

MAINTENANCE ENGINEERING BUREAU USING MAINTENANCE DATA TO DRIVE IMPROVEMENT

S Safi & B Bigdeli
Covaris Pty Ltd

Summary: This paper presents an objective methodology for maintenance data analysis. The purposes of these analyses are to identify strengths and weaknesses in the maintenance management system, opportunities for improvements, and benchmark maintenance key elements against maintenance best practice. A wide range of reports can be provided from analysing the data from computerised maintenance management systems. These reports can be categorised as Performance Reports, Benchmarking Reports, Optimisation Reports, and Data Integrity Reports.

Failure Modes and Effect Analysis is one of the main outcomes of the maintenance engineering bureau services. This analysis is an easy to use and yet powerful, proactive maintenance engineering method, which can identify potential failure modes, determine their effect on the maintenance costs, and identify actions to mitigate the failures. The results of the analyses of the various maintenance system data sets based on the developed methodology are presented.

Keywords: Maintenance Systems, Maintenance Reporting, FMEA, Weibull Analysis.

1 INTRODUCTION

The purpose of the Maintenance Engineering Bureau Service is to provide a third party objective maintenance data analysis for companies. This analysis is expected to be performed by skilled maintenance engineers on a regular basis, allowing companies to effectively contract out their maintenance data reporting, as well as gain the benefit of benchmarking results against comparable industries. The reports generated from the information analysis fall into the following categories.

Performance Reports: These are process specific reports that identify process capability and maintenance performance. Included in this set of reports will be the Maintenance Key Performance Indicator's (KPI's) of a company; however they are not the entire set of reports. These reports will often point towards areas of process improvement opportunities and may be quite specific. The best presentation of data will require targets for measures that have been agreed to by the business. These targets will be obtained during an initial plant audit.

Benchmarking Reports: These reports for an individual process or manufacturing facility may be meaningless, however, when compared to other plants in similar industry, they can show a requirement for improvement.

Optimisation Reports: These reports differ from Performance reports as these are used to manipulate the data that drives the maintenance system. They are designed to assist in optimising the maintenance processes for changes in business requirements. Included in these reports are those that are used to increase the accuracy of current data (often in conjunction with a manual review).

Data Integrity Reports: These reports are used to judge the quality of data being captured. Information found in the performance reports may only be considered accurate if the system is being used in a manner that ensures the data is reliable. These reports point to not only whether data is being captured completely (according to business requirements), but also to assure that accurate data is being recorded (not just defaults etc.).

It is envisaged for any particular company, large amount of reports could be available for creation. Failure Modes and Effect Analyses (FMEA) is the main outcome of the bureau services. FMEA presented in this paper is an easy to use and yet powerful proactive maintenance engineering method. FMEA is used to identify potential failure modes, determine their effect on the maintenance costs, and identify actions to mitigate the failures.

In general, FMEA is a disciplined approach used to identify every possible failure mode of a process or product and to determine its effect on other sub-items and on the required function of the product or process. The FMEA is also used to rank

and prioritize the possible causes of failures, determine the frequency and impact of the failure as well as develop and implement preventative actions (1). This analysis is a costly and time-consuming exercise, which is normally justified for high critical items or equipment with serious failure consequences.

However, the FMEA presented in this paper is a quick approach, which analyses the corrective maintenance work orders from a maintenance system. It captures work orders from the Computerised Maintenance Management System (CMMS) and allocates selected work orders to defined failure modes. It also specifies, what equipment is affected by a selected failure mode, what is the total cost of the work, and what is the total amount of labour hours spent on work for each particular failure mode. This exercise is performed by analysing historic data collected by the CMMS and includes all assets captured in the system.

2 ELEMENTS OF MAINTENANCE SYSTEM

Before analysing data from maintenance systems it is important to understand the key elements of the maintenance system. This section presents the key elements of a well-structured maintenance management system (2). The first element is a plant dictionary that has all maintainable equipment listed in hierarchical form. The next element is the development of a comprehensive and efficient maintenance procedure database, which should also include safety procedures as they relate to maintenance tasks. The third element is a master schedule that ensures all registered equipment is covered by an appropriate maintenance strategy. The last element is monitoring maintenance management system with a reporting system. All this information is linked together in a Computerised Maintenance Management System (CMMS). The CMMS will allow efficient handling of the data and appropriate planning of scheduled work. The CMMS will also store equipment data that can be helpful in future review of current maintenance strategies and help identify which items can benefit the organization if further improvements are made to the maintenance system.

