BRAKE OIL LEAK	J39	REEL GUARD / SWITCH NOT WORKING
A43	ENGINE OVER HEAT	E14	AIR LEAK	J40	PANEL BOARD MAIN BRAKER DEFECT
A44	RADIATOR FAN PULLY BROKEN SEIZED / FAN BELT CUT	E16	BRAKE WHEEL CYLINDER LEAK	K4	EXHAUST LEAK
A45	ENGINE OIL / FUEL MIXING	E20	BRAKE SWITCH NOT WORKING	K7	A/C SYSTEM NOT WORKING
A46	OIL SEPARATOR HOSE CUT / COMPRESSOR UNIT	E26	PARKING BRAKE CABLE CUT	K8	EXHAUST LEAK
A49	ENGINE NOISE	E28	BRAKE VALVE NOT FUNCTIONING	L1	HYDRAULIC PUMP PROBLEM
A50	ENGINE LOW OIL PRESSURE - SENSORS / SWITCH / METER / OIL VISCOS	G1	TYRE PUNCTURE FRONT RIGHT	L2	HYRDAULIC HOSE CUT
A51	ENGINE OIL AND WATER MIXING - LINER "O" RING CUT - ENGINE WORK	G2	TYRE PUNCTURE FRONT LEFT	L3	OIL LEAK CONTRON VALVE - HYD OIL
A53	ENGINE LOW OIL PRESSURE	G3	TYRE PUNCTURE REAR INNER RHS	L4	OIL LEAK TELESCOPIC CYLINDER SEAL / SCORING
A54	ENIGNE RPM NOT RAISED - CAM SHAFT SENSOR PROBLEM	G4	TYRE PUNCTURE REAR OUTER RHS	L5	CONTROL VALVE NOT WORKING
A55	ACCELERATOR SPRING CUT	G5	TYRE PUNCTURE REAR INNER LHS	L6	REAR JACK OIL LEAK
A59	RADIATOR CHOKED	G6	TYRE PUNCTURE REAR OUTER LHS	L7	HYD STEERING PUMP L/R ROTATION HARD
B1	FUEL PUMP PROBLEM	G18	WHEEL HUB OIL SEAL REAR INNER LEAK	L8	HYD WINCH OIL LEAK
B2	INJECTOR PROBLEM	G29	TYRE BURST	L9	FRONT OUTRIGGER JACK/LH AUTOMATICALLY DOWN
B7	FUEL INLET PIPE LEAK	H12	STEERING HARD	L11	REAR BACHOE CYL UNION BROKEN
B9	ENGINE STARTING TROUBLE - HAND PRIMER PROBLEM	H13	STEERING PUMP / WHEEL TURNING AREA NOT COVERED	L12	FRONT LOADED ARM CYLINDER SEAL LEAK
B15	ENGINE OVER HEATED AUTOMATICAALY TRIPPED	H14	STEERING CYLINDER OIL LEAK	L13	FRONT BUCKET AUTOMATICALLY DOWN / WHILE OPERATING
B16	ENGINE NOT CRANKING	H15	STEERING UNIVERSAL AND BUSH WORNOUT	L14	OIL LEAK HYD TANK LEVEL TUBE BROKEN
B17	ENGINE OVER CRAKING/ FUEL LINE FEED PUMP PROBLEM	I10	WHEEL VOBBLING	L15	SWING MOTOR BRAKE PROBLEM
B18	LOW ALTERNATOR PROBLEM	I16	REAR AXLE BROKEN	L16	SWING ROTOR OIL LEAK
B20	STARTING TROUBLE - FUEL LIFT PUMP NOT WORKING	J1	STARTING TROUBLE	L18	BOOM INNER CYLINDER HOSE LEAK
C1	GEAR BOX ABNORMAL SOUND WHILE GEAR CHANGE	J2	SELF STARTER PROBLEM	L20	HYDRAULICK TEMPERATURE INCREASED
C2	CABLE CUT GEAR SHIFTING	J3	STARTING TROUBLE	L21	OIL LEAK / FILTER BODY

Table 6.22 Breakdown Symptom Code List

BSyC	Breakdown Symptom Code Details	BSyC	Breakdown Symptom Code Details	BSyC	Breakdown Symptom Code Details
A1S1	Knocking sound/ low oil pressure	A34S1	Engine running but compressed air not delivered	B1S7	Pump seized / Starting trouble
A1S2	Oil pressure "0" level indicating on dash board	A34S2	Compressor unit not functioning	C18S1	Machine will not move
A1S3	Engine not cranking	A37S1	Engine oil low pressure indicating on board	C20S1	Machine will not move
A1S4	Exessive sound	A37S2	Excessive noise coming from pump / pressure low	C24S1	Machine will not move
A1S5	Engine over heat	A37S3	Engine oil low pressure indicating on board / exceessive consumed	D5S1	Gear not enage / not moving
A1S6	Engine oil and coolant mixed	A37S4	Excessive oil consumed	D5S2	Gear operation hard
A1S7	Coolant escaping from radiater/starting trouble	A38S1	Radiator coolant color changed / low oil pressure	D5S3	Machine not moving but gear engaged
A1S8	Engine oversmoke	A38S3	Engine oil color changed / level increased	D6S1	Not getting pickup speed
A1S9	Engine oil exessive consumed	A38S5	Radiator coolant color changed / starting trouble	D6S2	Not moving with any gear
A3S1	Coolant excessive consumed	A38S6	Engine oil color changed / starting trouble	D12S1	Starting trouble / gear slippery sound
A3S6	Coolant excessive consumed/engine over heat	A39S1	Excessive sound developed in engine side / overheated	D18S1	Girinding noise developped while driving
A4S1	Oil consumed due to leakage	A39S2	Excessive sound developed in engine	D21S1	Humming noise developped
A5S1	Temparature point indicating of dash board	A42S1	Suddenly getting noise	D21S2	Grinding noise
A5S2	Engine overheated but radiator not heated	A42S3	Belt cut - overheated	D21S3	Excessive sound while vehicle movung
A5S3	Temparature suddenly raised	A42S4	Engine overheated on full speed	D21S4	Excessive sound while brake apply
A6S1	Engine starting trouble/over cranking	A42S5	Excessive noise	D22S1	Exessive oil consumed
A6S2	Engine over smoke/fuel improper combustion	A42S6	Belt cut - overheated	D26S1	Gear not enage
A6S3	Engine oil amd Warter mixing	A43S1	Coolant excessive consumed	D26S4	Excessive sound While reverse moving
A6S4	Engine not raising speed	A43S3	Coolant excessive consumed / heat developed	D26S5	Forward / Reverse moving problem
A6S6	Engine over heated	A43S6	Engine suddenly getting overheated	H12S1	Steering hard with exessive sound
A7S1	Engine coolant boiling water escaped from radiator	A43S7	Temperature meter indicating red mark / but coolant normal temperature	H12S2	Steering locked
A7S2	Coolant excessive consumed daily	A43S8	Engine overheated immediately	H12S3	Steering hard with exessive sound (left & right turn)
A7S4	Engine overheated	A43S9	Coolant excessive consumed / heated	J1S1	Starting trouble/ Light indicating on dash board
A8S1	Engine low oil pressure light indicating on fault display board/pressure meter indicating red	A44S1	Abnormal noise coming from engine side	J2S1	Starting trouble
A9S1	Engine vibration	A45S1	Exhaust color changed (white smoke)	J4S1	Engine crank but will not start
A10S1	Engine vibration	A45S3	Engine oil level increased / oil viscosity dropped	J8S1	Bulb fused
A16S1	Engine oil excessive consumed	A45S5	Exhause color changed (white smoke) / level increased	J14S1	Alternater not charged
A17S4	Engine coolant excessive consumed / leak	A50S1	Engine stopped intermittent due to low oil pressure - Display on board	J20S1	Exessive sound / vibration
A19S1	Temparature suddenly raised	A50S2	Engine not started	J25S1	Reverse gear not engaging / reverse not moving
A19S2	Temparature red mark indicating on meter	A50S3	Engine not started / suddenly stopped while running	J31S1	Engine crank but will not start
A19S3	Amps meter not worked on dash board	A50S4	Engine Pressure indicated as low	J31S3	Engine crank but will not start /getting sound
A19S4	Battery symbol light display on dash board	A50S5	Engine stops with vibrationh	L2S1	Exessive oil consumed / oil dropped
A24S1	Coolant excessive consumed / heat	A53S1	Low oil pressure light indicated / showing meter	L4S1	Telescopic jack autimaticaly downed while operaton and idle
A27S1	Coolant excessive consumed / heat	A53S2	Low oil pressure light indicated / showing meter / noise developed	L5S1	Hydraulic function failure
A28S1	Coolant excessive consumed / heat	B1S1	Starting trouble /over cranking	L6S1	Exessive oil consumed
A30S1	Required output pressure not come	B1S2	engine not getting speed / White smoke	L7S1	Steering hard while right & left turn
A31S1	Engine oil excessive consumed	B1S3	Starting trouble /over cranking	L11S1	Back hoe vibration while operation
A31S2	Engine oil excessive consumed / pressure low	B1S4	Abnormal sound	L13S1	Bucket automaticaly downed with sound while operation
A33S1	Compressor air and oil mixed	B1S5	Starting trouble /over cranking	L16S1	Hyd oil exessive consumed
A33S2	Output pressure low	B1S6	Engine not getting speed / sound variation		

