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TRAINING MATERIAL IN MAINTENANCE MANAGEMENT

HANDBOOK

WITH THE SUPPORT
OF THE EUROPEAN COMMISSIONS LEONARDO DA VINCI PROGRAMME
AND THE STATE SCHOLARSHIPS FOUNDATION OF GREECE

CONTENTS

_/1 Introduction to the TRAIN-IN-MAIN Handbook

Dear Reader,

This material, developed as part of the Train-In-Main project, represents a guide in the form of a series of modules, which has been designed and developed to support maintenance management in European Small-Medium Enterprises (SMEs). It is the outcome of a trans-national partnership and is partly funded by the Leonardo da Vinci Programme of the European Commission.

This guide is an introduction to some basic tools which can help to support the implementation and management of maintenance procedures in SMEs. The material informs you about the available methods and techniques that can be used to this end and helps you in providing the right answers in questions such as: which maintenance strategy is suitable in your case, how you can effectively implement it, how you will be able to measure and analyze the implementation results etc.

Numerous examples and case studies are provided in order to underpin the understanding and illustrate practical applications. At the end of all modules you will find links and references for more detailed information as well as a glossary and keywords. A question and answer section will allow you to check if substantial issues within the content have been understood.

After reading the content you will be in a better position to make a sound decision on the usefulness of certain maintenance management tools for your own working environment.

We hope that this guide will prove to be of real value to users as they strive to achieve enhanced competitiveness and improved maintenance management in their organisations. However, we would appreciate your comments and suggestions for further improvement regarding the material. You can do this by contacting one of the project partners.

Besides this printed version there is also an online portal (www.traininmain.eu) which you are welcome to visit. The portal contains references and links for further information, as well as a library of relevant sources and case studies.

We wish you success and enjoyment in your use of the Train- In-Main guide!

Best regards,
The Train-In-Main project team

_/2 Description of the Handbook

The Handbook can be divided into four main sections as follows:

1ST SECTION

The first section of Train-In-Main Handbook constitutes an introduction to Maintenance Management. It provides readers with basic definitions, theories and concepts, such as various policies and strategies for maintenance. It highlights the necessity of a defined and standardised terminology regarding maintenance in order to improve communication and prevent misunderstandings. In addition, this section presents the basic maintenance policies, goals and strategies and provides a framework which helps decision makers to select the most successful way to manage maintenance.

2ND SECTION

The second section of the Handbook is devoted to everyday activities, such as work planning and materials management. It presents and analyses specific tools and techniques concerning work planning and scheduling, work execution and safety, implementation of condition based maintenance and spare parts management. The scope is to provide instructions for the efficient implementation of the selected policies as well as for the achievement of the goals set, since the success of the maintenance procedures necessitates well defined and organised everyday activities.

In fact, this section helps the maintenance department to perform the right maintenance activities, in the right manner and with proper quality using the right resources and to minimise both direct and indirect maintenance costs. Detailed instructions are also given for the effective management and control of spare parts, since availability of spare parts is very critical in fulfilling service requirements and eliminating downtimes.

3RD SECTION

This section deals with the evaluation and improvement of maintenance procedures which constitute a significant part of maintenance management and consequently a critical success factor. Several methods and techniques for measuring and evaluating the efficiency of a maintenance program, which can be used either in isolation or in combination, are presented. More specifically, the most popular measurement and improvement methods are presented along with information concerning their suitability in each process.

The methods described in this section on one hand serve as supporting tools in assessing the efficiency of the maintenance related activities and the maintenance policies as a whole, while on the other hand they identify and reveal the potential weaknesses of the system. In addition, this section emphasizes that measurement and analysis of results can and should be used as a feedback for further improvement and provides detailed instructions to this end.

4TH SECTION

The aim of the last section of Train-In-Main Handbook is to emphasize the necessity of using a Computerised Maintenance Management System (CMMS) to support maintenance activities. It is shown that a CMMS can greatly improve the management of large amounts of maintenance related data and actions in a cost effective way. This section also explains in detail what the expected benefits of a CMMS for the company are, i.e., reduced cost, better organisation, reduced paperwork and better communication.

_/ 3 Programme Support

Education and Culture

Leonardo da Vinci

The TRAIN IN MAIN Project is supported by the European Commissions Leonardo da Vinci Programme.

Leonardo da Vinci is a European Community programme which aims to support national training strategies through funding a range of transnational partnership projects aimed at improving quality, fostering innovation and promoting the European dimension in vocational training.

Leonardo sponsors pilot projects, like TRAIN IN MAIN, as they provide a vehicle for improving quality and promoting innovation in vocational training. Pilot projects develop tangible products, using new information and communications technologies where appropriate.

The aims of Pilot projects include some of the following:

To promote the design, development, testing, assessment and dissemination of innovative vocational training products, tools, methods and approaches, including training for trainers and guidance counsellors;

To develop new vocational training tools, services and products using ICT which will promote access to vocational training;

To support the creation of trans-national open and distance learning vocational training networks to make the broadest possible range of innovative teaching tools and methods available to the public;

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ΙΔΡΥΜΑ ΚΡΑΤΙΚΩΝ ΥΠΟΤΡΟΦΙΩΝ

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TRAINING MATERIAL IN MAINTENANCE MANAGEMENT

A/ MAINTENANCE FUNDAMENTALS

A/1 Terminology

A/2 Policies, Goals, Strategies

A/1 Terminology

A/1. Introduction

The aim of this module is to explain the necessity of the usage of a defined and standardized terminology in maintenance.

By using the same terminology that is understood by everybody involved in the maintenance activities, the quality assurance is supported in the companies as it will avoid misunderstandings in written and oral communications. Particular this is important in the formulation of maintenance contracts, in the measurement of key performance indicators and in maintenance instructions.

In Europe there has been developed a standard for the maintenance terminology, “CEN EN 13306, Maintenance terminology”.
This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement. According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard. Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.
The standard can be required from the national standardization institute in each country.

The possibility to describe the terminology included in the European standard CEN EN 13306 in this module has its limitations as the standard is not allowed to copy (copyright). Therefore this module only includes some basic terms, and further information has to be collected from the complete standard.

After reading this module you will be able to understand the definitions of the most common terms within maintenance.

A/1.2 Theoretical Background

This European Standard, EN 13306, Maintenance terminology (2001), has been prepared by European maintenance experts in the Technical Committee CEN/TC 319 "Maintenance". The standard was first adopted in 2001. (CEN = Comité Européen de Normalisation")

This European Standard specifies generic terms and definitions for the technical, administrative and managerial areas of maintenance. The purpose of the standard is to be used for all types of maintenance and maintenance management irrespective of the type of item considered. It is not intended to be applicable to terms which are used for the maintenance of software only.

As a part of the requirement of TC 319 it was necessary to produce a comprehensive structured maintenance vocabulary standard containing the main terms and their definitions.

The standard IEC 60050 (191) has been used as a basis for the preparation of this standard but some terms have been modified and some terms have been added. Not all terms specified in IEC 60050 (191) are included in this European standard.

The European standard contains specified terms in the following areas:

- **Fundamental terms**
- **Item related terms**
- **Properties of items**
- **Failures and events**
- **Faults and states**
- **Maintenance types and strategies**
- **Maintenance activities**
- **Time related terms**
- **Maintenance support and tools**
- **Measurement and technical indicators**

A/1.3 Implementation and Use

I. WHAT ARE THE SUCCESS FACTORS?

It is important that every company has its own copy of the European standard and is implementing the usage of the terms in the standard in the whole organization. Thereby

- **the misunderstandings in the com-munication among the employees will be reduced,**
- **the written and oral instructions will be easier to understand and the risk for faulty actions will be minimized,**
- **the written agreements/contracts – internally and externally – will clearly define the specified expectations, requirements and responsibilities, understandable for both parties,**
- **the measurement of achieved results of the maintenance activities will be unambiguous and possible to use for benchmarking.**

II. SOME EXAMPLES OF THE GENERAL TERMS

Here below are some terms, their definitions from EN 13306 and some additional comments.

1. Maintenance
Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function.

NOTE: See also the definition of improvement and modification.

2. Improvement
Combination of all technical, administrative and managerial actions, intended to ameliorate the dependability of an item, without changing its required function.

3. Modification
Combination of all technical, administrative and managerial actions intended to change the function of an item.

NOTE 1: Modification does not mean replacement by an equivalent item.

NOTE 2: Modification is not a maintenance action but has to do with changing the required function of an item to a new required function. The changes may have an influence on the dependability or on the performance of the item, or both.

NOTE 3: Modification may be allocated to the maintenance organization.

> Comments to 1 – 3 here above:
>
> As seen from the above "modification" is not a maintenance action.
>
> However, it is very common that the main-tenance department is not only taking care of maintenance actions, but also modification and installation activities.
>
> The definitions here above also lead to an interest to separate the costs for maintenance and other costs in the budget and in the economical accounts. This will also result in a more fair comparison of the maintenance costs from year to year.
>
> Note that the action "improvement" may be included in the maintenance budget as it has an influence on the availability performance (the dependability).

4. Preventive maintenance
Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item.

The preventive maintenance action can be Condition based or Predetermined maintenance.

4.1. Condition based maintenance
Preventive maintenance based on performance and/or parameter monitoring and the subsequent actions.
NOTE: Performance and parameter monitoring may be scheduled, on request or continuous.