2.1 Plant Dictionary

The level of detail that is necessary for adequate maintenance system design is quite extensive. This is often a major problem to the improvement team given the poor state of documentation and local knowledge regarding some machines, despite their criticality to the process.

We recommend the plant dictionary to be structured according to a parent-child hierarchy. The lowest level in the hierarchy is a maintainable item that needs to be checked or inspected – a PM work order is not usually provided for an item at this level but is more normally associated with a singular task such as a corrective maintenance work order or a breakdown.

The second tier is used to logically identify a group of maintainable items – the PM work order covering one or more inspections is assigned to an entity at this level, which normally identifies the equipment types (e.g. boiler). The top tier is a multiple layer of levels, which identifies a department.

The plant dictionary includes important equipment information such as manufacturer, date of supply, serial number, criticality, equipment and location identifiers.

2.2 Maintenance Procedures and Routines

This section is concerned with the identification and specification of Maintenance Strategies. These are procedures that specify a range of tasks for a specific equipment type. A maintenance strategy for an equipment type is a set of procedures, which covers all preventive maintenance activities for that asset base. These strategies will be subsequently allocated to many incidents of the same type of equipment across the site.

Assigning a procedure to a specific item of equipment creates a routine. Specifying the timing of the first release of the routine as a work order is an important issue to obtain a balanced workload during the year and avoid the backlog built-up during the busy period of the year for a particular site. Adjusting the duration of the routine is required to allow for either travel or access to the equipment.

2.3 Master Maintenance Schedule

Preventive maintenance work needs to be planned which sets out the generation of preventive works. Specifying the timing of the first issue of a routine as a work order is accomplished by Master Maintenance Schedule (MMS) worksheets.

In developing the MMS, scheduler defines the first release of each routine, which will automatically allocates the subsequent dates when the routine is due. The master PM scheduler provides a forecast of all work-orders for the planned PMs. The scheduler can then check the workload for each trade or the total workload for the preventive maintenance for the entire site or a particular department. These will help the scheduler to examine the effectiveness of the scheduling process and to avoid congestion in any particular week, during the busy period of the year or for a specific work group.

An Implementation Plan for the go-live of the PM system is also an important part of a well-defined MMS. It is important to define a smooth path from breakdown maintenance to a planned maintenance system. It will provide sufficient information for developing a smooth transition in the plant considering available resources and existing workloads on maintenance crews.

2.4 Reporting Key Performance Indicators

A healthy maintenance management system should always be monitored with appropriate reporting system. Key performance indicators (KPIs) form the basis of the monitoring process for performance-based maintenance. Use of various KPIs will be dependant on the capability of the information system to provide accurate data for calculation purposes. Most CMMSs are capable of capturing most of the information necessary for these KPIs. Others should be developed in collaboration with production departments and require more involvement from the management to become alive (3). The remaining sections of this paper provide a wide variety of reports which can be set up for monitoring the performance of a maintenance management system.

3 FAILURE MODES AND EFFECT ANALYSES

FMEA is an effective engineering tool for analysing data from maintenance systems. The FMEA is used to identify failure modes of the maintainable equipment and the effects of these failures. FMEA analysis can be used to specify the areas where improvements can have substantial impact.

Traditional FMEA as explained in MIL-STD-1629A identifies maintenance plan analysis as an application for FMEA (4). Other applications identified by this Standard include “The FMEA shall also be used to define special test considerations, quality inspection points, preventive maintenance actions...”.

However, the FMEA presented in this paper is a quick approach, which analyses the corrective maintenance work orders from a maintenance system as explained in this section.

A Software called MaintSpeak has been developed to perform FMEA analysis (5). The FMEA analysis of the corrective maintenance work orders from a maintenance system (independent of CMMS in use) has the following methodology:

- A first cut of work orders is allocated to a set of primary failure modes derived on inspection from the work orders – hence this first cut process achieves the following:
 - Specifies the primary failure modes
 - Makes some bulk allocations of work orders to these failure modes
 - Identifies that portion of the work order data set which will not be allocated to failure modes since the work is more to do with housekeeping, etc
- A second, finer cut is made where a primary failure mode with a very large grouping of work orders is broken out into a number of more specific failure modes, and the accuracy of the work order allocation is improved by a more detailed view of each registered failure mode (in the first cut, the thousands of work orders were viewed and considered, when making the second cut the tens to hundreds of work orders allocated to a failure mode were considered)
- Each primary failure mode is then considered in detail and a set of very specific “secondary failure modes” is derived. The logic is that a PM work order is intended to address the failure mode and the operations within a PM are intended to address each of the secondary failure modes.
- The list of work orders allocated to each failure mode is then considered, and the effects of the failure mode are specified by:
 - The range of equipment affected by the failure mode – as determined by the equipment associated with work orders allocated to the failure mode
 - The sum cost of work orders allocated to a failure mode - the software also handles the sum amount of labour hours.
 - The Mean Time To Failures MTTF for each failure mode – this has been derived from a Weibull analysis of the work order data set allocated to each failure mode.

3.1 FMEA Case Study

The case study presented in this section is the application of the FMEA analysis explained in this paper for analysing data from maintenance system of a food factory (6).

The failure modes detected for the factory were based on a study of 21,624 corrective work orders with 17,148 allocated to a failure mode, noting that the General failure mode which is used as a catch-all contained 1,068 work orders. Hence 16,080 work orders were attributed to useful failure modes, which represent 74% of the data. It would be preferred to see over 80% so attributed but found it necessary to dump numbers of work orders into the General category since they represented highly infrequent failure modes (i.e. less than 5 work orders for the failure mode over the period of four years).

Failure modes and their impact on the plant are tabulated below. This body of work represented \$6.11M of maintenance costs over four years. A plot of the top 10 failure modes is shown in Figure 1. The N Equip refers to the number of equipment which are affected by the relevant failure mode.

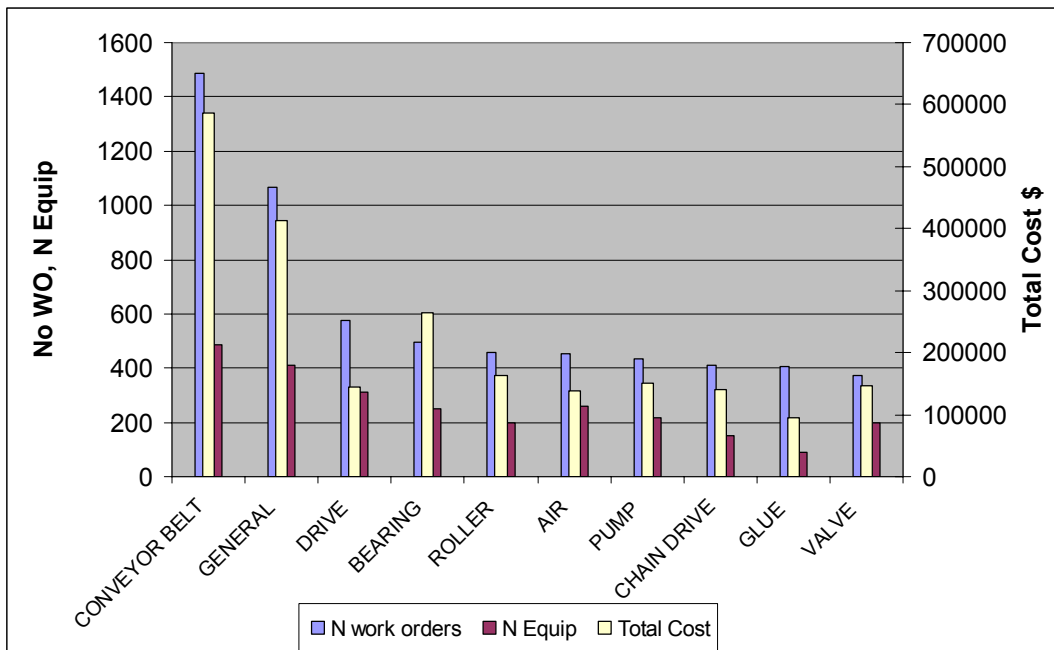


Figure 1 Top 10 Primary Failure Modes

It can be seen that failure modes associated with rotating items (i.e. drives, bearings, rollers, pumps, chain drives and drive belts) dominate the list of top 10 failure modes. We also note that conveyor belt issues tend to be the most dominant failure mode in most food factories that we have studied so far. In this instance, 346 conveyors are affected by this failure mode. The secondary failure modes are represented by the following work order work statements are shown in Table 1.