Table 6.23 Breakdown Reason Code List 1

BRC	Breakdown Reason Code Details	BRC	Breakdown Reason Code Details
A1R1	Cam shaft bush wear & tear	A17R4	Packing
A1R2	Oil pump gear failure	A17R5	Seating malfunction
A1R3	Push rod bent/ broken	A17R6	Mounting Bolt malfunction
A1R4	Connecting rod bearing wear & tear	A17R7	Mounting Bolt loose
A1R5	Coolant loss /exeessive consumed	A19R1	Alternator bearing seized
A1R6	Engine liner crack/ o ring/seal malfunction	A19R2	Radiator cover broken
A1R7	Engine cylinder head gasket	A19R3	Water pump bearing seized
A1R8	Engine rings jammed/Turbo seal malfunction	A19R4	Fan clutch not working
A1R9	Engine oil exessive consumed	A24R1	Thickness of copper coating reduced
A3R1	Radiator cap / core	A27R1	Coolant pipe cut
A3R2	Radiator hoses leak	A27R2	Pipe sealant compound
A3R3	Radiator reservoir tank leak	A27R3	Pipe crack
A3R4	Radiator hoses clip damaged	A28R1	Gasket malfunction
A3R5	Water pump seal leak	A28R2	Seal malfunction
A3R6	Water pump shaft	A28R3	Bearing seized
A3R7	Engine block water dummy leak	A30R1	Separator chocked
A4R1	Seal damamge	A30R2	valve spring broken
A4R2	Seal seating cover wear & tear	A30R3	Valve seal damaged
A4R3	Crank shaft rear end wear &tear	A31R1	Engine oil filter body 'O' ring damaged
A4R4	Oil filled in excess	A31R2	Filter body O ring become hard
A4R5	Seating cover over tightened / loose	A31R3	Filter body mounting bolt loose
A4R6	Seal hard due to over heating	A31R4	Filter body seating not proper
A4R7	Cransk shaft sleeve wear & tear	A31R5	Bolt washer damaged
A5R1	Spring/washer failure	A33R1	Valve spring damaged
A6R1	Engine cylinder head gasket cut	A33R2	Valve seal and 'o'ring damaged
A6R2	Engine cylinder head gasket cut/bolt cut	A34R1	To check engine mounting
A6R3	Engine cylinder Head and gasket crack	A34R2	To check compressor mounting
A6R4	Engine cylinder head gasket cut and head facing problem	A34R3	Compressor housing bolt
A6R5	Engine head bolt cut	A37R1	Gasket malfunction
A6R6	Engine head gasket malfunction	A37R2	Gear malfunction
A7R1	Radiator choked/ core blocked	A37R3	Shaft cotter pin malfunction
A7R2	Radiator top /bottom tank leak	A37R4	Leakage
A7R3	Radiator core damaged	A38R1	Oil cooler O ring damaged
A7R4	Radiator core fins blocked	A38R2	Oil cooler core damaged
A8R1	Gasket malfunction	A38R3	Water punp seal damaged
A8R2	O ring cut	A38R4	Engine liner o ring damaged
A8R3	Shaft cut/ wear & tear	A38R5	Engine cylinder head gasket malfunction
A8R4	Gear wear & tear	A38R6	Engine cylinder head crack
A8R5	Pump strainer pipe crack	A39R1	Lock broken
A9R1	Engine mounting bolt cut	A39R2	Lock wear &tear
A9R2	Rubber Damaged	A42R1	Alternator bearing seized
A10R1	Engine mounting rubber cracked	A42R2	Radiator cover broken
A10R2	Engine mounting rubber bolt cut	A42R3	Water pump bearing seized
A16R1	Packing damage	A42R4	Fan clutch not working
A16R2	Sump cover bolt loose	A42R5	Fan bolt malfunction
A16R3	Oil seal damaged	A42R6	Belt over tight
A17R1	Other seals damaged	A43R1	Radiator core leakage
A17R2	Water pump shaft	A43R2	Radiator hoses leakage
A17R3	Bearing		

Table 6.24 Breakdown Reason Code List 2

BRC	Breakdown Reason Code Details	BRC	Breakdown Reason Code Details
A43R3	Radiator top / bottom tank leakage	D21R4	Disc brake wear & tear
A43R4	Radiator choked	D22R1	Breather choke
A43R5	Fan belt cut	D26R1	Solenoid switch
A43R6	Temperature switch malfunction / sensor	D26R2	Relay
A43R7	Thermostat not functioning	D26R3	Fuse
A43R8	Water pump leak	D26R4	Reverse gear slipped
A44R1	Bearing seized	D26R5	Reverse unit malfunction
A44R2	Pulley wedge damaged	H12R1	Hydraulic oil level low
A45R1	Injector sealing washer malfunction	H12R2	Pump failure
A45R2	Injector barrel/plunger malfunction	H12R3	Steering jack seal leak
A45R3	Fuel pump hard malfunction	J14R1	Alternater armature over heated due to rectifier failure
A45R4	Fuel return line malfunction	J1R1	Regulater/rectifier short circuit due to bearing seizure
A45R5	Fuel pump malfunction	J2R1	Solenoid failure(bentex not released)
A50R1	Oil pressure sensor switch short circuit	J2R2	Ignition key struck
A50R2	cam shaft sensor terminal short circuit	J4R1	Solenoid heated due to engine over cranking
A50R3	sensor switch - fused	J8R1	Switch malfunction
A50R4	oil pressure meter malfunction	J8R2	Fused
A50R5	oil pressure meter line blocked	J8R3	Mounting clamp loose
A53R1	cam shaft bush wear & tear	J20R1	Rotar bearing
A53R2	Connecting rod bush wear & tear	J20R2	Rotar balance improper
B1R1	Cam shaft broken	J20R3	Alternater mounting broken
B1R2	Delivery valve and plunger barrel	J25R1	Switch short circuited (loose contact / water deposit)
B1R3	Governer malfunction	J25R2	Solenoid malfunction
B1R4	Timer malfunction	J25R3	Relay short circuited due to water deposited
B1R5	Fuel and water mixing due to improper fuel used	L2R1	Wrong operation and working place
B1R6	Accelator rack broken	L2R2	Hose getting hard
B1R7	Oil lubrication line blocked	L2R3	Over load operation
C18R1	Drum bearing seized	L4R1	Oil seal damaged
C18R2	Chain tensioner wear and tear	L4R2	Cylinder tube scoring / one side load operation
C18R3	Chain cover packing damaged / sand deposited with lubricant	L4R3	Telescopic return valve not working
C18R4	Roller drive spracket cotter pin play	L4R4	Hydraulic oil change poor condition
C18R5	Hydraulic motor pump shaft cut	L5R1	Hydraulic oil pump not funtioning
C18R6	Roller drive sprocket teeth damaged	L6R1	Oil seal (pressure seal)
C20R1	Tensioner mounting bolt cut	L6R2	Gland nut 'o' ring thread damaged
C20R2	Tensioner cut	L7R1	King pin kit seized
C24R1	Bearing malfunction	L7R2	Jack cylinder seal / oil leak
D5R1	Over load	L7R3	Pump not funtioning (piston damaged)
D5R2	Recless operation	L11R1	Bracket bolt lose / cotter pin cut
D5R3	Release bearing jammed	L11R2	Bracket cut due to over load
D6R1	Over load operation	L13R1	Operater lever spool
D6R2	Continuously using clutch while operation & driving	L13R2	Pilot control valve
D6R3	Wrong operation	L13R3	Pressure valve
D12R1	Selfstarter bentex teeth damaged	L13R4	Bucket jack seal kit / barrel
D12R2	Selfstarter bentex not released	L16R1	Rotar seal
D18R1	Shaft yoke play	L16R2	Hydraulic oil tank breather valve malfunction
D18R2	Lubrication not applied prober interval	J31R1	Rear and front armature bush
D21R1	Oil lost due to seal damage / bearing seized	J31R2	Water inside due to Insulation rubber damage
D21R2	Sun / Star gear malfunction	J31R3	Ignition switch struck
D21R3	Pinion play more due wear & tear	J31R4	Compressed air not released before starting

6.7.5.3 First Ring of Breakdown Main Code (BMC)

The BMP is prepared as a BMP Ruler just like any other analytical rulers. There are four rings which are self- rotating. The first ring (figure 6.21) is the inner most ring, smallest in diameter and it has the listing of all the breakdown main codes (BMC). The BMC's are listed in segments, each segment representing a component or a system of the construction machine, (consciousness in construction include the most contributing breakdown main codes, which cause most of the breakdowns to the construction machineries are only selected). The BMCs are segmented as engine (AA), fuel feed (BB), gear box & torque convertor (CC), transmission (DD), brakes (EE), suspension & hub axles (FF), tyre & wheel (GG), steering & linkages (HH), suspension, main & rear axles (II), electrical (JJ), body works & exhaust (KK), hydraulics (LL). Each segment is colored in unique color so that the identification becomes easy for the end user while comparing various codes for utilization to identify the breakdown causes. The numbers of BMCs (107) against each segment are listed in Table 6.25.

