LIST OF TABLES

Table No.	<u>Title</u>	Page No
1.1	Compilation of Questionnaire Results on Breakdown Maintenance of Construction Plant and Machinery	4
4.1	Breakdown Strategies on Construction Machinery	60
5.1	Preventive Maintenance Lags due to Machinery Breakdowns	79
5.2	Types of Construction Machinery	80
5.3	Breakdown Consequential Costs – Dumper breakdowns	91
5.4	Consequential Losses of Breakdowns with Durations	92
5.5	Average Cost Per Breakdown	94
5.6	Critical Machinery based on Breakdown Ratio (2007 - 2011)	96
5.7	Selected Machinery Contributions to Breakdowns (2007- 2011)	98
5.8	Consolidated Breakdown Details of Components - Dumper (2007 - 2011)	106
5.9	Consolidated Component Details with BD Percentage - Dumper (2007 - 2011)	107
5.10	Reliability Analysis Results - Dumper (2007 - 2011)	107
5.11	Consolidated Breakdown Details of Components - Wheel Loader (2007 - 2011)	112
5.12	Reliability Analysis Results for Wheel Loader (2007 - 2011)	112
6.1	Analysis of failures on systems of Wheel Loader (2007 - 2011)	120
6.2	Analysis of Failures on systems of Dumper (2007 - 2011)	120

6.3	List of Breakdown Main Code (BMC) and Breakdown Sub Code (BSC)	125
6.4	Critical BMC for Dumper from Pareto Analysis	137
6.5	Critical BMC for Wheel Loaders from Pareto Analysis	140
6.6	Cumulative Effect Analysis of BMC with BSC for Wheel Loader	141
6.7	Cumulative Effect Analysis of BMC with BSC for Dumper	141
6.8	Effect of Reduction in BMC with Pareto Analysis	142
6.9	Details of Codes reduced from Pareto Analysis for machinery	143
6.10	FMEA for Engine Oil and Coolant Oil Mixing	145
6.11	FMEA for Front Bucket Automatic Lowering During Operation	146
6.12	FMEA for Engine Overheating	147
6.13	FMEA for Oil Pump Problem (Engine Low Oil Pressure)	148
6.14	FMEA for Control Valve not working - Slow Operating Speed	148
6.15	FMEA for Alternator Problem - Starting Trouble	149
6.16	Consolidated FMEA details for Sub Codes	150
6.17	Identified Symptom Codes and Reason Codes from FTA	153
6.18	List of identified Breakdown Symptom Codes and Breakdown Reason Codes	156
6.19	Codes Relations Chart to be used with the BMP Ruler	171
6.20	Breakdown Main Code List	174
6.21	Breakdown Sub Code List	175

6.22	Breakdown Symptom Code List	176
6.23	Breakdown Reason Code List 1	177
6.24	Breakdown Reason Code List 2	178
6.25	Breakdown Main Codes - Details of Arrangement	179
6.26	Breakdown Sub Codes - Details of Arrangement	181
6.27	Breakdown Symptom Codes - Details of Arrangement	183
6.28	Breakdown Reason Codes - Details of Arrangement	185
6.29	Breakdown Maintenance Protocol (BMP) Resource Sheet	190
6.30	Protocol Resource Details	191
6.31	Method of Rectification (MOR) for BMP 24	192
6.32	MOR for BMP 47	192
6.33	MOR for BMP 48	193
5.34	MOR for BMP 82	193
5.35	MOR for BMP 84	194
5.36	BMP Consolidated Resource Sheet with Maintenance Supervisor	196
7.1	Breakdown Data Sheet for BSC D18	215
7.2	Breakdown Data Sheet for BSC D6	217
7.3	Breakdown Data Sheet for BSC A6	219
7.4	Breakdown Data Sheet for BSC J2	221

LIST OF FIGURES

Figure no.	<u>Title</u>	Page no
1.1	Survey Results on Breakdown Maintenance Concepts and Beliefs for Construction Machinery	5
1.2	Survey Results on Breakdown Maintenance Crew Stress Level during Breakdowns on Construction Machinery	5
1.3	Survey Results on Needs of Breakdowns Maintenance Optimization for Construction Machinery	6
4.1	General Categories of Construction Plant and Machinery	53
4.2	Procedural Objectives to Maintenance of Construction Machinery	57
4.3	Reasons for Failures / Breakdowns on Construction Machinery	59
4.4	Results of Unplanned Breakdowns to Construction Machinery	63
4.5	Quality Attributes of Breakdowns	64
4.6	Newer Developments in Maintenance Strategies	65
4.7	Conventional Flow Process of Breakdown Maintenance Execution	68
5.1	Cumulative Consequential Cost Effect Model – For construction machinery	90
5.2	Cumulative Cost Effects during Breakdowns with durations	93
5.3	Bathtub Curve on Failures	102
5.4	Component Block Diagram - Dumper	106
5.5	Reliability Value Bar Chart for Dumper Components (2007 - 2011)	108
5.6	MTBF Value Bar Chart for Dumper Components (2007 - 2011)	108
5.7	MTTR Value Bar Chart for Dumper Components (2007 - 2011)	109