CONVEYOR BELT	
0	Repair infeed conveyor
1	Repair broken flight lug
2	Repair broken flat belt on grister mill
3	Repair belt joins
4	Repair tensioning mechanism
5	Eliminate spills at sides of belt
6	Conveyor belt keeps tracking off
7	Torn belt
8	Bars catching on crossover conveyor
9	Conveyor gate not operating properly
10	Conveyors out of alignment
11	Conveyor jammed reset o/load

Table 1 Secondary Failure Modes for Conveyor Belt

3.2 Annual Trend

The annual trend of the top 10 failure modes is provided below. In general the 2004 results exhibited a step change upwards in numbers of registered failure modes. This is a direct function of the increased use of the CMMS in 2004.

The number of jobs in the table have been normalised on the basis of total number of jobs recorded in the CMMS for any given year. This allowed a more accurate understanding of possible growth in any specific failure mode. Hence the figures below represent %content of total work order set for the year represented by the work orders specific to the nominated failure mode.

Year	2002	2003	2004	2005
No of Work Order	805	4509	14707	1597
Failure Mode	%			
Conveyor Belt	6	7	7	8
General	4	5	5	4
Drive	2	2	3	3
Bearing	4	3	2	1
Roller	3	2	2	2
Air	2	3	2	2
Pump	2	2	2	1
Chain Drive	2	2	2	2
Glue	0	1	2	2
Valve	2	2	2	1
Belt	1	1	2	2

Table 2 Annual Trend of the Top 10 failure Modes

Using the normalised view of the data, the following comments can be made:

1. Bearings have shown considerable improvement due to a condition motoring program started in 2004.
2. It is disappointing to see Drive problems increased – this primarily refers to electric motor issues.
3. It is a characteristic of plants where PM improvement is very much needed is that “simple” failure modes persist. Examples of what we call simple failure modes include chains and belts. Both of these modes are on the top 10 list and we would consider these modes as being amenable to treatment by improvement in routine PM work. We noted that belt related problems have increased and chain drives have remained steady.
4. Issues with conveyor belts are increasing, which need further attention.

3.3 Weibull Analysis

Weibull analysis is used to test the shape factors and MTTF of various primary failure modes. The rule of thumb for Weibull results is as follows (6):

- Beta values (shape factors) of less than 1 are very rare and would represent a gross design problem more than anything else. This would be where an item was continually being replaced almost as soon as it entered service.
- Beta values of between 1.3 and 1.7 indicate one of two possibilities: there are multiple failure modes in the category or more likely, there is a manageable driver on the defect rate such as maintenance quality of work or operational cleanliness.
- Beta values between 1.7 and 2.2 represent achieving a respectable life but there is scope for improvement in the PM strategy.
- Beta values greater than 2.5 mean that the PMs are doing their job and there is no operational driver to early failure such as cleanliness or overload.

These descriptions would not be found in the textbooks but represent our experience in analysing the trends in maintenance work orders.

The Weibull plots all tend to look the same but the key characteristics are:

- The shape factor
- The x intercept – which is the likely minimum time to failure

The MTTF does not particularly help us since we are taking a lot of data over the period of four year, and hence this tends to remain between 150 to 220 days for just about all failure modes. We are interested to find out if the failure is being driven by something we can manage (ie the shape factor), and whether we are going to see a potential failure every day, every week or every month. Since we are dealing with high frequency failure modes in this section (ie the top 10), their potential to occur will be at least once a week. A typical plot is shown in Figure 2.