4.2. Predetermined maintenance
Preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation.

5. Corrective maintenance
Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function.

The corrective maintenance action can be performed as Deferred or Immediate maintenance.

5.1. Deferred maintenance
Corrective maintenance which is not immediately carried out after a fault detection but is delayed in accordance with given maintenance rules.

5.2. Immediate maintenance
Maintenance which is carried out without delay after a fault has been detected to avoid unacceptable consequences.

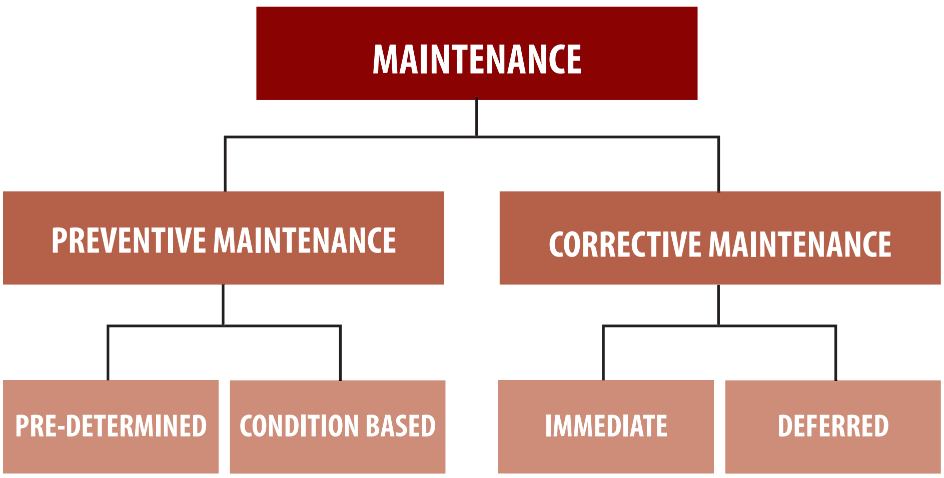


Figure 1: Maintenance - Overview

6. Availability performance
Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided.

NOTE 1: This ability depends on the combined aspects of the reliability, the maintainability and the maintenance supportability.

NOTE 2: Required external resources, other than maintenance resources, do not affect the availability of the item.

7. Reliability
Ability of an item to perform a required function under given conditions for a given time interval.
NOTE: The term "reliability" is also used as a measure of reliability performance and may also be defined as probability.

8. Maintainability
Ability of an item under given conditions of use, to be retain in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

NOTE: The maintainability is also used as a measure of maintainability performance.

9. Maintenance supportability
Ability of a maintenance organization of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant of time or during a given time interval.

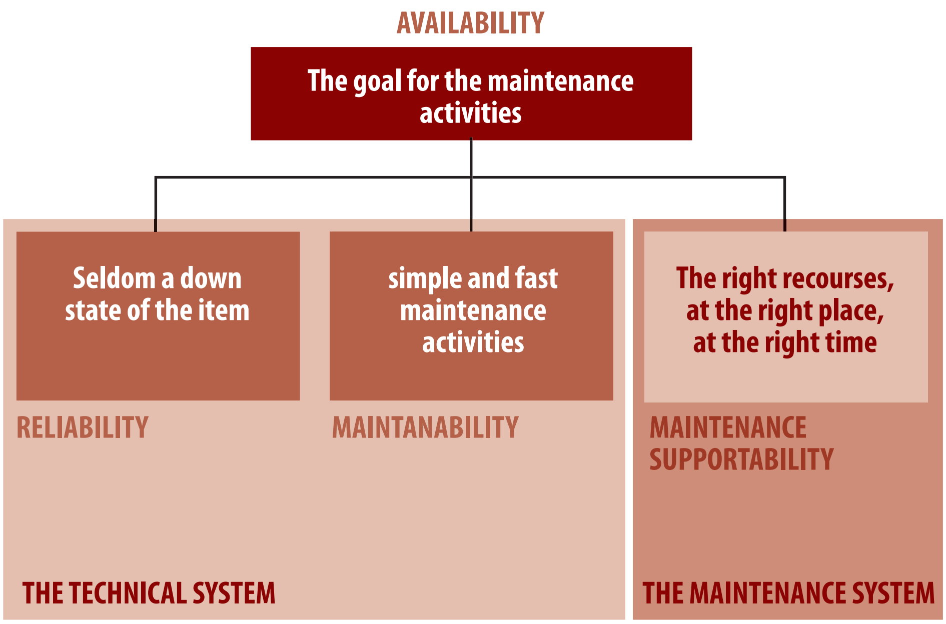


Figure 2: The relation between some terms for the availability performance

A/1.4 Case studies

Many companies arrange special one day seminars for the key personnel in an implementation process for the usage of the defined terms.

In some countries they combine the seminars with a delivery of small information pamphlets to their employees. (Such a pamphlet has been developed in Sweden and is translated into other languages. See the List of References.)

A/1.5 Keywords

Maintenance terminology, European standardised terms, Maintenance types, Availability performance.

A/1.6 Glossary

For this module some terms are already defined here above. For other terms, please use the European standard EN 13306.

A/1.7 Questions

1. What is predetermined maintenance?

a) A maintenance activity that is planned and scheduled
b) A maintenance activity as a result of an inspection
c) A maintenance activity in accordance with established intervals
d) A risk based and immediate maintenance activity

(Answer : c)

2. What is not a maintenance activity?

a) The replacement of a faulty component to a functioning component
b) Cleaning and lubrication
c) The replacement of a component with better reliability
d) The replacement of a component with another function

(Answer : d)

3. What can not influence the availability?

a) A maintenance activity as a result of an inspection
b) The cost effectiveness of some maintenance activities
c) Tailor-made maintenance tools and instruments
d) A deferred maintenance activity, when it is performed

(Answer : b)

A/1.8 List of References

1. European Standard EN 13306, Maintenance terminology (2001), CEN, European Committee for Standardization, Belgium.

2. IEC 60050(191): 1990, International Electrotechnical Vocabulary IEV – Chapter 191: Dependability and quality of service.

3. "The easy way to understand some of the general terms within Maintenance", The Swedish Maintenance Society, UTEK, Box 10231, 100 55 Stockholm, Sweden. Third edition, 2008.

A/ MAINTENANCE FUNDAMENTALS

A/2 Policies, Goals and Strategies

A/2.1 Introduction

Where the method, technique aims?
The methods and techniques covered here aim at understanding asset management in terms of maintenance and reliability fundamentals. This is achieved through presenting some definitions and proposing models that capture different policies.

What are the benefits for the company?
The main benefits of such approach are that it will help to improve understanding of asset management related concepts. Maintenance and reliability in terms of it policies, goals and strategies are critical for every successful company. Maintenance is a unique business process. To be successfully managed, it requires an approach different from other business processes. This module provides a framework for managing maintenance with options that allow decision makers to select the most successful ways to manage maintenance. Measuring, comparing and improving maintenance practice underpins the success of the whole business process.

Are there any preconditions, limitations?
It provides some models (not all models) and presents one perspective of attempting to approach a very wide subject in a concise format.

Learning objectives for the trainees?
After reading this module you will be able to appreciate maintenance and reliability related policies, goals and strategies in order to decide on their uses and limitations.

A/2.2 Theoretical Background

The following is a proposed model that aims to classify different maintenance policies

Maintenance types and strategies can be classified (Ref: BS EN 13306:2001) into:

1. **Preventive maintenance:** Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item.
2. **Scheduled maintenance:** Preventive maintenance carried out in accordance with an established time schedule or established number of units of use.
3. **Predetermined maintenance:** Preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation.
4. **Condition based maintenance:** Preventive maintenance based on performance and/or parameter monitoring and the subsequent actions.
5. **Predictive maintenance:** Condition based maintenance carried out following a forecast derived from the analysis and evaluation of the significant parameters of the degradation of the item.
6. **Corrective maintenance:** Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function.
7. **Remote maintenance**: Maintenance of an item carried out without physical access of the personnel to the item.
8. **Deferred maintenance:** Corrective maintenance which is not immediately carried out after a fault detection but is delayed in accordance with given maintenance rules.
9. **Immediate maintenance:** Maintenance which is carried out without delay after a fault has been detected to avoid unacceptable consequences.
10. **On line maintenance:** Maintenance carried out during the time that the item is in use.
11. **On site maintenance:** Maintenance carried out at the location where the item is used.
12. **Operator maintenance:** Maintenance carried out by a user or operator.

Figure 1 attempts top group types of maintenance policies.

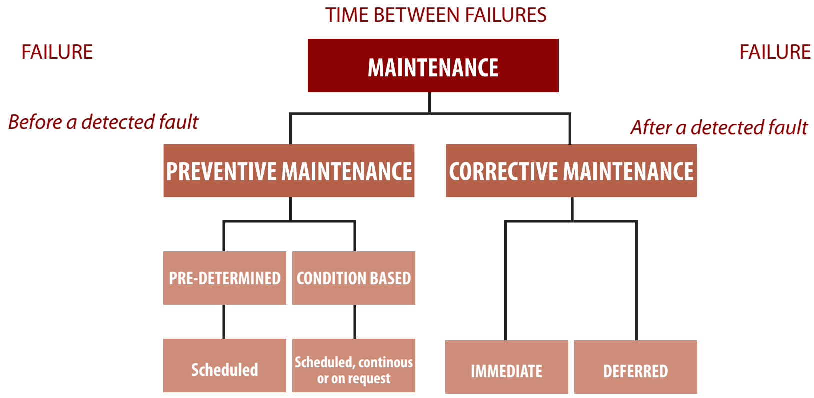


Figure 1: Maintenance Types and Policies.