Table 6.25 Breakdown Main Codes – Details of Arrangement

Code	Component/System	Color	BMC
AA	Engine	Blue	12
BB	Fuel Feed	Bright Green	9
CC	Gear Box	Aqua Blue	12
DD	Transmission	Lavender	11
EE	Brakes	Lime Green	17
FF	Suspension	Violet	3
GG	Tyre and Wheel	Dark Green	8
HH	Steering	Grey	10
II	Axles	Yellow	5
JJ	Electrical	Peach	8
KK	Body and Exhaust	Magenta	3
LL	Hydraulic	Olive Green	9
	Total		107

Method of Identification – CEA Tools, Additional Tools used - Pareto Analysis; Support Resources – Mechanics, Maintenance Teams, Failure Data; Level in the diagnosis - First

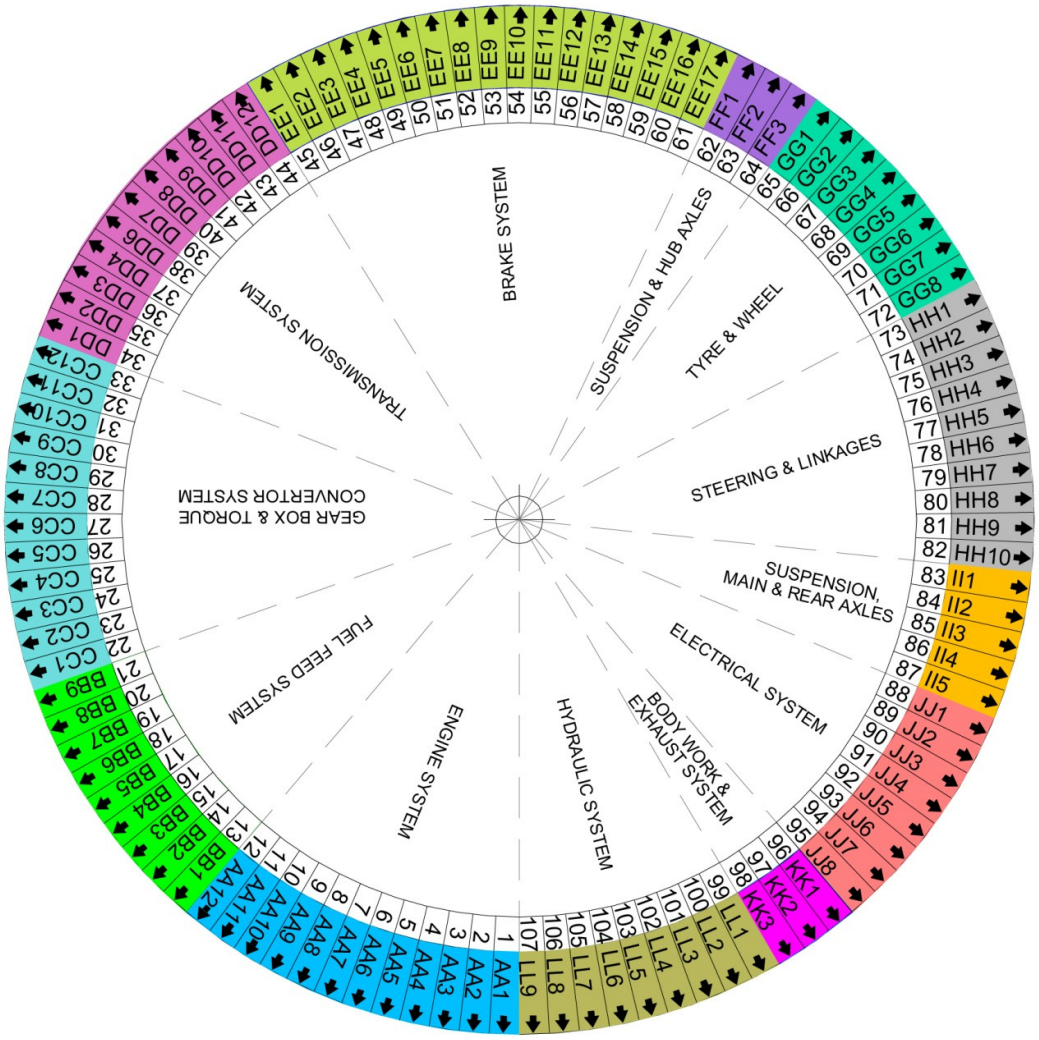

Figure 6.21 BMP Ruler - First Ring

BMP Ruler First Ring, Front side (Figure 6.21) denotes the components and systems of the equipment and the resultant Breakdown Main Codes with numerals attached with to link with the next level of code BSC. The systems include: engine, fuel feed, gear box, transmission, brakes, suspension, tyre and wheel, steering, axles, electrical, body and exhaust and hydraulic systems.

6.7.5.4 Second Ring – Breakdown Sub Code (BSC)

The second ring (figure 6.22) is larger in diameter than the first inner ring. It constitutes a ring listing all the breakdown sub codes (BSC). The BSCs are matched in color with the respective BMC ring. The first ring and the second ring have similar coding procedures. All the codes are identified as engine (A), fuel feed (B), gear box & torque convertor (C), transmission (D), brakes (E), suspension & hub axles (F), tyre & wheel (G), steering & linkages (H), suspension, main & rear axles (I), electrical (J), body works & exhaust (K), hydraulics (L). The Suspension and hub axles which are coded as F are not listed in this present ruler, as there were no breakdowns found with the machines for last five years in these components. Also the BSC's are not sequel in number, due to selection of sub codes which are critical to the breakdown causes. These are identified with the process of pareto principles or 80/20 rule and also further with FMEA tools. The number of BSC's (162) against all the segments is listed in Table 6.26.

Table 6.26 Breakdown Sub Codes – Details of Arrangement

Code	Component/System	Color	BSC
A	Engine	Blue	43
B	Fuel Feed	Bright Green	9
C	Gear Box	Aqua Blue	13
D	Transmission	Lavender	15
E	Brakes	Lime Green	11
F	Suspension	Violet	-
G	Tyre and Wheel	Dark Green	8
H	Steering	Grey	4
I	Axles	Yellow	2
J	Electrical	Peach	36
K	Body and Exhaust	Magenta	3
L	Hydraulic	Olive Green	18
	Total		162

Method of Identification – CEA Tools, Additional Tools used - Pareto Analysis, FMEA Tools; Support Resources – Mechanics, Maintenance Teams, Failure Data; Level in the diagnosis - Second