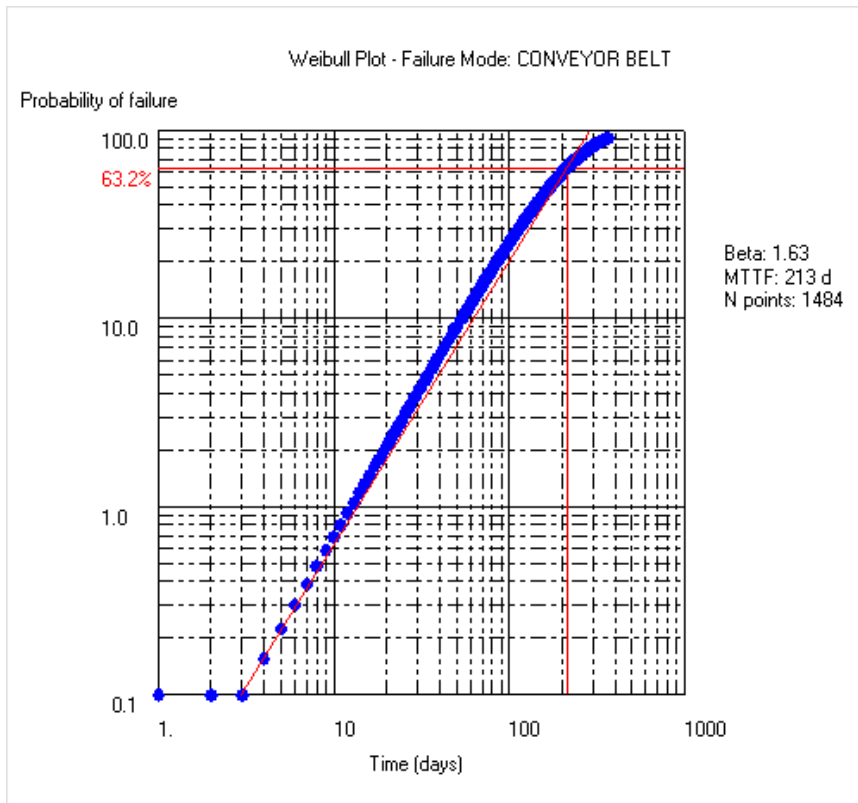


Figure 2 Weibull Plot for the First Failure Mode - MaintSpeak Plot (5)

This result has a low shape factor (<2) indicating that it is not a wear out condition – we expect there are contributing factors such as past maintenance and/or operational cleanliness driving this failure mode (6).

Minimum time to failure is about twice a week when the intercept with the x-axis is considered.

4 EXPLANATION OF SAMPLE REPORTS

FMEA process described in previous section was based on analysing corrective work orders history. This section, however, presents a systematic approach in evaluating maintenance performance, and some types of reports that can be expected for the bureau service to provide are presented. This is not the entire suite of reports, but is a large enough sample to demonstrate the type of required information that will need to be processed.

PM Scheduling Optimisation: Proper scheduling of works is a common issue in almost all maintenance departments. To check the PM scheduling program, we generate a forecast of the whole PM schedules for the next 12 months. The number of work orders and the workload will be calculated against the weeks. The report will show that how effective PM schedules have been setup. If the works load (Number of work orders if the work load is not available) is not distributed evenly over the weeks, the site needs to improve its PM scheduling process.

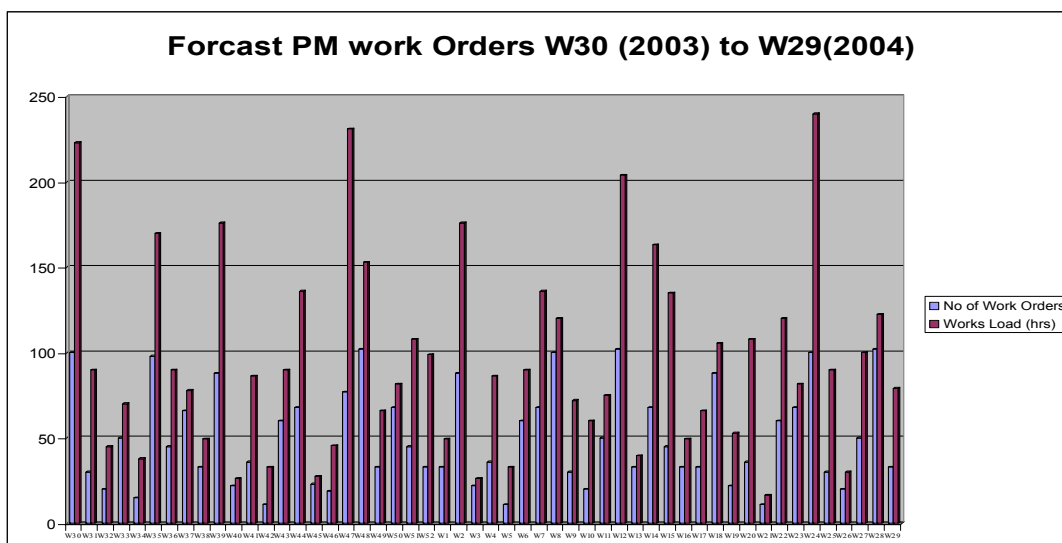


Figure 3 Forecast PM Work Order for One year Period.