MAINTENANCE & RELIABILITY POLICIES

Maintenance policies can be broadly categorised into the technology or systems oriented (systems, or engineering), management of human factors oriented and monitoring and inspection oriented.

Reliability Centered Maintenance (RCM):

Reliability Centered Maintenance (RCM) is a technological based concept where reliability of machines is emphasised.

RCM is a method for defining the maintenance strategy in a coherent, systematic and logical manner.

It is a structured methodology for determining the maintenance requirements of any physical asset in its operation context.

The primary objective of RCM is to preserve system function.

The RCM process consists of looking at the way equipment fails, assessing the consequences of each failure (for production, safety, etc), and choosing the correct maintenance action to ensure that the desired overall level of plant performance (i.e. availability, reliability) is met.

Techniques allied to RCM: Fault Tree Analysis, and Reliability Block Diagrams.

Pioneering industry: Aviation industry.

The term RCM was originally coined by Nolan and Heap (1979). For more details on RCM see Moubray (1991, 2001), and Netherton (2000).

Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is human based technique in which maintainability is emphasised.

TPM is a tried and tested way of cutting waste, saving money, and making factories better places to work.

TPM gives operators the knowledge and confidence to manage their own machines. Instead of waiting for a breakdown, then calling the maintenance engineer, they deal directly with small problems, before they become big ones.

Operators investigate and then eliminate the root causes of machine errors. Also, they work in small teams to achieve continuous improvements to the production lines.

Techniques allied to TPM: Overall Equipment Effectiveness, Ask Why 5 Times.

Pioneering industry: car Manufacturing (TPS).

For more details on TPM see Nakajima (1988), Hartmann (1992), and Willmott (1994).

Condition Based Maintenance (CBM

Condition Based Maintenance (CBM) – not Condition Based Monitoring – is a sensing technique in which availability based on inspection and follow-up is emphasised.

In the British Standards, CBM is defined ast the preventive maintenance initiated as a result of knowledge of the condition of an item from routine or continuous monitoring." (BS 3811, 1984).

It is the means whereby sensors, sampling of lubricant products, and visual inspection are utilised to permit continued operation of critical machinery and avoid catastrophic damage to vital components

The integral components for the successful application of condition monitoring of machinery are: reliable detection, correct diagnosis, and dependable decision-making.

Techniques allied to CBM: Vibration Analysis, Infra-red Thermography.

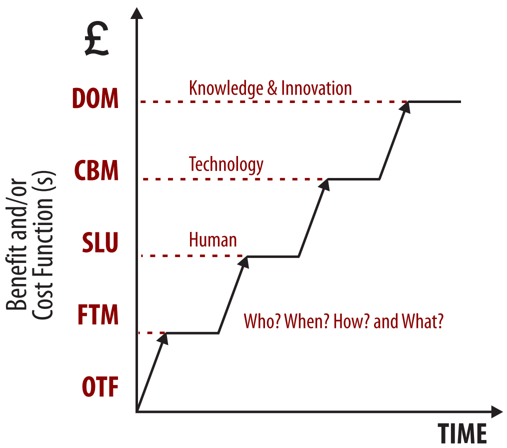
Pioneering industry: Various Process industry (e.g. Oil & Gas).

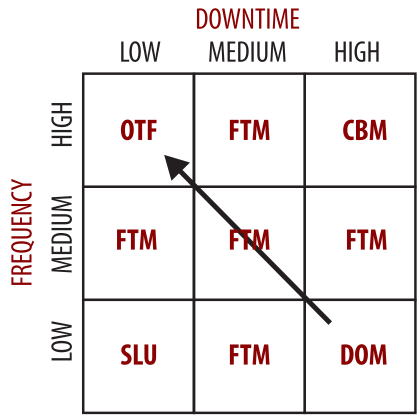
For more details on CBM, see Brashaw (1998), and Holroyd (2000).

The proposed approach (Labib, 2004) offers a decision map adaptive to the collected data where it suggest the appropriate use of RCM, TPM, and CBM.

PROPOSED MODEL

The Decision Maintenance Grid (DMG) is a model that helps to choose different models in maintenance. The model identifies 5 levels of maintenance strategies which have an impact on performance.





OTF: Operate to Failure **SLU:**Skill Level Upgrade **CBM:**Condition Based Maintenance **FTM:**Fixed Time Maintenance **DOM:**Design Out Maintenance

Figure 2: Evolution and Ranking of Maintenance Policies

Figure 3: Design Maintenance Grid (DMG)

It acts as a map where the performances of the worst machines are placed based on multiple criteria. The objective is to implement appropriate design actions that will lead to the movement of machines towards an improved state with respect to multiple criteria. The outputs of the model are: a) classification of design related policies, and b) prioritisation of the proposed actions.

A/2.3 Implementation and Use

Maintenance policies are fundamental to the maintenance function. When dealing with this issue, one looks at the following:

- identification of available policies,
- performing a trade-off analysis to choose most appropriate policy that satisfies the business objectives at a specific instant of time and,
- at minimum cost.

What are the success factors?

An understanding of maintenance and reliability policies and strategies and their techniques and means of applying them.

Ability to apply techniques to the chosen case.

A/2.4 Case study – Title Example: The DMG through an industrial case study.

This case study demonstrates the application of the proposed model and its effect on asset management performance. The application of the model is shown through the experience of a company seeking to achieve World-Class status in asset management. The company has implemented the proposed model which has had the effect of reducing total downtime from an average of 800 hours per month to less than 100 hours per month as shown in Figure 4.

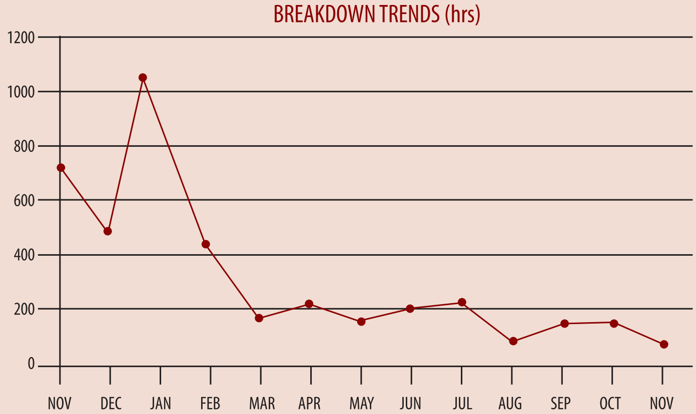


Figure 4: Total breakdown trends per month

Company Background and Methodology

In this particular company there are 130 machines, varying from robots, and machine centres, to manually operated assembly tables. Notice that in this case study, only two criteria are used (frequency, and downtime). However, if more criteria are included such as spare parts cost and scrap rate, the model becomes multi dimensional, with low, medium, and high ranges for each identified criterion. The methodology implemented in this case was to follow three steps. These steps are i. Criteria Analysis, ii. Decision Mapping, and iii. Decision Support.

Step 1: Criteria Analysis

As indicated earlier the aim of this phase is to establish a Pareto analysis of two important criteria Downtime; the main concern of production, and Frequency of Calls; the main concern of asset management. The objective of this phase is to assess how bad are the worst performing machines for a certain period of time, say one month. The worst performers in both criteria are sorted and grouped into High, Medium, and Low sub-groups. These ranges are selected so that machines are distributed evenly among every criterion. This is presented in Figure 5. In this particular case, the total number of machines is 120. Machines include CNCs, robots, and machine centres.

CRITERIA	DOWNTIME	
	NAME	DOWNTIME (hrs)
HIGH	Machine[A]	30
	Machine[B]	20
	Machine[C]	20
MEDIUM	Machine[D]	17
	Machine[E]	16
	Machine[F]	12
	Machine[G]	7
LOW	Machine[H]	6
	Machine [I]	6
	Machine[J]	4
CRITERIA: EVALUATION	SUM OF TOP 10:	138
	SUM OF ALL:	155
	PERCENTAGE:	89%

FREQUENCY		
NAME	FREQUENCY (no off)	
Machine[G]	27	HIGH
Machine[C]	16	
Machine[D]	12	
Machine[A]	9	MEDIUM
Machine [I]	8	
Machine[E]	8	
Machine[K]	8	
Machine[F]	4	LOW
Machine[B]	3	
Machine[H]	2	
SUM OF TOP 10:	97	
SM OF ALL:	120	
PERCENTAGE:	81%	

Figure 5: Step1: Criteria Analysis

Step 2: Decision Mapping

The aim of this step is twofold; it scales High, Medium, and Low groups and hence genuine worst machines in both criteria can be monitored on this grid. It also monitors the performance of different machines and suggests appropriate actions. The next step is to place the machines in the "Decision Making Grid" shown in Figure 6, and accordingly, to recommend asset management decisions to management. This grid acts as a map where the performances of the worst machines are placed based on multiple criteria. The objective is to implement appropriate actions that will lead to the movement of machines towards the north - west section of low downtime, and low frequency. In the top-left region, the action to implement, or the rule that applies, is OTF (operate to

failure). The rule that applies for the bottom-left region is SLU (skill level upgrade) because data collected from breakdowns - attended by maintenance engineers - indicates that machine [G] has been visited many times (high frequency) for limited periods (low downtime). In other words maintaining this machine is a relatively easy task that can be passed to operators after upgrading their skill levels.