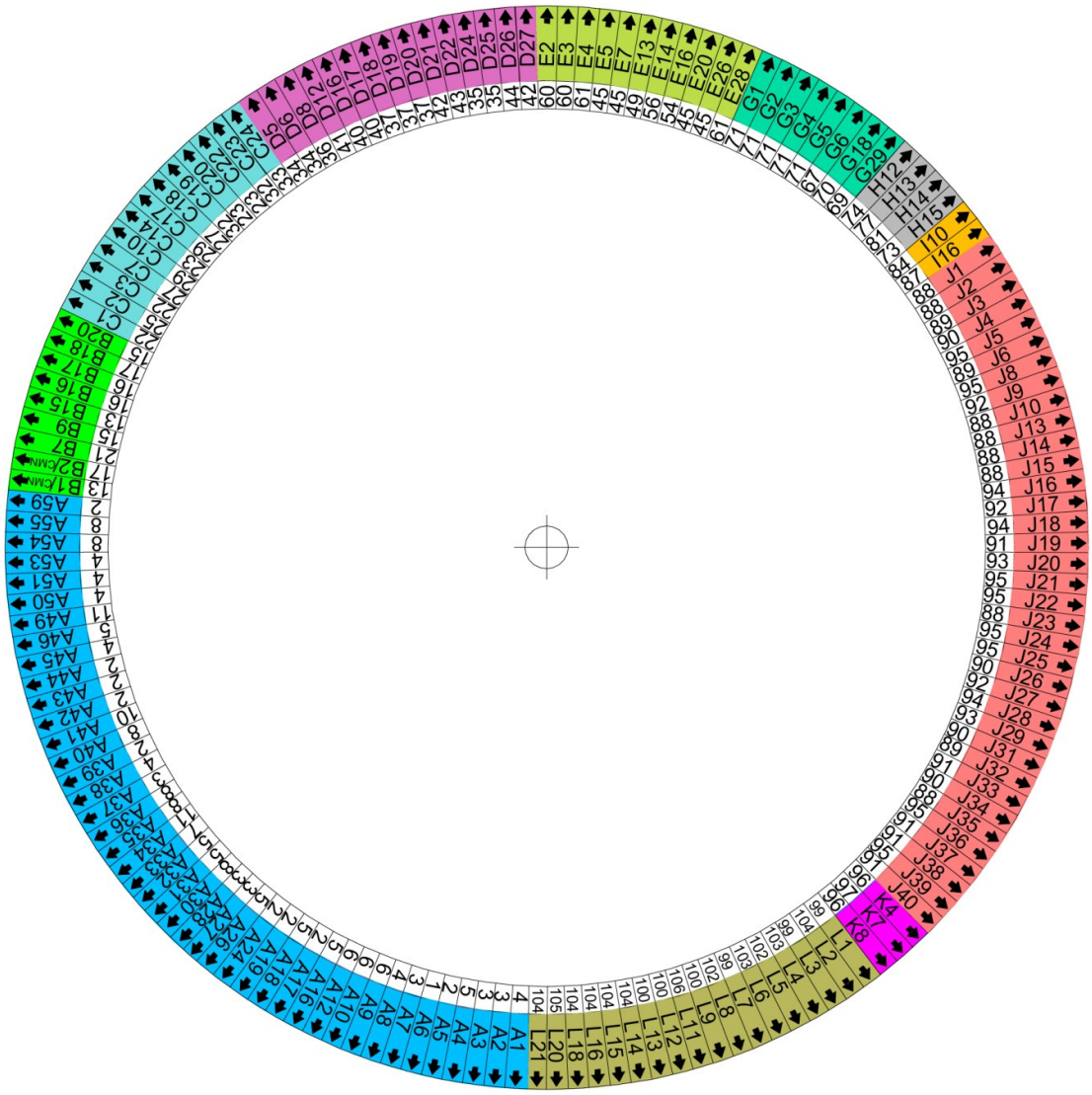

Figure 6.22 BMP Ruler - Second Ring

BMP Ruler second ring, front side denotes the breakdown sub codes (BSC) with reference to the main codes (BMC). The colors help to match the similar color codes on all the rings. The numbers associated with this ring will help to associate the physical number with the same number of the first ring which is the main code ring.

6.7.5.5 Third Ring – Breakdown Symptom Code (BSyC)

The third ring (figure 6.23) in sequence next to the BSC ring is the Symptom Code (BSyC) Ring. It constitutes all the listing of Breakdown Symptom Codes (BSyC). The BSyC's are the codes which indicate the symptoms which are shown prior to any breakdown of components and systems of the machinery. Generally these symptoms are associated with one or multiple reasons which are the main causes of the breakdowns. The symptoms to be carefully identified based on the conditions at the site/location and to be related with the exact reason codes. The BSyC's are segmented as engine (A_nS_n), fuel feed (B_nS_n), gear box & torque convertor (C_nS_n), transmission (D_nS_n), brakes (E_nS_n), suspension & hub axles (F_nS_n), tyre & wheel (G_nS_n), steering & linkages (H_nS_n), suspension, main & rear axles (I_nS_n), electrical (J_nS_n), body works & exhaust (K_nS_n), hydraulics (L_nS_n). The number of BSyC's are not in sequence and all the components are not listed with BSyC. The BSyC's are listed based on the critical BSC's which are most contributing to the 80% of the breakdowns.

The numbers of BSyC's (119) against selected segments are listed in table 6.27.

Table 6.27 Breakdown Symptom Codes – Details of Arrangement

Code	Component/ System	Color	BSyC
AnSn	Engine	Blue	74
BnSn	Fuel Feed	Bright Green	7
CnSn	Gear Box	Aqua Blue	3
DnSn	Transmission	Lavender	15
EnSn	Brakes	Lime Green	-
FnSn	Suspension	Violet	-
GnSn	Tyre and Wheel	Dark Green	-
HnSn	Steering	Grey	3
InSn	Axles	Yellow	-
JnSn	Electrical	Peach	9
KnSn	Body and Exhaust	Magenta	-
LnSn	Hydraulic	Olive Green	8
	Total		119

Method of Identification – FTA Tools, Additional Tools used - Nil; Support Resources – Mechanics, Maintenance Teams, Failure Data, Breakdown Sub Codes; Level in the diagnosis - Third

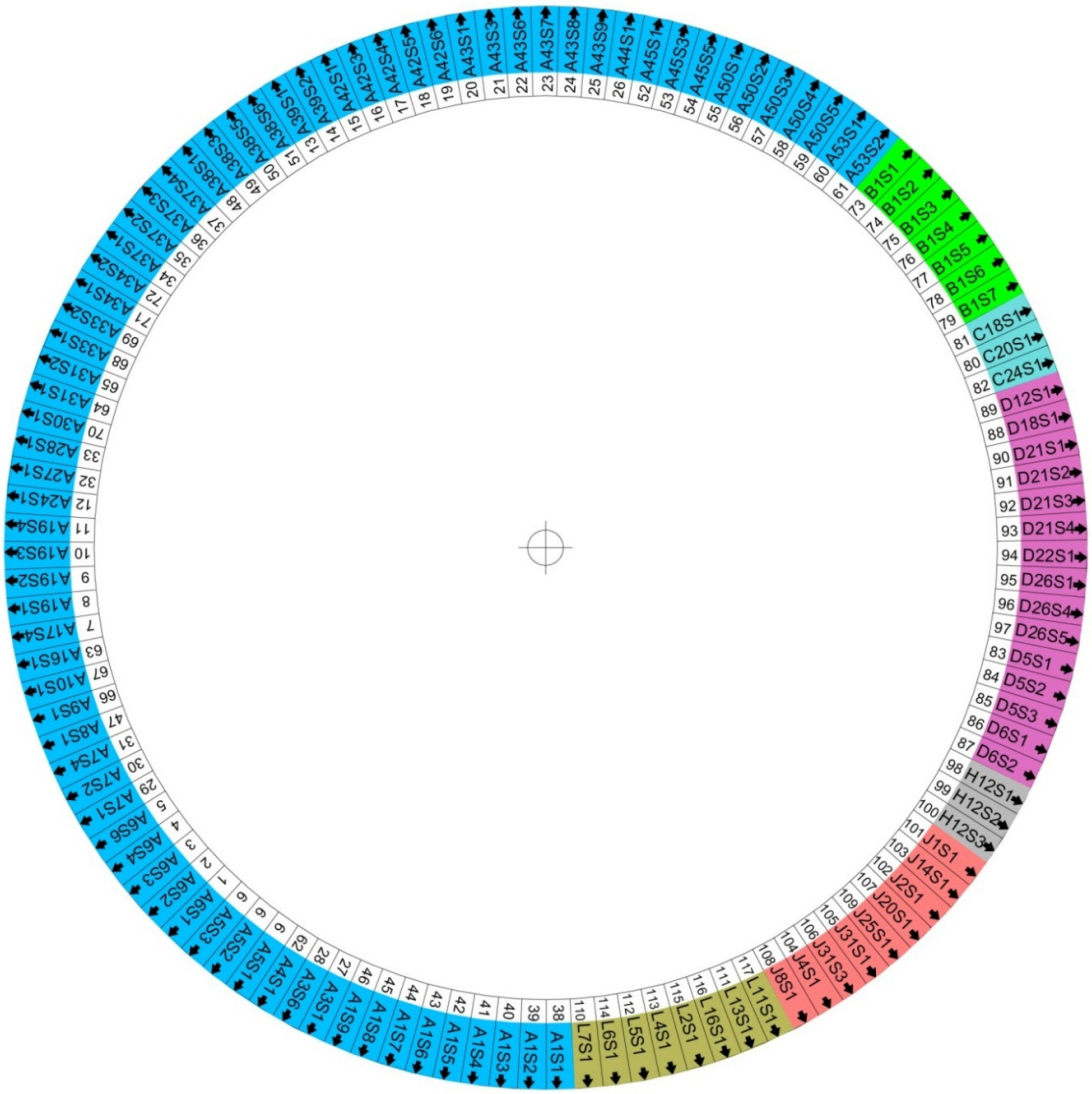

Figure 6.23 BMP Ruler - Third Ring

BMP Ruler third ring front side, denotes the breakdown symptom codes (BSyC) with reference to the breakdown sub codes (BSC). The color codes are uniformed maintained for easy relationships. The numbers to be matched against the same number codes on the fourth ring.