5.8	Availability Value Bar Chart for Dumper Components (2007 - 2011)	109
5.9	Component Reliability with System Reliability for Dumper (2007 - 2011)	110
5.10	Component Block Diagram Wheel Loader	111
5.11	Reliability Values Bar Chart for Wheel Loader Components (2007 - 2011)	113
5.12	MTBF Values Bar Chart for Wheel Loader Components (2007 - 2011)	112
5.13	MTTR Values bar Chart for Wheel Loader Components (2007 - 2011)	114
5.14	Component Reliability and System Reliability of Wheel Loader (2007 - 2011)	114
6.1	Breakdown Process with records analysis	119
6.2	CEA Diagram - Basic Failures in Construction Machinery	122
6.3	Basic Engine Failures - BMC Identification	123
6.4	BSC Analysis from BMC	123
6.5	CEA Diagram for Transmission Failures	124
6.6	Pareto Analysis for Dumper BMC – 2007	135
6.7	Pareto Analysis for Dumper BMC – 2008	135
6.8	Pareto Analysis for Dumper BMC – 2009	136
6.9	Pareto Analysis for Dumper BMC – 2010	136
6.10	Pareto Analysis for Dumper BMC – 2011	137
6.11	Pareto Analysis for Wheel Loader BMC – 2007	138
6.12	Pareto Analysis for Wheel Loader BMC - 2008	138

6.13	Pareto Analysis for Wheel Loader BMC – 2009	139
6.14	Pareto Analysis for Wheel Loader BMC – 2010	139
6.15	Pareto Analysis for Wheel Loader BMC – 2011	140
6.16	Fault Tree Analysis for BMC - Engine Oil and Coolant Oil Mixing	152
6.17	FTA Process for Engine Overheating (BMC) to Sub Codes, Symptom Codes and Reason Codes	153
6.18	FTA Process for Hydraulic Ram Slow to Operate to Sub Code, Symptom Code and Reason Code	154
6.19	Complete Process of Identifying Breakdown Codes	155
6.20	Medical Protocol – Flow Process	167
6.21	BMP Ruler - First Ring	180
6.22	BMP Ruler - Second Ring	182
6.23	BMP Ruler - Third Ring	184
6.24	BMP Ruler - Fourth Ring	186
6.25	BMP Ruler Assembled - Back Side	187
7.1	Breakdown Maintenance Management Model – The Approach	203
7.2	Breakdown Maintenance Management (BMM) Model – Flow Process	204
7.3	BMP Application – Process Flow	206
7.4	BMM Model – Application Process	209
7.5	Impact of BMM on Conventional Breakdown Flow Process	210
7.6	Active Breakdown Rectification Time	212

7.7	BSC D18 / Wheel Loader - Conventional Vs. BMM	216
7.8	BSC D6 / Dumper – Conventional Vs. BMM	218
7.9	BSC A6 / Dumper – Conventional Vs. BMM	220
7.10	BSC J2 / Wheel Loader – Conventional Vs. BMM	222
7.11	Breakdown Analysis Summaries – Comparison – Conventional Vs. BMM	223

ABBREVIATIONS

AED Arab Emirates Dirhams

AME Africa and Middle East

ASCON Associated Construction & Investments Company

BD Break Down

BITS Birla Institute of Technology and Science

BMA Breakdown Maintenance Activities

BMC Breakdown Main Code

BMI Business Monitor International

BMP Breakdown Maintenance Protocol

BPA Business Process Analysis

BRC Breakdown Reason Code

BSC Breakdown Sub Code

BSyC Breakdown Symptom Code

CAGR Compound Annual Growth Rate

CBM Condition Based Maintenance

CEA Cause Effect Analysis

CI Continuous Improvement

CP Cumulative Percentage

DOM Design Out Maintenance

ECM Electronic Control Modules

EMS Emergency Medical Services

EMT Emergency Medical Technician

ETA Emirates Trading Agency

FC Fitness Certificate

FMEA Failure Modes and Effects Analysis

FR Failure Rate

FTA Fault Tree Analysis

FTP File Transfer Protocol

GCC Gulf Cooperation Council

GDP Gross Domestic Product

GFC Global Financial Crisis

GPRS General Packet Radio Service

GPS Global Positioning System

HTTP Hyper Text Transfer Protocol

IP Internet Protocol

JCB J C Bamford

JIT Just In Time

LLC Limited Liability Company

LROA Lloyd's Register Quality Assurance

MB2M Modified Breakdown Maintenance Management

MEDCOM United State Army Medical Command

MEED Middle East News Data and Analysis

MM Maintenance Management

MOR Method of Rectification

MTBF Mean Time Between Failures

MTTR Mean Time To Repair

MWRA Massachusetts Water Resources Authority

OEE Overall Equipment Effectiveness

OHSAS Occupational Health and Safety Advisory Services

PM Preventive Maintenance

PMS Preventive Maintenance Schedule

PNM Plant and Machinery

POL Petroleum, Oil, Lubricants

RAM Random Access Memory

S Curve Sigmoid Curve

SKU Stock Keeping Units

SOP Standard Operating Procedure

TCP Transfer Control Protocol

TQM Total Quality Maintenance

TPM Total Productive Maintenance

UAE United Arab Emirates

VSM Value Stream Mapping

W Loader Wheel Loader

WMS World-Class Maintenance System