Machines that are located in the top-right region, such as machine [B], is a problematic machine, in maintenance words "a killer". It does not breakdown frequently (low frequency), but when it stops it is usually a big problem that lasts for a long time (high downtime). In this case the appropriate action to take is to analyse the breakdown events and closely monitor its condition, i.e. condition base monitoring (CBM).

A machine that enters the bottom-right region is considered to be one of the worst performing machines based on both criteria. It is a machine that maintenance engineers are used to seeing it not working rather than performing normal operating duty. A machine of this category, such as machine [C], will need to be structurally modified and major design out projects need to be considered, and hence the appropriate rule to implement will be design out maintenance (DOM).

If one of the antecedents is a medium downtime or a medium frequency, then the rule to apply is to carry on with the preventive maintenance schedules. However, not all of the mediums are the same. There are some regions that are near to the top left corner where it is "easy" FTM (Fixed Time Maintenance) because it is near to the OTF region and it requires re-addressing issues regarding who will perform the instruction or when will the instruction be implemented. For example, in case of machines [I] and [J], they are situated in region between OTF and SLU and the question is about who will do the instruction - operator, maintenance engineer, or sub-contractor. Also, a machine such as machine [F] has been shifted from the OTF region due to its relatively higher downtime and hence the timing of instructions needs to be addressed.

Other preventive maintenance schedules need to be addressed in a different manner. The "difficult" FTM issues are the ones related to the contents of the instruction itself. It might be the case that the wrong problem is being solved or the right one is not being solved adequately. In this case machines such as [A] and [D] need to be investigated in terms of the contents of their preventive instructions and an expert advice is needed.

DECISION MAKING GRID

		DOWNTIME		
		LOW	MEDIUM	HIGH
FREQUENCY	LOW	O.T.F. [H]	F.T.M. (when) [F]	C.B.M. [B]
	MEDIUM	F.T.M. [I] (who?) [J]	F.T.M. [E]	F.T.M. (what?) [A]
	HIGH	S.L.U. [G]	F.T.M. (how?) [D]	D.O.M. [C]

CBM: Conditioning Base Monitoring
SLU: Skill Level Upgrade
FTM: Fixed Time Maintenance
OTF: Operate to Failure
DOM: Design Out MC.

Figure 6: Step2: Decision Mapping

A/2.5 Keywords

Maintenance, Reliability, Policies, Strategies

A/2.6 Glossary

CBM: Condition Base Monitoring
OTF: Operate To failure
SLU: Skill Level Upgrade
DOM: Design Out M/C.
FTM: Fixed Time Maintenance

A/2.7 Questions

1. The prime objective of RCM is:

a) To provide reliable diagnosis of machinery condition
b) To ensure that production machinery is operating without faults
c) To preserve system function

(Answer: c)

2. Which technique utilises sensors, sampling of lubricant products and visual inspection to permit continued operation of critical machinery and avoid catastrophic damage to vital components?

a) RCM
b) TPM
c) CBM

(Answer: c)

3. What are the outputs of the Decision Making Grid ?

a) prioritisation of maintenance policies and classification of the proposed actions
b) maintenance policy selection
c) classification of design - related policies, and prioritisation of the proposed actions

(Answer: a)

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TRAINING MATERIAL IN MAINTENANCE MANAGEMENT

B/ WORK AND MATERIAL

B/1 Work planning and Scheduling

B/2 Work execution and safety

B/3 Condition based maintenance

B/4 Spare parts management

B/1 Work planning and Scheduling

B/1.1 Introduction

The aim of the work planning and scheduling is to make the applicable preparations to allow the right maintenance activities to be performed in the right manner and quality by using the right resources and at the right moments of time.

If the design of the work planning system is done right the cost of planning resources should result in significant savings in the direct and indirect maintenance cost in comparison with activities without a work planning.

The design and routines for usage of the system for work planning and scheduling is a responsibility for the maintenance manager. All people involved in the maintenance activities have to be involved of the usage of the system and have also a lot of benefits by using it.

After reading this module you will be able to understand the importance of work planning and scheduling as well as how you could contribute in making such a system effective in your company.

B/1.2 Theoretical Background

Work planning in maintenance is an important sub process in the dimensioning of a maintenance organization. This sub process forms the nerve centre of maintenance management. The work planning defines the way in which maintenance work (preventive and corrective) is planned, scheduled, allocated, implemented, monitored and controlled.

A large and complex work planning system is broken down to a number of inter-related planning sub-systems.

The vehicle for the flow of the work through the planning system is the work order. The work order is a key document for the planning and control of maintenance work. The main function of the work planning is the medium and long term planning and scheduling of the on-going maintenance workload. The planning horizon can extend from 48 hours to one year encompassing all the maintenance work other than the emergency jobs.

Besides, planning, scheduling and assignment, the work planning function will be involved for the work control with the help of the information and communication system.

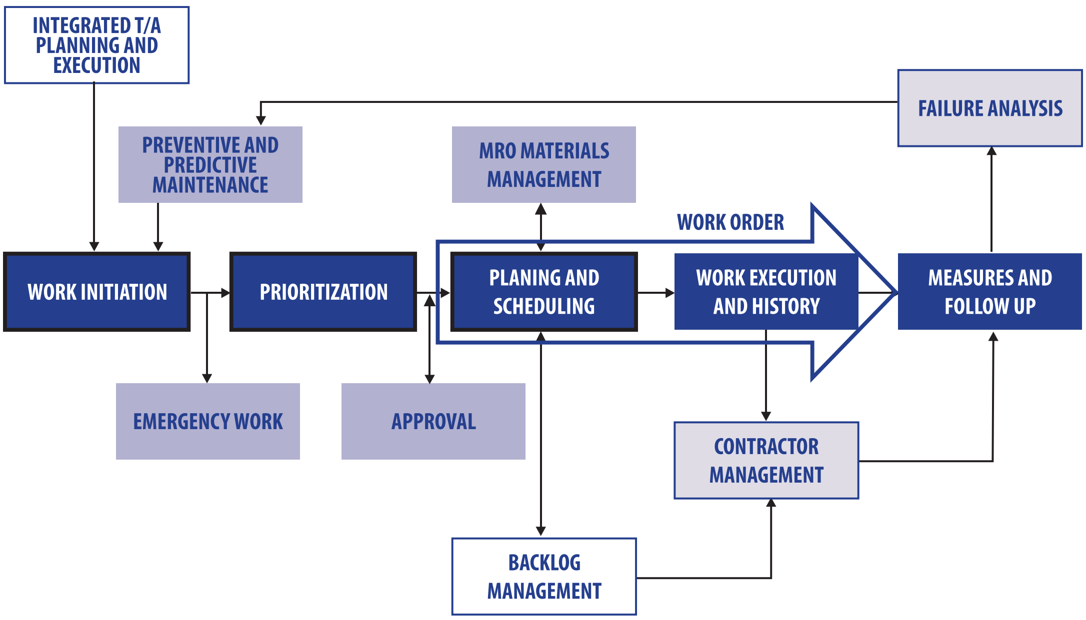

Figure 1: The work planning and Scheduling Process

B/1.3 Implementation and Use

Here below is a description in general terms about the main activities in the planning and scheduling process.

PLANNING	**Doing the right things**	In each situation perform the activity which will give the most cost-effective result for the company, including the maintenance organisation
PLANNING	**Doing the things right**	To perform the activity in accordance with actual instructions and recommended support
PLANNING	**Using the right resources**	To use personnel and technical resources which are the most suitable and cost effective
SCHEDULING	**Doing things at the right time**	To perform the activity that point of time which is suitable for both the production and the maintenance organizations
	Achieve the right result	The activity has been performed in accordance with required quality and the result is in accordance with the expected result

Of course it is a responsibility for the maintenance manager to make sure that the activities mentioned here above are carried out in accordance with the intended goal of always achieving the "right" result.

Doing the right things

In the selection of the most cost-effective activity, the following alternatives have to be chosen from:

Corrective Maintenance

Immediate Maintenance)

No Scheduling is possible. Planning can already have been done for failures that are expected to happen sooner or later, but normally there is no time for a serious planning.

Deferred Maintenance

Will be scheduled. Planning might also be able to perform, or is already done for this type of fault.

Preventive Maintenance

Planning and Scheduling always possible.

Predetermined Maintenance

(Most common approach to maintenance)
Maintenance performed on a fixed interval
Inspection frequencies based calendar
Can be a scheduled replacement

Condition Based Maintenance

Condition Monitoring performed on a fixed interval Activities will be performed before a failure when the monitoring so indicate

Doing the things right, using the right resources and perform at the right times

The intention of the Work Order is to give the necessary information for the work to be performed, such as:

- **Where the maintenance shall be performed**
- **Which item that shall be maintained**
- **When the maintenance is scheduled to take place**
- **Which written instructions that shall be used**
- **Which documents that is needed (descriptions, instructions, drawings, spare part catalogues)**

- **Tools and measurement instruments to be used**
- **Any necessary handling and transport equipment to be used**
- **Expected spare parts to be used**
- **The expected number of people for the maintenance activity and their qualifications (including the possibility to hire external personnel resources)**
- **Any special safety rules to take care of**
- **The production person to contact (if any) to get the work permit from**

The right result

If the work planning and scheduling is performed in the right way it shall also support the maintenance policy and goals of the company and its actual strategies to support those goals. Among other things this normally means that the required availability performance is achieved.