6.7.5.6 Fourth Ring – Breakdown Reason Code (BRC)

The fourth ring (figure 6.24) is the outer ring and it is largest in diameter. This constitutes the listing of all the Breakdown Reason Codes (BRC). The BRC's are in relation to the BSyC's and do match the same number of components each other. The BRC's are final code elements in the BMP Tool and it is the contributor of any particular breakdown. Each BRC is associated with a Protocol which provides the methods of rectification, all the resource requirements etc. The BRC's are segmented as engine (A_n R_n), fuel feed (B_nR_n), gear box & torque convertor (C_nR_n), transmission (D_nR_n), brakes (E_nR_n), suspension & hub axles (F_nR_n), tyre & wheel (G_nR_n), steering & linkages (H_nR_n), suspension, main & rear axles (I_nR_n), electrical (J_nR_n), body works & exhaust (K_nR_n), hydraulics (L_nR_n).

The numbers of BRC's (195) against selected segments are listed in table 6.28.

Table 6.28 Breakdown Reason Codes – Details of Arrangement

Code	Component/ System	Color	BRC
AnRn	Engine	Blue	117
BnRn	Fuel Feed	Bright Green	7
CnRn	Gear Box	Aqua Blue	9
DnRn	Transmission	Lavender	20
EnRn	Brakes	Lime Green	-
FnRn	Suspension	Violet	-
GnRn	Tyre and Wheel	Dark Green	-
HnRn	Steering	Grey	3
InRn	Axles	Yellow	-
JnRn	Electrical	Peach	18
KnRn	Body and Exhaust	Magenta	-
LnRn	Hydraulic	Olive Green	21
	Total		195

Method of Identification – FTA Tools, Additional Tools used - Nil; Support Resources – Mechanics, Maintenance Teams, Failure Data, Breakdown Sub Codes, Breakdown Symptom Codes; Level in the diagnosis - Third

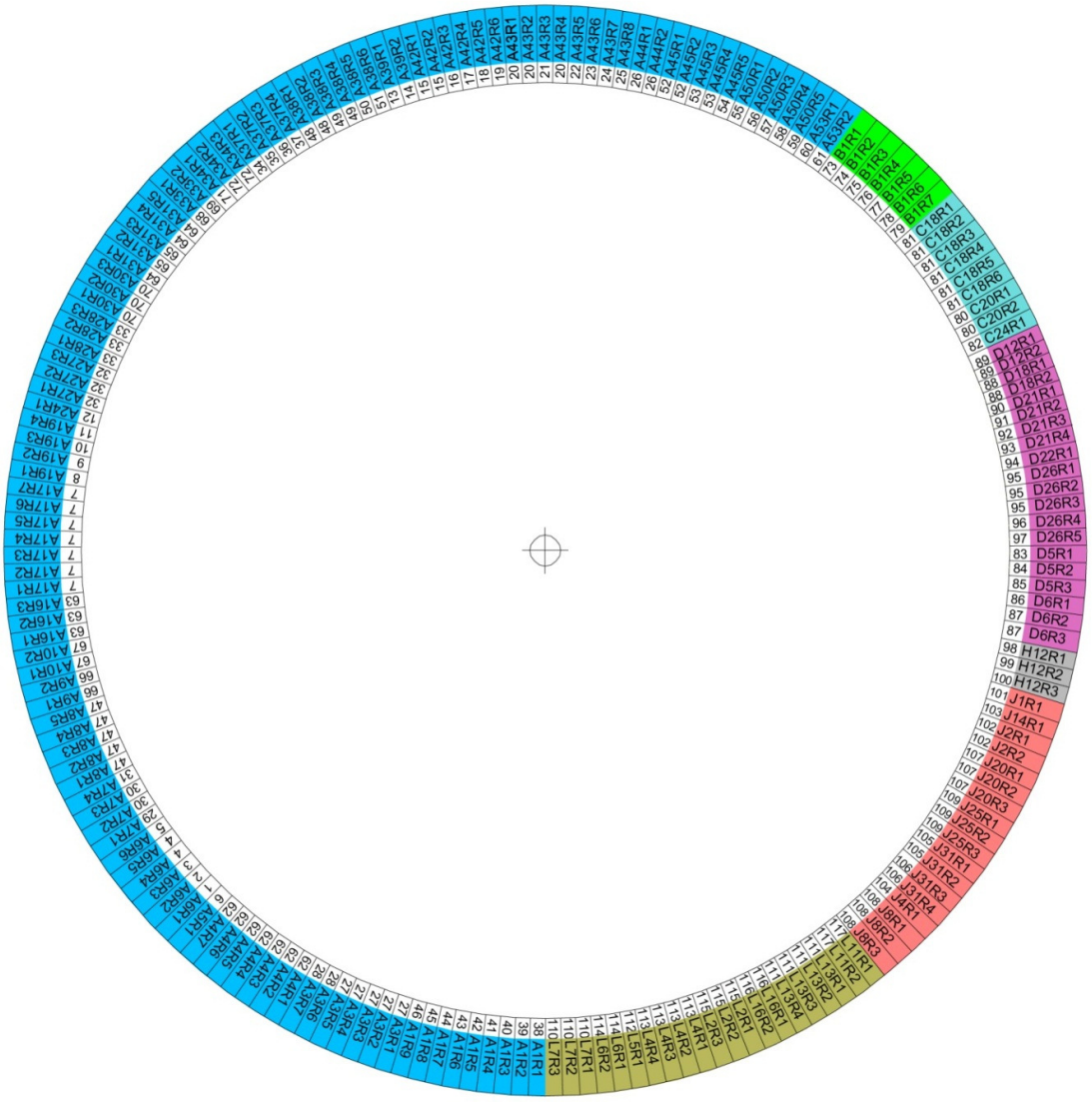

Figure 6.24 BMP Ruler - Fourth Ring

BMP Ruler fourth ring front side, denotes the Breakdown Reason Codes (BRC) with reference to the Breakdown Symptom Codes (BSyC). The color codes are uniformly maintained for easy relationships. The numbers mentioned alongside the ring to be matched against the same numbers on the fourth ring.

6.7.5.7 Main Ring (Back Side)

The back ring (figure 6.25) is mainly for the BMP listings. Each BRC is associated with a BMP which is designated with a unique number. There are totally 196 Protocols listed so far for this study and depending on the increase in data and newer breakdowns, the study will get further enhanced and number of protocols may get developed in the future. At present the study covers the management of the 80% of the breakdowns which are caused by the 20 % of the critical breakdown codes and the relative information are presented. The target organization has got an overall breakdown of less than 3 % on the overall machinery, and thus we are targeting to manage effectively the 2.4 % breakdowns, so that effective reduction of breakdown hours and better utilization of machinery achieved with the target organization.