Work Type Ratio: This report displays the ratios of maintenance work by the type of work that is being performed, and the report is determined by the number of work orders. An example of the distribution of work types across the key maintenance areas is shown in Figure 4. Ratio of the reactive work (B) to all work may be compared to best practice figure of 15% (the lower the figure the better the result). Table 3 gives the description of work type used at the particular site.

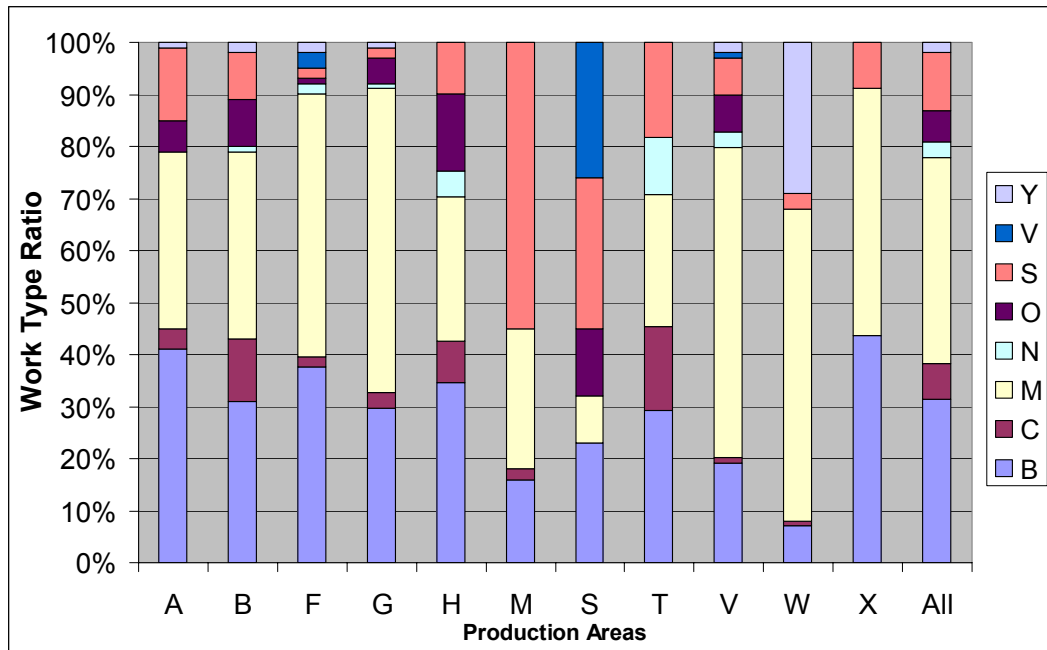


Figure 4 Work Type Ratios per Production Areas (7).

Work Type	Description
B	Breakdown
C	Corrective
M	Maintenance / Overhaul
N	New / Project Work
O	Product Change Over
S	Service – including all preventative
V	Condition Monitoring
Y	Safety.

Table 3 Maintenance Work Types

% PM work orders in weekly schedule: This report is one of the Key Performance Indicators (KPI) which we considered for assessing the health of maintenance system. Figure 5 shows an example of this KPI in a food factory. The chart may be compared to best practice figure of 80% (the higher the figure the better the result). The calculated KPI for the site is only 19%. Any value below 40% for this metric represents a state of breakdown maintenance.