Nowadays most of the companies have installed CMMS to support the work planning and scheduling activities.

B/1.4 Case Study

Here below is a decision/activity scheme regarding the different situations for the possibilities of planning and scheduling in practice.

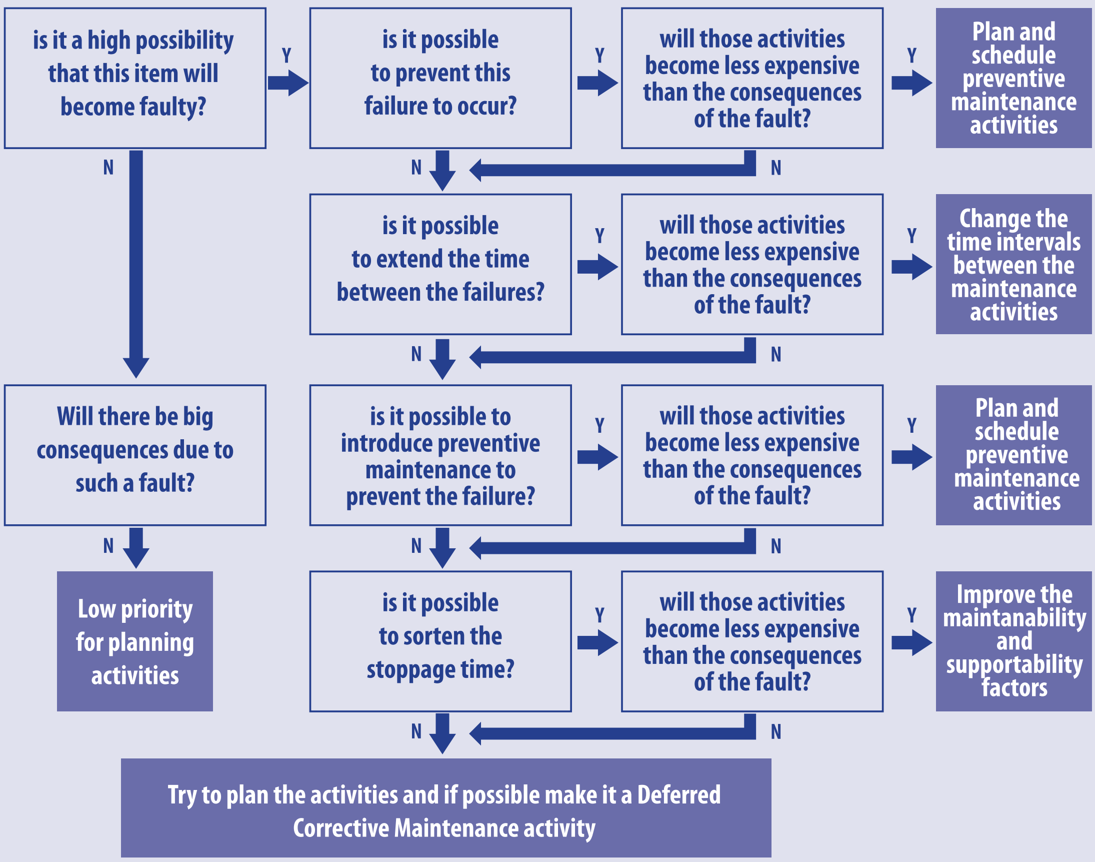

Figure 2

The idea is to analyze all the items and for each of them find out which will be the relevant activity (activities with yellow background).

B/1.5 Keywords

Work planning in maintenance, Scheduling, Work order, Resource planning

B/1.6 Glossary

Planning (Maintenance task preparation): The supplying of all of the necessary information and identifying the required resources to enable the maintenance task to be carried out

NOTE: The preparation may include description of how to perform the work, required permits, spare part, skill, tools, etc.

Scheduling: A decision taken in advance of when a specific maintenance task should be carried out assuming the required resources are available

CMMS: Computerized Maintenance Management System

B/1.7 Questions

1. What is predetermined maintenance?

a) A maintenance activity that is planned and scheduled
b) A maintenance activity as a result of an inspection
c) A maintenance activity in accordance with established intervals
d) A risk based and immediate maintenance activity

(Answer: c)

2. What is not a planning activity?

a) The estimation of the expected time to perform an activity
b) The decision when a specific activity should take place
c) The identification of the instructions for a certain activity
d) The competence needed for a certain activity

(Answer: b)

3. What is the expected usage of a Work Order?

a) A document issued by the production, ordering maintenance
b) To give information of typical reasons for a certain failure
c) To keep the maintenance people busy
d) To give the essential information for performing an activity right

(Answer: d)

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B/ WORK AND MATERIAL

B/2 Work Execution and Safety

B/2.1 Introduction

On this module the key features of maintenance work execution are presented. These key features are the following:

a) Perform the work on the right way, therefore "Best Maintenance Repair Practices" should be implemented.

b) Perform the work safely, so a safety and health program should be developed on the company.

c) Perform the work effectively, so a work measurement system should be developed.

Case studies on 'safety at work' and 'work measurement system' will be presented.

B/2.2 Theoretical Background

I. BEST MAINTENANCE REPAIR PRACTICES

The first feature of maintenance work execution is to perform the work on the right way. A number of surveys conducted in industries have found that 70% of equipment failures are self-induced. [1, p.1]

Maintenance personnel who are not following what are termed "Best Maintenance Repair Practices" substantially affect these failures. Between 30% and 50% of the self-induced failures are the result of maintenance personnel not knowing the basics of maintenance. Maintenance personnel who, although skilled, choose not to follow best maintenance repair practices potentially cause another 20% to 30% of those failures. The results indicated that over 90% lacked complete basic fundamentals of mechanical maintenance. "Best maintenance Repair Practices" are necessary for maintenance personnel to keep equipment operating at peak reliability and companies functioning more profitably through reduced maintenance costs and increased productivity and capacity.

The potential cost savings can often be beyond the understanding or comprehension of management. Many managers are in a denial state regarding maintenance. The result is that they do not believe that repair practices impact an organisation's bottom line or profitability.

More enlightened companies have demonstrated that, by reducing self-induced failures, they can increase production capacity by as much as 20%.

A few of the most common reasons that a plant does not follow best maintenance repair practices are:

1. **Maintenance is totally reactive and does not follow the definition of maintenance, which is to protect, preserve, and prevent from decline (reactive plant culture).**

2. **Maintenance personnel do not have the requisite skills.**

3. **The maintenance workforce lacks either the discipline or direction to follow best maintenance repair practices.**

4. **Management is not supportive, and/or does not understand the consequences of not following the best practices.**

In order to solve the problem of not following Best Maintenance Repair Practices, a sequential course of action should be taken:

First, identify whether a problem exists (i.e. track repetitive equipment failures).

Second, identify the source of the problem (this could be combination of issues):

- **Maintenance skill level:** Perform skills assessment to evaluate whether skill levels are adequate to meet "Best Maintenance Repair Practices".

- **Maintenance culture:** Provide training to all maintenance and management relative to a change in maintenance strategy and how it will impact them individually.

- **Maintenance strategy:** Develop a plan to introduce a proactive maintenance model with "Preventive and Planned Maintenance" at the top of planned priorities.

Third, implement the changes needed to move toward following "Best Maintenance Repair Practices" and measure the financial gains. [1, p.6]

The entire concept of Best practices is to prevent defects, not to correct them [5, p.171].

II. SAFETY AT WORK

The most important feature of maintenance work is to perform the work safely. Thus, a safety and health program should be developed.

The purpose of the safety and health program is to prevent accidents and illnesses; protect workers, property, and community; control or reduce losses; provide means for management/ employee involvement in the safety and health program; and to comply with legal requirements. Managers and supervisors must understand the importance of systematic approach to identifying, evaluating and controlling those factors in the work environment which are responsible for accidents and their effects. [3, p.1]

a) Impact of Accidents and Injuries on Small Businesses

Each year accidents continue to take their toll on workers in all types of industries. In 1998, annual statistics compiled by the National Safety Council indicate that over 3.800.000 workers were disabled and over 5.100 workers were killed that year as a result of work place accidents. Actual figures are much higher because many accidents are not reported.

Accidents are harmful not only when measured in human terms, that is, injuries and illnesses to workers, but also when measured in terms of their adverse affects on the overall business. Accidents can result in fiscal losses to the business due to the costs of replacing damaged equipment and materials, medical treatment expenses, administrative costs, and any liabilities or penalties incurred.

b) Definition of an Accident

Generally, the term accident refers to an unusual event caused by human, situational, or environmental factors which result in or has the potential to result in injuries, fatalities, or property damage. Three important points contained in this definition are:

- Accidents do not have to result in actual injuries. If, for example, a worker slips and falls on an oil spot but the fall does not injure the worker or cause any damage, the incident is still classified as an accident because it interrupted the production process and had the potential and had the potential to cause injury and damage.

- Accidents are unusual and unexpected events. It is important to recognize that the potential for accidents is always present. Unless supervisors and workers are aware of the fully alert to the ever present possibility of accidents, and unless they act to discover and eliminate potentially dangerous situations, the potential for accidents will remain.