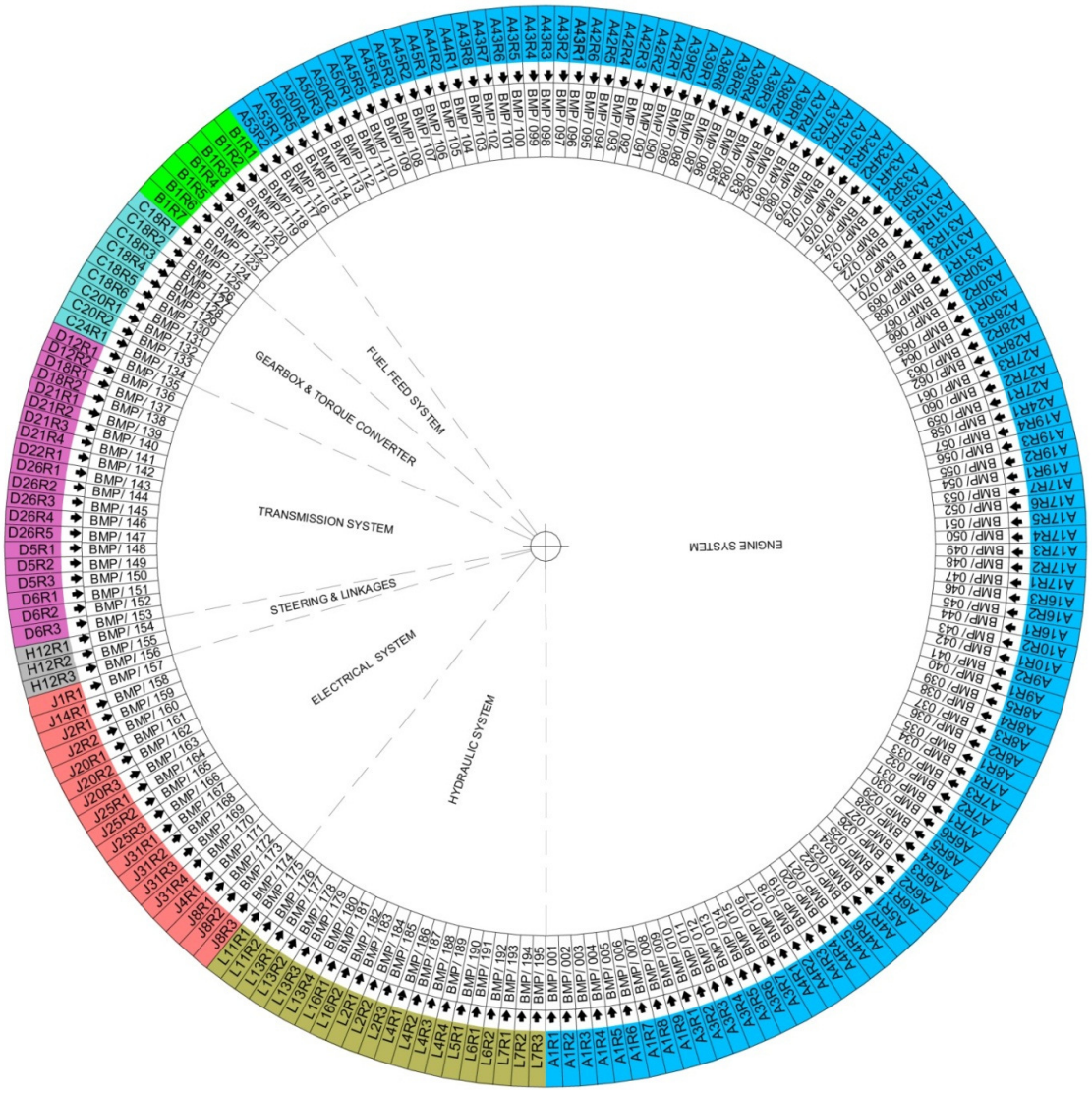

Figure 6.25 BMP Ruler Assembled - Back Side

BMP Ruler back side ring denotes the Breakdown Reason Codes (BRC) and the relative Breakdown Maintenance Protocol Number (BMP Number).

6.7.5.8 Assembled Main Ring Front Side of BMP Ruler

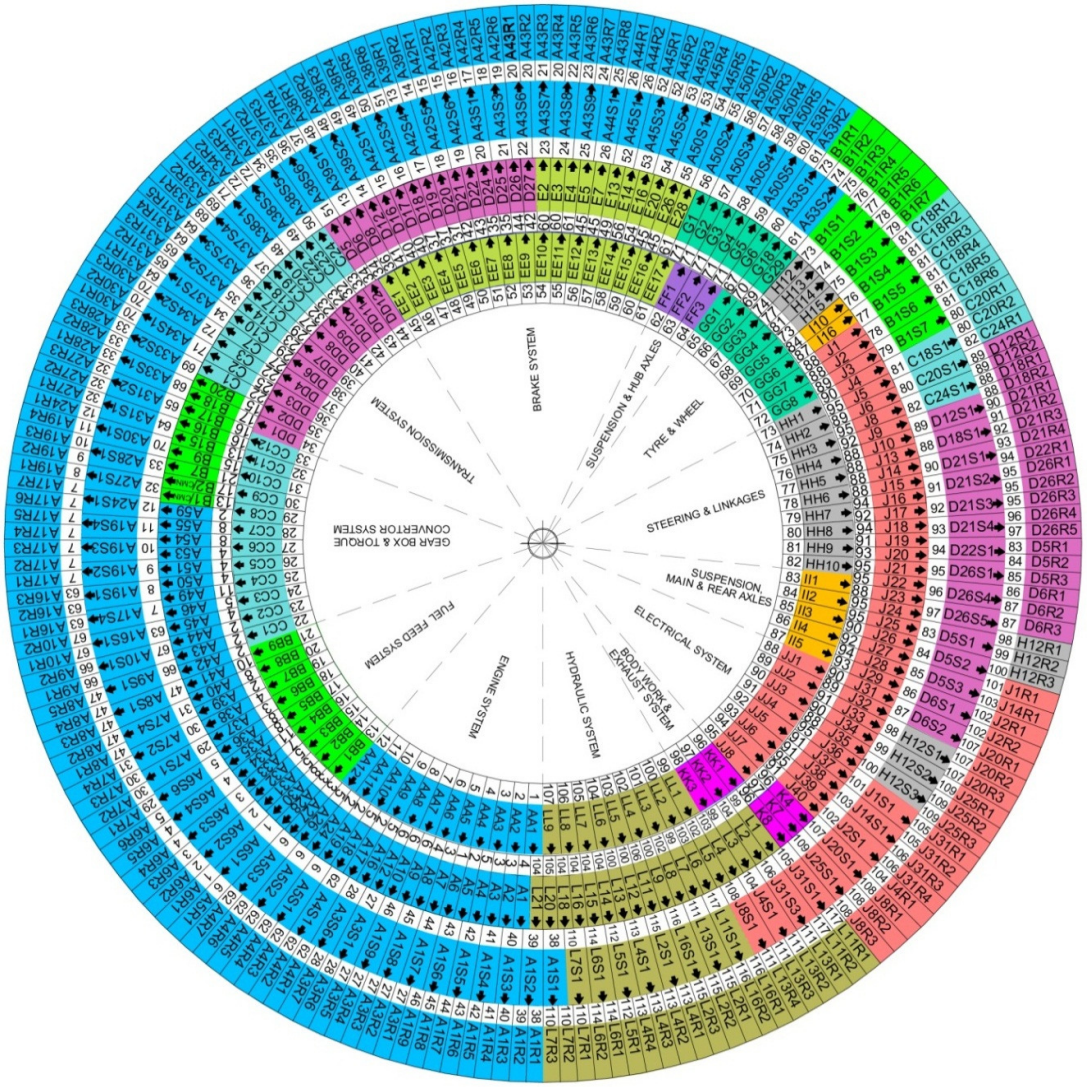

Figure 6.26 BMP Ruler Assembled - Front Side

BMP Ruler assembly (figure 6.26) has all the rings assembled together, which is used by the person at site and the relative crew members who are in connection with the breakdown maintenance execution. It has four levels of rings as BMC, BSC, BSyC and BRC respectively. The color codes are uniformly maintained for easy relationships of components and systems. The numbers printed on the first two rows of rings namely BMC Ring and BSC

Ring to be matched together. Similarly the numbers printed on the last two rows of rings namely BSyC Ring and BRC Ring to be matched together.

6.8 Development of BMP Ruler Resource Sheet

The maintenance will be optimized if all resources are available during execution of the process. The overall support of logistics and other resources act as performance enhance for both preventive and reactive maintenance. The non-availability of resources like personnel, spares and consumable materials needs to be planned properly as otherwise it can act as a performance killer and prevents the achievement of the desired results of maintenance (Parida A, 2006).

The BMP understands the need of the resources for effective planning and execution of maintenance. The protocol sample resource sheet (table 6.29) contains all the resources required for the execution of each breakdown. As mentioned in the earlier pages, each breakdown reason code is associated with a BMP, which has a unique identification number. To manage each breakdown effectively, a mechanic or a crew member or the supervisors should be provided with the required resources. The resources include Safety Officer, Engineer, Senior Supervisor, Foreman, Senior Mechanic, Assistant Mechanic, Tyreman, Tinker, Helper, Hydraulic Mechanic, Assistant Hydraulic Mechanic, Auto Electrician, Power Electrician, Operator, Hand tools, Power tools, Special Tools, Auto electrician Tools, Breakdown Vehicle, Recovery Vehicle, Lubricant and Consumables, Work Place, Machinery, External Agencies and Method of Rectification. The complete list of BMPs to all 195 BRC's are listed in Appendix F.