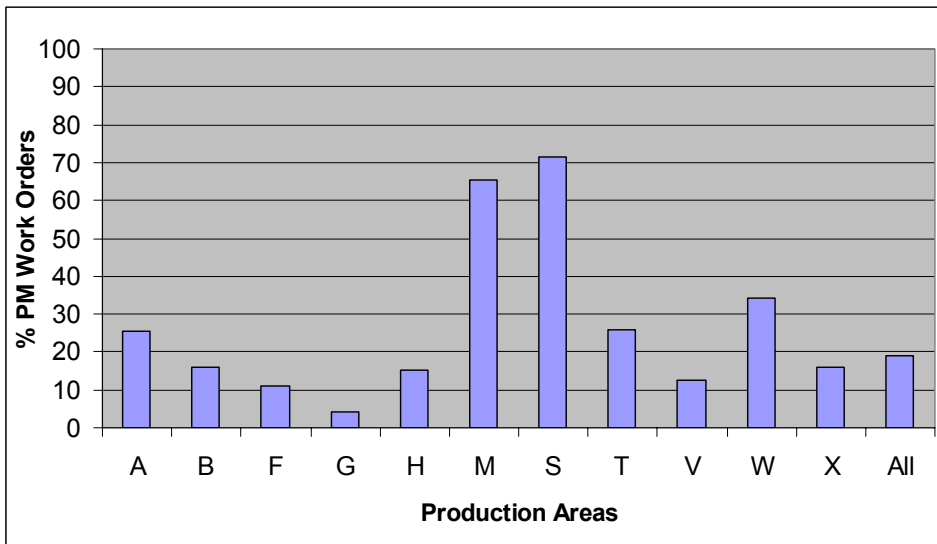


Figure 5 % of PM Work Orders in Weekly Schedule (7).

%Work completed in a week which was scheduled the week before: This report is the second KPI which we considered in analysis of maintenance system. Figure 6 shows an example of this KPI which is from the same food factory. The chart may be compared to best practice figure of 85% (the higher the figure the better the result). The calculated KPI for the site is 68% which points toward a good maintenance practice.

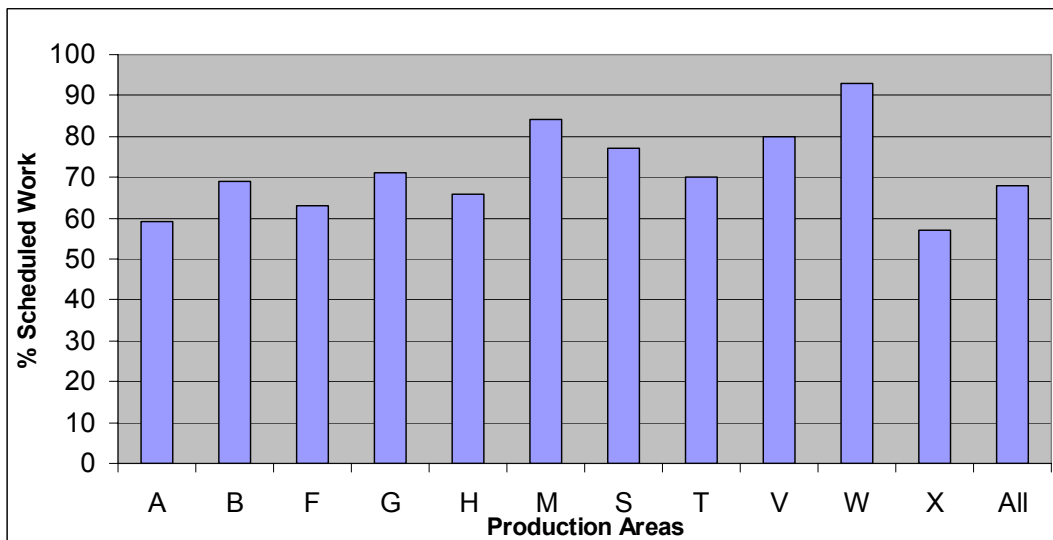


Figure 6 %Work completed in a week which was scheduled the week before (7).

Maintenance Backlog: This report will help a maintenance department in determining which work is most important to conduct, on the basis of the risk, and the time overdue. Each point on the graph represents a work order that is in the backlog.

In this analysis we have correlated the requested task priority, described by Table 4, against the time in backlog for tasks. 30% of the work is in excess of 500 days, and 7% are in excess of 1000 days. We expect that such work will either already have been done and has not been closed out, or will never proceed.

The red line in Figure 7 represents the business rule for managing backlog based on Table 4. Hence all work orders to the right of the red line is outstanding for too long.