- Accidents do not occur without reason, they are caused. Some common causes of accidents include the improper use of tools and machines, the failure to use protective equipment, the failure to follow protective equipment, the failure to follow correct procedures, the use of faulty equipment and tools, the poor condition of walking and working surfaces, improper maintenance of equipment, and inadequately guarded machinery.

c) Definition of Hazard

Generally, safety professionals refer to accident causes as hazards. A hazard may be defined as any existing or potential condition which, by itself or by interacting with other variables, can result in the unwanted effects of property damage, illnesses, injuries, deaths and other losses. Hazards are generally grouped into two broad categories, hazards dealing with safety and hazards dealing with health.

d) Causes of Accidents

Accidents are caused by either human, situational, or environmental factors. In each accident situation, the cause can be directly or indirectly attributed to the supervisor or worker (human factors); to the operations, tools, equipment and materials (situational factors); or to work place conditions such as noise, vibration, and poor illumination (environmental factors).

Human factors: An accident can be attributed to human factors if a person caused the accident either by something they did or by something they failed to do.

Situational factors: Include the operations, tools, equipment, and materials which contribute to accident situations.

Environmental factors: There are three categories the physical, chemical and biological. [3, p.5]

e) Sources of Situational and Environmental Hazards

Situational and environmental hazards enter the work environment from many sources. The primary contributors are the workers; those responsible for purchasing items for use in the work environment; those responsible for tool, equipment and machinery placement and for providing adequate machine guards; and those responsible for maintaining shop equipment, machinery, and tools.

Workers may contribute to situational and environmental hazards by disregarding safety rules and regulations, by making safety devices inoperative, by using equipment and tools incorrectly.

f) Major components of a Safety and Health Program

The major components include Inspection Programs, Maintenance Programs, Hazard Analysis, Housekeeping, Standards Compliance, Accident Investigation, Safety Committees, etc.

g) Developing a Policy Statement

The first step in developing a safety and health program is the development of a formal policy. The policy statement should reflect the emphasis the organization places on efficient operations with a minimum of accidents and losses.

h) Establishing responsibilities

Responsibility for the safety and health program should be established at the following levels:

- Managers are required to safeguard employees' health by ensuring that the work environment is adequately controlled.
- Supervisors are in strategic positions to control hazards. Without their full support, the best designed health and safety program will not be effective. Their leadership and influence ensure that safety and health standards are enforced and upheld and that standards and enforcement are uniform throughout the facility.
- Workers are critical for ensuring the success of the safety and health program. Highly trained workers who actively participate in the program can make the greatest contribution to the program.

i) Monitoring Program

In order to maintain control over hazards in the facility, small business owners must implement a safety and health monitoring program. The purpose of the monitoring program is to detect potential hazards, provide early and effective countermeasures, and measure the effectiveness of the program. Management must decide what the program should yield in terms of reduced accidents, injuries, or illnesses. Metrics specific to the program should be developed in order to measure its performance.

Summary

In order to ensure a safe work place, an effective safety and health program must be developed. Safety and health programs are successful at reducing the number of accidents and removing hazards only when the causes and nature of accidents are fully understood and the managers and the supervisors actively support and promote the program. A reduction in work place accidents will save small businesses from undue financial losses and prevent countless injuries, illness, and deaths. [3, p.11]

III. WORK EFFICIENCY

It has been said that: To manage, you must have controls. To have controls, you must have measurement. To have measurement, you must have information. To have information, you must collect data. [5, p.147]

The challenge is to develop a job estimate that will establish a challenging expectancy on one hand but produce an achievable schedule on the other. [2, p.95]

Maintenance personnel are fond of stating: 'Maintenance jobs never go the same way twice'. While this much of the statement is basically true, they add: 'Therefore, maintenance cannot be measured'. The latter portion of this statement is false. Maintenance work is repetitive and therefore it can be measured. Many jobs occur weekly, some monthly, or quarterly, and even annual jobs are repetitive.

Industrial engineers strive to achieve accuracy plus or minus five percent (+-5%) for production incentive standards, but in maintenance we strive for plus or minus fifteen percent (+-15%). This level of accuracy is adequate for the applications to which we apply estimates in the maintenance arena. Accuracy for individual jobs may not be reliable, but combined accuracy over the dozens of jobs most maintenance crews complete within a week is adequate. Especially when the focus is on trends over time, rather than excessive emphasis on results within a specific time period.

Maintenance work often does certain unpredictable elements, but those elements seldom influence the entire job. If disassembly should double due to working conditions; troubleshooting, re-assembly, clean up, and feedback are not impacted proportionately. The total job, most likely, will not increase beyond the fifteen percent range. The objective is to consistently achieve reasonable accuracy of time needed.

An area where estimates can go wrong is where the scope of work changes dramatically. If the job is to change a simple bearing and ends up replacing all bearings plus the shaft, impeller, and housing, the scope change dictates a new estimate. Judgment must be used.

Levels of Maintenance Work Measurement. [2, p.97]

- **Construction Trade Estimates**
  They are not recommended for application to in-house maintenance. The reasons are that construction is not among our most efficient industries and the estimates reflect that level of efficiency, they also include engineering safety factors in the interest of the bidder, and most relate to construction jobs rather than maintenance jobs.

- **Gross Estimates**
  Most installations begin with Gross Estimates, which are the least costly and least time consuming. The disadvantage is that they reflect personal judgment and different person guess differently.

- **Historical Averages**
  If the average length of time that a job has been taking is known, what would possibly be a better estimate? The answer is nothing… provided the maintenance crews are working at 100 percent efficiency and the state of maintenance excellence has already been achieved. Unfortunately, the efficiency of reactive maintenance tends to be in the 50% range. If world-class is to be achieved, such mediocrity cannot be expectancy.

  Efficiency is standard labor-hours divided by actual labor-hours.

- **Adjusted Averages**
  Adjusted averages are the first reflection of a true expectancy (a standard). They require a base period of perhaps six months during which time averages are collected for repetitive maintenance jobs and activity sampling is performed concurrently.

- **Analytical Estimates**
  This is a recommended approach to maintenance work measurement. Analysing and estimating maintenance work seems hard at first because they are nearly always elements that are unpredictable. Normally however, these elements do not constitute the whole job and quite often are only a minor portion. The technique is simple and based on the following principles:

a. For persons who have had practical experience performing maintenance jobs, it is relatively easy to visualize and establish a time requirement for simple, short duration jobs. Because of their experience, ex-craftsmen usually make the best planners.

b. Long, complex jobs cannot be estimated as a whole. Estimation of such jobs is easier and more accurate when the job is broken down into separate steps or tasks and estimated at that level, then summarized into an estimate for the total job.

c. Pinpoint accuracy in estimating is not justified or achievable because all the variables in maintenance work cannot be known until after the job is completed. In maintenance we therefore look for +/- 15% accuracy.

- **Job Slotting and Labour Libraries**
  Slotting compares jobs to be evaluated with a group of jobs that are well known, and have been carefully described and estimated. Usually it is easier to determine whether a job is bigger or smaller to determine, in isolation, how long the job will take.

- **Universal Maintenance Standards**
  Predetermined Motion Times, Time Study, and Standard Data take work measurement too far for the needs of Maintenance Management. In combination they evolve into Universal Maintenance Standards (UMS) and these have faded from common usage. Although they are the most accurate method by which to develop maintenance standards, such standards are too time consuming and expensive to set-up as well as maintain. [2, p.100]

WHICH METHODOLOGY BEST SERVES THE SEVERAL APPLICATIONS OF WORK MEASUREMENT?

The key to effective work measurement is to establish standards and measure current efficiency relative to standard. Although it is desirable to use management tools with 'pool' to drive improvement, it is not practical to expect efficiency to improve from 50% to 100% (or even 85%) in near-term. In fact, 10% improvement in a quarter is a lofty goal.

Efficiency reports should be developed weekly for the total crew or team responsible to a given supervisor. Using a one-week time frame means that the average efficiency for each crew is based on several dozen jobs, thereby balancing abnormally difficult jobs with unusually trouble free jobs.

Properly utilized, the measurement of individual and team efficiency is an important motivator. Without it, workers do not get sufficient and accurate feedback about their job performance. The feedback a worker does receive relates more to moods of supervisors and customers than to job quality or duration. Standards help by providing the expectations of management. When mechanics meet the standards, they know they are meeting management's expectations. This form of communication and feedback improves morale.

JOB CREEP [2, P.104]

This is what happens when the scope of work changes as the job progresses. Often the time increase is not incurred on the planned job but on other jobs the customer may request while the technician is in the area. On the surface such requests seem reasonable enough, but the customer normally has no concept of other commitments that depend upon the scheduled capacity the given technician represents. Planners need to clarify why jobs 'presumably' exceeded the estimate before making any changes to the expectation.

Experience, age, gender, and health of individual technicians are not reflected in proper standards. To begin with, planners should be promptly qualifying the backlog of plannable jobs. This maybe weeks before the job will be scheduled. Therefore at time of estimating, they have limited knowledge as to whom the job will eventually be assigned.

Any study of standards (job time requirements) is incomplete without discussing job quality. Standards must include sufficient time for the worker to perform the proper job in a quality manner (define the right job, perform it right, the first time). Supervisors must make sure that timely job completion is not achieved at the sacrifice of job quality.