The details specifications of the resources including manual resources, material resources, tool resources, special requirements, methods of rectifications and the detailed requirement of spares and parts are spelt out specific to each of the BMP which directly denote a respective failure. The specification sheet is detailed in the Table 6.30 while the Method of rectification for five of the BSC's is detailed in the tables 6.31, 6.32, 6.33, 6.34 and 6.35 as samples. Additional MOR's are listed in Appendix G.

Table 6.29 Breakdown Maintenance Protocol (BMP) Resource Sheet

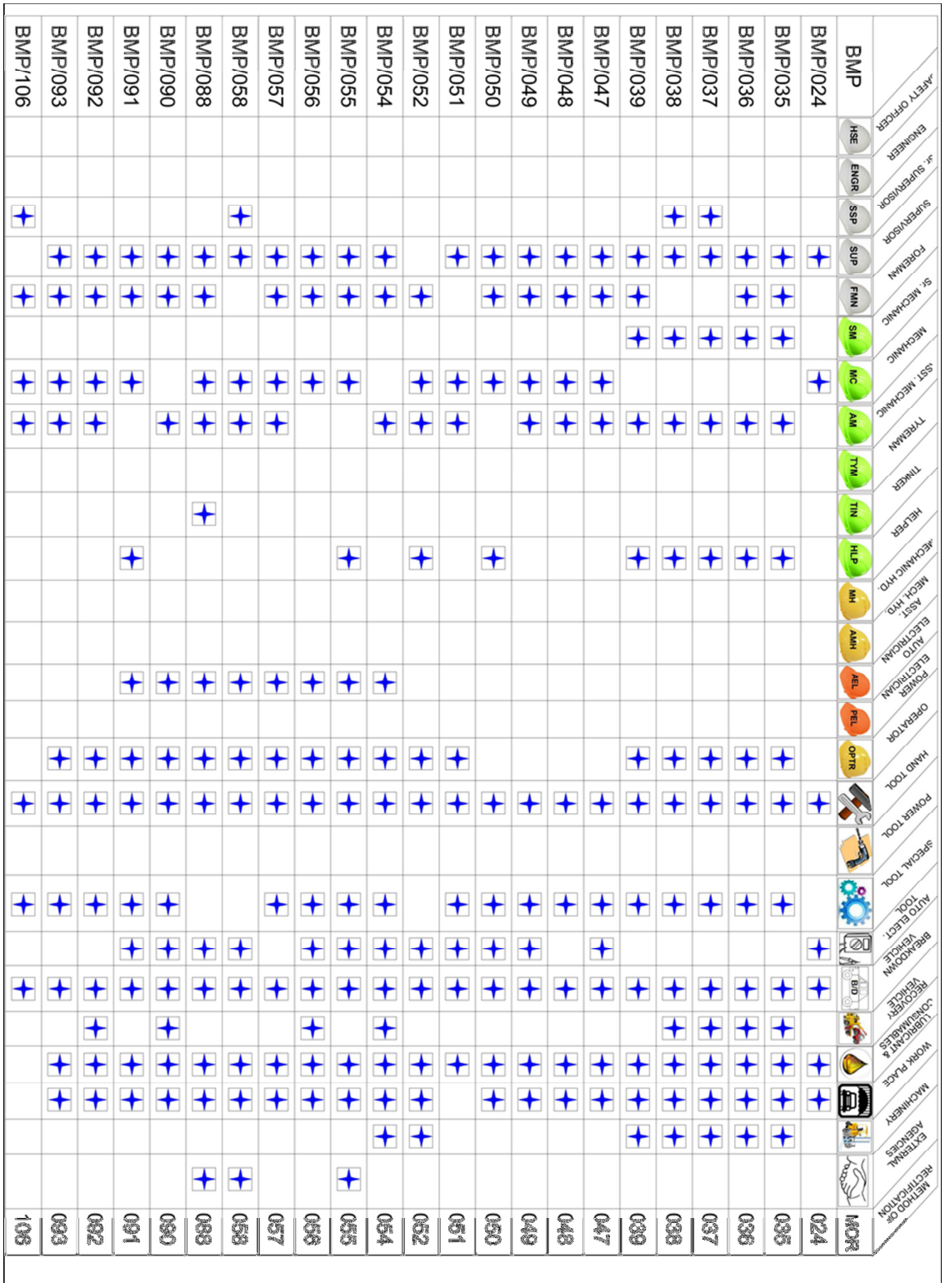

Table 6.30 Protocol Resource Details

S.No.	Resource Name	Resource details
1	Safety Officer	Safety officer is required for the jobs which involves critical activites, where job safety and enviroment safety is important and as well there is requirement of specialist job analysis requirments.
2	Engineer	Whenever special jobs like engine works, hydraulic ram, main boom and transmission,complex jobs are present.
3	Senior Supervisor	Engine, gearbox, transmission, clutch and other overhauling jobs.
4	Foreman	Required for all shop floor related jobs where proper allocation of tools, resources and other requirment exists
5	Senior Mechanic	Complex and critical jobs where more knowledge sharing to the mechanics is required.
6	Assistant Mechanic	All jobs as per the job requirments
7	Tyreman	All wheel and tyre related including puncture problems
8	Tinkerer	All body works including welding, gas cutting, brazing and tinkering works
9	Helper	All jobs as per the job requirments
10	Hydraulic Mechanic	All specialist hydraulic and realted jobs including jacks,seals,pumps and valves.
11	Asst. Mechanic Levels - Hydraulic	All assistance required for other jobs
12	Auto Electrician	All electrical related jobs including battery, alternator, self-starter, lights, ECM, solenoids and control valves.
13	Power Electrician	Circuit breakers, winding issues, capacitor and other electrical related jobs in motor and pumps
14	Operator	All jobs where testing and commissioning is required on the equipment where the operative is required
15	Hand tools	Combination spanners, wrenches, screw drivers, hammers, nose plier, cutting plier, circlip plier, feeler guage, wratchet, metalscale, allenkey set, mini puller and oil can
16	Power tools	Megger, tester, testing lamp, multimeter, power wrench, drilling machine, hand grinder, air blower and soldering machine
17	special tools	Hydraulic puller, pnematic wrench, torque wrench, dial guage, vernier guage, screw gauge, spiral guage, tap and die wrench
18	Auto Elect.tools	Allen key set, hydro meter, multimeter, tacho meter, testing lamp, pressure gauge and temperature gauge.
19	Breakdown vehicle	Vehicle required for specialized utilities like arrangments for tyre puncture, heavy duty tools, air compressor,water jet pump,hose making facilites, bench vice with the breakdown maintenance crew.
20	Recovery vehicle	Vehicle used for towing, shifting. Loading the equipmnet under failure.
21	Lubricants & consumables	Engine oil, hydraulic oil, transmission oil, gear oil, brake oil, coolant, clutch oil, grease, steering oil, orings, washers, cotton waste, packing sheets, hand gloves sope liquid, thinner and umbrella.
22	Work place	Space requirments for doing repair works including engine, gear box,transmission, differetial works.
23	Machinery	Machinery required for lifting, towing and shifiting requirments.
24	External Agencies	External services provides for radiator coring, rewinding, fuel pump and injectors calibrations, machining , reconditioning of engines, hoses and seals making.
25	Method rectification - MOR	Specific method of rectfication which provides details of work requirment for specific BMP Number in relation to the BRC (with details from start of the work to the completion of the work).

Table 6.31 Method Of Rectification (MOR) for BMP 24

Method of Rectification: BMP 24 (A5R1)
- To check the engine temperature, if it is heated do not open the thermostat valve.
- To reduce the pressure and drain the coolant water from the radiator.
- To open the thermostat housing cover and remove the thermostat valve.
- To clean thoroughly thermostat seating area.
- Apply packing paste and fix the packing.
- To fix the new thermostat valve and re-fix the housing.
- Thoroughly tight the all housing bolts.
- To plug the drain nut and fill up the coolant water at required level.
- To start the engine and check the leakages.

Table 6.32 MOR for BMP 47

Method of Rectification: BMP 47 (A17R1)
- To check the engine temperature, if it is heated do not remove the water pump.
- To reduce the pressure and drain the coolant water from the radiator.
- To loose the radiator top hose, bottom hose clips and radiator mountings after remove the radiator from the engine.
- To remove the fan belt, radiator cover and fan leaf.
- Remove the water pump from the engine.
- To dismantle the water pump.
- Change the seal and kit.
- To reassenble the water pump.
- To clean thoroughly water pump seating place.
- Apply packing paste on seating place.
- To fix gasket and water pump on engine.
- To re-fix fan belt radiator and fan assy.
- To tight the drain plug and fill up the coolant water at required level.
- To start the engine and check the leakages.