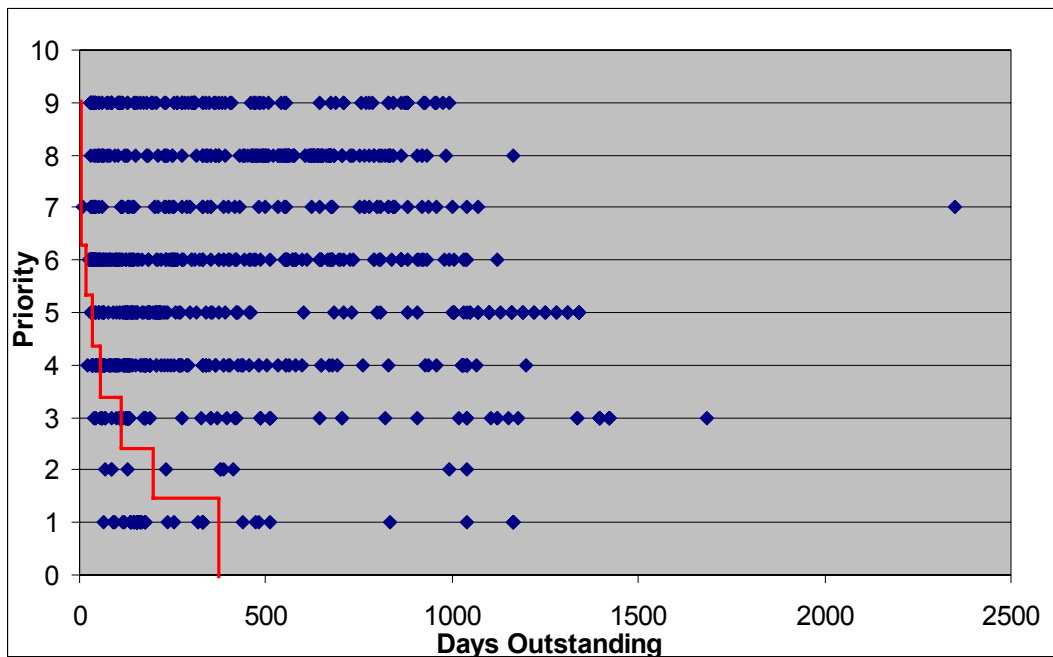


Figure 7 Backlog Analysis for Priority (8).

Attend to immediately.	9
Complete today.	8
Complete within 2-3 days.	7
Complete within one week.	6
Complete within two weeks.	5
Complete within one month.	4
Complete within three months.	3
Complete within six months.	2
Complete in this budget year.	1

Table 4 Work Order Priority

5 CONCLUSIONS

This paper presented a methodology to analyse maintenance data sets from a broad range of computerised maintenance management systems. The purposes of these analyses are to identify strengths and weaknesses in the maintenance management system and opportunities for improvements. The developed methodology to perform failure modes and effect analysis was described. Easy to use and yet powerful software have been developed to facilitate FMEA. It captures work orders from the CMMS and allocates selected work to defined failure modes. It also specifies which equipment is affected by a selected failure mode, what is the total cost of the work and what is the total amount of labour hours spent on work in this mode. Weibull analysis is also used to test the shape factors and MTTF of the various failure modes. The results from various case studies, showing outcomes from FMEA and Weibull analysis and wide range of reports, which can be provided from analysing the computerised maintenance management system data sets were presented.

6 ACKNOWLEDGEMENTS

The authors acknowledge the input of work colleagues at Covaris Pty Ltd and the many clients and research partners who have contributed to this work.

7 BIBLIOGRAPHY

1. iSixSigma website, [http://www.isixsigma.com/dictionary/Failure_Modes_and_Effects_Analysis_\(FMEA\)-86.htm](http://www.isixsigma.com/dictionary/Failure_Modes_and_Effects_Analysis_(FMEA)-86.htm)
2. S. Safi, S. Mozar, "From Reactive Maintenance to Proactive Preventive Maintenance System," The International Conference of Maintenance Societies, ICOMS-2004, paper 029, pp. 1-8, May 25 – 28, 2004, Sydney, Australia.

3. R. Platfoot, Informed Maintenance Planning, Integrated Maintenance Summit'98, IIR Pty. Ltd., Sydney (1998).
4. MIL-STD-1629A Military Standard Procedures for Performing a Failure Mode, Effects and Criticality Analysis, 24 November 1980.
5. MaintSpeak, FMEA Analysis Software, Covaris Pty Ltd, 2005.
6. R. A. Platfoot, A. Banks, Report on SAP PM Maintenance History, Covaris Pty Ltd, Unpublished Internal Document for a food industry company (2005).
7. S. Safi, Report on Maintenance Improvement, Covaris Pty Ltd, Unpublished Internal Document for a food industry company (2004).
8. S. Safi, R. A. Platfoot, Report on Maintenance Improvement, Covaris Pty Ltd, Unpublished Internal Document for a power industry company (2004).