B/2.3. Implementation and Use

SOME SUCCESS FACTORS FOR WORK EXECUTION ARE:

The supervisor is responsible for job execution [2, p.147]
The supervisor becomes responsible for tactical execution of the schedule. The supervisor has to be in several places at once. He or she has to be ahead of jobs that are about to start and periodically check in on jobs that are already in process. In this manner, the progress of each job relative to the schedule is continually reviewed to determine if the situation has changed in any material way.

This requires timely information to determine when projects and other jobs are progressing unfavorably. An accurate schedule helps supervisors to judge when exceptions fall outside of reasonable boundaries and intervention is in order.

Effective supervisors also assure that team members reference their planned job packages to minimize exceptions before they occur. The packages have been prepared for good reasons. Use them!

Staying abreast of job status relative to schedule enables the supervisor to take corrective action before problems become serious. When a timeline is included within the planned job package, the supervisor can make a well-informed judgment. If the schedule shows the job should be half done by lunchtime, the supervisor quickly looks for a certain amount of work to have been completed. If the amount of work completed is within reasonable boundaries, no intervention is needed. However, if the supervisor finds that an important job is falling behind schedule, tactical decisions (larger crew, overtime, contractor support) can be made to correct the situation before a major shortfall develops. Intervention while the job is still in process can make a real difference in downtime and equipment availability.

If thirty minutes after job start the crew is still looking for a ladder to begin the job, the supervisor should jump into action. The above scenario reflects true management. Explanation of variances after the fact does not.

Daily schedule adjustment [2, p.149]
The schedule requires adjustment after each day, to provide a recasting for the balance of the week. Ultimately this recasting is a supervisory responsibility but, until the transition from reaction to proaction is well underway, the planner/scheduler will probably need to do it. Planners should get beyond this stage as quickly as possible. Until they do, they will spend too much time on scheduling to the detriment of planning.

The morning meeting [2, p.150]
A well-thought-out schedule provides a framework for achievement of weekly targets, but problems do occur and changes need to be made on a daily basis.

The meeting is short, perhaps 15-30 minutes. Therefore, it is often conducted standing up. The focus should be on getting the desired result and not on who made the mistake.

SOME SUCCESS FACTORS FOR WORK MEASUREMENT ARE:

Given proper scope, there are several essentials that make estimating easier, more accurate, and more consistent between those who estimate – planners. These include:

- **Breaking large jobs into steps. Long, complex jobs cannot be estimated accurately as a whole.**
- **Not trying to estimate with 'pinpoint' accuracy.**
- **Relative comparison of new jobs to common known jobs – 'benchmarks'. The new job need not 'match' the benchmark. It is necessary simply to determine which benchmark is the closest comparison. [2, p.104]**

Individual (as opposed to crew) efficiency should be the exception rather than the rule, and should only be used in a constructive manner to guide individual development and training. Analysing the efficiency of individuals over time uncovers specific training needs. [2, p.102]

B/2.4 Case Studies

Company A was founded in 1983 based on the know-how and licence of the german mother Company B. The head office of the company is situated in the Industrial Area of Kilkis in Northern Greece, while office locations and showrooms exist in Athens and Thessaloniki as well.

Company A's activities concern both the manufacturing and trading of **Complete Lift Systems**. It is enlisted among the largest companies of this field in the European and international market (more than 14.000 installed systems or 4% of the world lift market. In Greece, the company holds a leading position in the constantly developing lift market with a 73% market share of total units installed and 47,3% of total value. International sales equal to 35% of the total turnover of the company in 2004. They are held in more than 50 countries, with England, USA, Germany, Belgium, Ireland, Yugoslavia, Turkey and Cyprus to be the main markets

For Company A safety on Maintenance is a very critical issue, so special regulations exist. These regulations are presented in the following Company A document:

SAFETY ON MAINTENANCE WORK AT COMPANY A

MAINTENANCE

Maintenance is a critical parameter for the safe use of equipment because, on the one hand, it ensures its good condition and on the other hand, maintenance itself is an emergency work and due to this it involves special dangers. Manufacturers usually give clear instructions for the preventive maintenance schedule and in many cases they undertake it themselves.

General principles for maintenance:

- The Preventive maintenance schedule, suggested by the manufacturers, must be followed to ensure the good condition and operation of the equipment.
- Special attention must be paid on maintenance works when equipment is on (gradual system on-off). When possible, maintenance work should be carried out when equipment is off.
- Electrical and any other kind of supplies must be isolated during maintenance, as well as all supplies that include danger (e.g. electric energy, liquids, air, etc).
- Establishment of specific procedures for maintenance and faithful implementation by all persons involved, in order to have all maintenance works absolutely controlled.

DANGEROUS SITUATIONS
during equipment maintenance can emerge from:

- **Hydraulic liquids under pressure.** All hydraulic systems must be out of pressure and with the safety valves on.
- **Compressed air-liquids.** Energy stored in liquids or air might cause violent expansion causing great dangers.
- **Energy saved in springs** or generally in schemes where mechanical energy is stored.
- **Generally energy sources** that can cause unexpected movement of parts of the equipment.
- **Electricity.** Maintenance works must be done when the general switch key is in OFF position and the key is in a remote safe place. When settings have to be done on equipment under voltage, then special protection measures have to be taken, such as appropriate shoes and gloves. Only electricians with special license must carry out electrical works.

- **High voltage.** Works in positions of high voltage, such as substations or parts of equipment that operate under that, are forbidden and the works have to be carried out only by electricians that have special license.
- **Human factor-inattention.** False step, slip, fall when works are carried out on slippery surfaces and height.
- **Exposure to radiation.** Works that include weldments, settings-repair of a Laser generator and beam, works in external places without protection.
- **Exposure to chemicals**. When using chemicals to clean surfaces there might be a skin or eye contact, which can result in burns or blindness.
- **Exposure to extreme physical conditions.** Work in places with high-low temperature or low-high humidity may cause health problems.
- **Musculoskeletal disorders.** During transfer of heavy weights, such as motors, reducers, pumps or lubricants, musculoskeletal disorders and waist injuries can occur.

INSTRUCTIONS FOR THE SAFE EXECUTION OF MAINTENANCE WORKS:

- **Use of Personal Protection Means.** Mandatory use of all Personal Protection Means necessary for every work, i.e. gloves, shoes, ear plugs, helmet, protective belt, facemask, special clothing.
- **Maintenance must be carried out when machine is off** and, if possible, not connected to any source of energy.
- **Parts of machines and tubes with steam, liquids and air under pressure must be isolated** in order not to cause an accident. The system must be out of pressure with the safety valves off.
- **Parts of equipment that can fall during maintenance works and cause accidents should be well supported.**
- **Movable parts must be waited to stop** before any maintenance work starts.
- **Hot parts must be left to cold and cold parts should be left to acquire room temperature** so as hot or cold burns to be avoided.
- **The engine of movable equipment must be turned off, the gear box must be in neutral position with the break on and the wheels blocked by an external mean if needed.**
- **Tanks that contain flammable materials must be cleaned thoroughly well especially before hot works.** Even small quantities can ignite by a lamp or a lens during maintenance.
- **Marking of equipment** during maintenance – repair with warning signs at apparent positions, notification of workers at neighboring positions.
- When maintenance is carried out at height, safe

means of access must be taken into action according to the nature, duration and frequency of works (aerial ladder, loft, e.t.c.)

- **Use of immediate release devices** when works are carried out in closed - restricted areas by the presence of auxiliary personnel for the keeping of emergency procedures.
- **The selection of garment** for maintenance workers must be made in such a way that the apparel is ergonomic and states their position during works. Preference in light color apparel having stripes with phosphorescent material.

EFFICIENCY OF MAINTENANCE WORK AT COMPANY A

Company A controls the Maintenance Department efficiency in different ways. One of the most important reports is presented in figure 1 (next page)

On this monthly report, addressed to top management, it is presented information related to Staff. These are:

- **Work force (Number of technicians per week) (A),**
- **Working hours per week (B),**
- **Absenteeism in hours (C),**
- **Overtime (D),**
- **Hours taken from other departments (E),**
- **Hours ginen to other departments (F),**
- **Available hours (G = (A * B) – C + D + E – F).**

On the next 3 sessions the Actions and the Hours spent in different types of Actions (Preventive Maintenance, Breakdowns, Projects). In addition in Preventive Maintenance, there're theoretical hours which give the relevant productivity. The next session is presenting Totals of the previous 3 sessions.

Finally, there are some Key Performance Indicators (KPIs) are presented, like percentage of Actions for Preventive Maintenance (PM), percentage of Hours for PM, percentage of Actions for Breakdowns, percentage of Hours for Breakdowns, percentage of Actions for Projects, percentage of Hours for Projects, percentage of Absenteeism (compared to Available hours), percentage of Overtime compared to Available hours), percentage of net productivity and percentage of productivity.