Table 6.33 MOR for BMP 48

Method of Rectification: BMP 48 (A17R2)

- To check the engine temperature, if it is heated do not remove the water pump.
- To reduce the pressure and drain the coolant water from the radiator.
- To loose the radiator top hose, bottom hose clips and radiator mountings after remove the radiator from the engine.
- To remove the fan belt, radiator cover and fan leaf.
- Remove the water pump from the engine.
- To clean thoroughly water pump seating place.
- Apply packing paste on seating place.
- To fix gasket and new water pump on engine.
- To re-fix fan belt radiator and fan assy.
- To tight the drain plug and fill up the coolant water at required level.
- To start the engine and check the leakages.

Table 6.34 MOR for BMP 82

Method of Rectification: BMP 82 (A38R1)

- To check the engine oil temperature, if it is heated do not remove the cooler & Radiater.
- To reduce the oil pressure and temperature.
- To drain the oil from cooler body.
- To drain the coolant oil from the radiater.
- To loose the radiater hoses & remove the radiater from the engine.
- Remove the cooler body from the engine.
- Remove the damaged gasket from the cooler body.
- To clean thoroughly gasket seating place.
- To check the pressure test on oil cooler.
- Apply packing paste on seating place.
- To fix new gasket on cooler body.
- To fix cooler body on engine.
- To check and clean the radiater.
- To fix the radiator and hoses as same.
- To plug the drain plug on radiater.
- To re fill the coolant oil in radiater at required level.
- To start the engine, check the leakages and pressure.

Table 6.35 MOR for BMP 84

Method of Rectification: BMP 84 (A38R3)
- To check the engine temperature, if it is heated do not remove the water pump. - To reduce the pressure and drain the coolant water from the radiator. - To loose the radiator top hose, bottom hose clips and radiator mountings after remove the radiator from the engine. - To remove the fan belt, radiator cover and fan leaf. - Remove the water pump from the engine. - To dismantle the water pump. - Change the seal and kit. - To reassenble the water pump. - To clean thoroughly water pump seating place. - Apply packing paste on seating place. - To fix gasket and water pump on engine. - To re-fix fan belt radiator and fan assy. - To tight the drain plug and fill up the coolant water at required level. - To start the engine and check the leakages.

6.9 Application of BMP ruler

A statistics presented by the Brazilian Association of Maintenance reveals that there is an increase in the percentage of corrective maintenance and reduces the share of preventive and predictive maintenance. The cost of maintenance versus gross revenue percentage at Brazil has been calculated at 4.14 % for the year 2009 (Bartz T. et al, 2011). Hence a world class competitiveness and maintenance approach is essential for industrial organizations and particularly to the construction industry. With the financial crisis in place all over the world, multi-tasking, globalization, venturing into new related fields, cutting of costs, ensuring effective utilization of the resources has become necessary for the organizations. To improve the systems reliability and availability there should be additional efforts are required. It is a necessity to evolve improvement methodologies and techniques for reliability and availability allocation amongst various units of a system with minimum effort (Aqqarwal et al, 1993). As the competition grows, there tends to be a technological push combined with the market pull, and the increased customer requirements at the reduced costs put forward lot of challenges for the organizations, who need to ensure effective utilization of their resources. As the cost of operation needs to be reduced, even the machinery manufacturers tend to make products, which may be subjected to speedy wear and tear possibilities and reduced life cycles and to add more, these plant and machinery need to work under higher stress always and hence the

failure on these machinery are inevitable and an effective tool for the same is always essential.

The application analysis of BMP with conventional breakdown management and the relative BMP inclusive methods indicate the reduction in the recovery time and breakdown costs. The BMP will also enable overall lead time reduction of the projects and further enhance the capabilities of the contractors to crash down the construction time. BMP supports the entire breakdown process to be focused and targeted and paves the way for the maintenance crew to manage quick recovery of the construction plant breakdowns with ease of mind and solve the same in an effective manner. The proposed BMP is highly adaptable to similar industries and various other industries operating in the Middle East and other regions.

The BMP consolidated resource sheet is shown below in Table 6.36, which indicates the breakdown sub code, symptom code and the reason code. The resource requirements are clearly tabulated which will be used by the maintenance coordinator upon information received from the mechanic/operative on the breakdown reason code and the relative BMP number.

Table 6.36 BMP Consolidated Resource Sheet with Maintenance Supervisor

BREAKDOWN MAINTENANCE RULER [AA2 - A5 - (A5S1/A5S2/A5S3) - A5R1] | **BREAKDOWN MAINTENANCE PROTOCAL - BMP 024**

Main Code: Code	Main Code: Description	Breakdown Subcode: Code	Breakdown Subcode: Description	Breakdown Symtoms: Code	Breakdown Symtoms: Description	Breakdown Reasons: Code	Breakdown Reasons: Description	Estimated Repair Time: Hrs	Estimated Repair Time: Mins	Safety Officer	Supervisory Skills: Engr	Supervisory Skills: SSP	Supervisory Skills: SUP	Supervisory Skills: FMN	Operator For Inspection	Breakdown Vehicle	Recovery Vehicle	External Agency / Dealers	Tools: Hand Tools	Tools: Power Tools	Tools: Special Tools	Tools: Auto Electrical Tools	Technician Category/Rate: SM	M	AM	MH	AE	TM	TK	Spares	Consumables	Work Place	Machinery
AA2	Engine Over Heating (Cooling System)	A5	Thermostat Failure	A5 S1	Temperature point indicating on dash board.	A5R1	Spring / Washer failure	-	30	N/A	-	-	√	-	N/A	√	N/A	N/A	√	N/A	N/A	√	-	A	-	-	-	-	-	Thermostat Valve / Packing / Paste	Coolant / Cotton Waste	Required	N/A
				A5 S2	Engine Over heated but radiator not heated.																												
				A5 S3	Temperature Suddenly raised.																												

Method of Rectification:

- To check the engine temperature, if it is heated do not open the thermostat valve.
- To reduce the pressure and drain the coolant water from the radiator.
- To open the thermostat housing cover and remove the thermostat valve.
- To clean thoroughly thermostat seating area.
- Apply packing paste and fix the packing.
- To fix the new thermostat valve and re-fix the housing.
- Thoroughly tight the all housing bolts.
- To plug the drain nut and fill up the coolant water at required level.
- To start the engine and check the leakages.

BREAKDOWN MAINTENANCE RULER [AA2 - A17 - A17S4 - A17R2] | **BREAKDOWN MAINTENANCE PROTOCAL - BMP 048**

Main Code: Code	Main Code: Description	Breakdown Subcode: Code	Breakdown Subcode: Description	Breakdown Symtoms: Code	Breakdown Symtoms: Description	Breakdown Reasons: Code	Breakdown Reasons: Description	Estimated Repair Time: Hrs	Estimated Repair Time: Mins	Safety Officer	Supervisory Skills: Engr	Supervisory Skills: SSP	Supervisory Skills: SUP	Supervisory Skills: FMN	Operator For Inspection	Breakdown Vehicle	Recovery Vehicle	External Agency / Dealers	Tools: Hand Tools	Tools: Power Tools	Tools: Special Tools	Tools: Auto Electrical Tools	Technician Category/Rate: SM	M	AM	MH	AE	TM	TK	Spares	Consumables	Work Place	Machinery
AA2	Engine Over Heating (Cooling System)	A17	Water Pump Leak	A17S4	Engine coolant excessive consumed / leak.	A17R2	Water pump shaft	1	-	N/A	-	-	√	√	Required	Required	N/A	N/A	√	N/A	√	√	-	B	A	-	-	-	-	Pump assy / Coolant / Gasket Packing / Paste	Coolant / Cotton Waste / Hand Gloves / Bearing	Required	N/A

Method of Rectification:

- To check the engine temperature, if it is heated do not remove the water pump.
- To reduce the pressure and drain the coolant water from the radiator.
- To loose the radiator top hose, bottom hose clips and radiator mountings after remove the radiator from the engine.
- To remove the fan belt, radiator cover and fan leaf.
- Remove the water pump from the engine.
- To clean thoroughly water pump seating place.
- Apply packing paste on seating place.
- To fix gasket and new water pump on engine.
- To re-fix fan belt radiator and fan assy.
- To tight the drain plug and fill up the coolant water at required level.
- To start the engine and check the leakages.