Figure 1: Report of Maintenance Department

STAFF	2008					TOTAL
	27	28	29	30	31	
Work force	11	12	12	12	12	11.8
Working Hours	40	40	40	40	40	200
Absenteeism (hours)	120	90	141	160	168	679
Overtime	6	6.5	5	5	9	31.5
Hours from other departments	0	0	0	0	0	0
Hours to other departments	0	0	0	0	0	0
Available hours	326	396.5	344	325	321	1712.5
PREVENTIVE MAINTENANCE	**2008**					**TOTAL**
	27	28	29	30	31	
Actions	41	26	32	28	5	132
Theoretical hours	25.5	17	24.5	32	6.5	105.5
Hours spent	61.7	38.79	58.93	52.85	6	218.27
% Net productivity	41%	44%	42%	61%	108%	48%
BREAKDOWN	**2008**					**TOTAL**
	27	28	29	30	31	
Actions	41	42	44	40	52	219
Hours spent	99.48	158.03	112.63	151.4	137.74	137.74
PROJECTS	**2008**					**TOTAL**
	27	28	29	30	31	
Actions	63	52	41	65	49	270
Hours spent	162.03	199.61	171.94	120.39	177.07	831.04
TOTAL	**2008**					**TOTAL**
	27	28	29	30	31	
Sum of actions	145	120	117	133	106	621
Sum of theoretical hours	287.01	374.64	309.07	303.79	321.31	321.31
Sum of hours spent	323.21	396.43	343.5	324.64	320.81	320.81
KPIs	**2008**					**AVERAGE**
	27	28	29	30	31	
% Actions Preventive Maintenance	28%	22%	27%	21%	5%	21%
% Time spent for Preventive Maintenance	19%	10%	17%	16%	2%	13%
% Actions Breakdown	28%	35%	38%	30%	49%	36%
% Time spent for Breakdown	31%	40%	33%	47%	43%	39%
% Actions Projects	43%	43%	35%	49%	46%	43%
% Time spent for Projects	50%	50%	50%	37%	55%	49%
% Absenteeism	27%	19%	29%	33%	35%	29%
% Overtime	1%	1%	1%	1%	2%	1%
% Net productivity	88%	94%	90%	93%	100%	93%
% Mixed productivity	99%	100%	100%	100%	100%	100%

B/2.5 Keywords

Work execution, Safety, Best Maintenance Repair Practices, Work measurement.

B/2.6 Glossary

Work Request: Formal request to have work performed. Subsequently, it is transformed into a Work Order upon authorization.

Work Order: Written authorization to proceed with a repair or other activity to be performed by the maintenance organization.

Emergency work: Maintenance work requiring immediate response from the maintenance staff. Usually it is associated with some kind of danger, safety, damage or failure of critical production equipment.

Call back job: Job to which maintenance must return because the asset failed again for the same reason because the job was not performed properly the first time.

B/2.7 Questions

1. How accidents within a company can be eliminated?

a. By setting safety rules and regulations
b. By developing a safety and health program
c. By tightening staff supervision
d. By making proper recommendations to maintenance staff

(Answer: b)

2. Which of the following can cause an accident at work?

a. Human actions
b. Equipment
c. Work place conditions
d. All the above

(Answer: d)

3. Which of the following does not contribute to effective work execution?

a. To perform the work on the right way
b. To perform the work safely
c. To perform the work quickly
d. To perform the work effectively

(Answer: c)

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B/3 Condition Based Maintenance

B/3.1 Introduction

WHERE THE METHOD, TECHNIQUE AIMS?

Condition based maintenance and condition monitoring techniques in general have been given a great deal of attention lately since their use can sometimes be much more effective than typical predetermined maintenance models. The aim of this technique is the use of advanced technology in order to determine the equipment condition and predict failures in a more accurate way.

WHAT ARE THE BENEFITS FOR THE COMPANY? (WHY TO USE IT?)

This way preventive maintenance actions can be scheduled just before failure and unnecessary process interruptions can be avoided resulting in decreased maintenance related costs.

ARE THERE ANY PRECONDITIONS, LIMITATIONS?

An important precondition for the implementation of condition based maintenance is the existence of intermediate operating states of the equipment that forebode failures. However, in practice the rule is that almost all mechanical equipment undergoes some kind of deterioration before failure that can be recognized prior to failure and maintenance actions can be scheduled in time to avoid the oncoming failure. Bloch and Geitner (1) have noted that 99% of all machine failures are preceded by certain signs, conditions or indications that a failure is going to occur. Many times, such signals precede failures by weeks or even months. Condition based (or predictive) maintenance implements closed loop maintenance control in which sensor feedback information from equipment is utilized in making maintenance planning decisions.

LEARNING OBJECTIVES FOR THE TRAINEES?

The scope of this chapter is to familiarize maintenance managers and technicians with the alternative types of condition monitoring techniques (such as vibration analysis, thermography, oil analysis etc.) and provide them with information for their implementation. In parallel, important tips for the every day operational issues of condition monitoring are also provided.

B/3.2 Theoretical Background

Condition based maintenance is in fact Preventive maintenance based upon performance and/or parameter monitoring and the subsequent actions. That is Condition based maintenance is a maintenance policy which uses advanced technology for the direct monitoring of the mechanical condition, system efficiency and other indicators to predict the actual time to failure or loss of efficiency.

More specifically, condition based maintenance involves the intermittent or continuous collection and interpretation of data relating to the operating condition of critical components of the equipment, determining when a failure mode has been initiated, predicting the time to complete equipment failure and making decisions on appropriate maintenance strategy (initiation of work order, what repair or replacement to perform and priority level of work).

A wide range of condition monitoring techniques has been developed for this purpose (2), the most common of which are the following:

- **Vibration analysis**
- **Thermography**
- **Oil analysis - Tribology**
- **Ultrasonics**
- **Visual inspection**

Vibration analysis
Vibration monitoring techniques can be used to detect malfunctions in systems with rotational or reciprocating parts, such as bearings, gear boxes, shafts, pumps, motors, engines and turbines. The operation of such mechanical systems releases energy in the form of vibration with frequency components which can be traced to specific parts in the system. The amplitude of each distinct vibration component will remain constant unless there is a change in the operating dynamics of the system.

Vibration can be characterized in terms of three parameters: amplitude, velocity and acceleration. Vibration analysis in condition monitoring is accomplished by comparing the vibration characteristics of the current operation to a baseline, which was measured when the machine was known to be operating normally

Thermography
Thermography measures surface temperature through infrared radiation and is most appropriate to detect problems in systems which rely on heat transfer or retention. Infrared cameras show surface temperature variations calibrated to provide the absolute temperature gradients through black-and-white or color variations. Anomalies of thermal conditions are taken as alarm signals of potential problems within the system.

Oil analysis - Tribology

A number of different techniques can be applied for the analysis of chemical composition of the oil.

More specifically, ferrography and magnetic chip detection examine iron-based wear particles in lubrication oils to determine the type and extent of wear. Spectrometric oil analysis measures the presence and amounts of contaminants in the oil through atomic emission or absorption spectrometer and determines any metallic and nonmetallic elements which can be related to the initial failure state of various machine components. Chromatography measures the changes in lubricant properties, such as viscosity, pH and water content through selective absorption and analysis.

Ultrasonics

There are several techniques for ultrasonic testing but they all are used to determine faults or anomalies in welds, coatings, piping, tubes, shafts and so forth. Cracks, gaps, build-ups, erosion, corrosion and inclusions are discovered by transmitting ultrasonic pulses or waves through the material and assessing the resultant signature to determine the location and severity of the discontinuity.

Visual inspection

Visual inspection of the equipment offers a simple method to detect problems. Besides, such inspections can be easily performed in parallel with other maintenance procedures. Hence, the incremental cost of visual inspection is often negligible.

B/3.3 Implementation and Use

For the successful implementation of a condition based maintenance policy a step-by-step approach is presented:

DATA COLLECTION AND FAILURE INFORMATION

Gathering of data related to the equipment, its working condition, times of failures, cause of failures, cost and duration of repair etc. is an important initial step. Such information in necessary in deciding whether a condition based maintenance program is recommended, how should the equipment be monitored, when a failure is going to occur and what should the work priorities be.

For this purpose an appropriate database must be developed to summarize all information needed. The collected data can be used for statistical and trending analysis to identify potential correlations between failures and other process parameters or equipment characteristics. Finally, such information is also of importance for the future evaluation of the maintenance efficiency.

PARAMETER SELECTION

Selection of the monitored parameters must take into account several factors such as the type of the plant facilities, the availability of reliable surveillance technology, investment in instrumentation, manpower requirements and operating costs.

It should be noted that an oncoming failure may show several types of symptoms, each of which may become detectable at different stages of degradation of the unit. However, symptoms which show up at later stages allow for a shorter reaction period to the occurrence of the failure. Thus, all symptoms as well as their applicable condition monitoring techniques should be considered in choosing the most cost – effective CBM procedure.

SENSOR INSTALLATION

Once the selection of the parameters to be monitored is done the condition monitoring sensors must be installed and the staff must be trained to use them.

DEVELOPMENT OF THE EXACT CONTROL TOOLS

In order to detect when fault condition is apparent, warning and/or alarm limits must be set. Either static or dynamic alarm limits can be used as triggers for diagnostic and repair action (9).

Static limits are pre-selected thresholds of the measured data. Standard alarm levels have been developed by major equipment manufacturers, diagnostic system retailers and standards organizations, such as ISO. Note that static limits are easier to apply but they do not have the diagnostic power for predicting when the alarm will be reached. Also note that despite this fact, standards are by far the most commonly used method in industry.

On the other hand, dynamic limits are used to monitor the rate of change of the measured parameter. Thus the use of dynamic limits enhances the diagnostic capabilities of a CBM procedure.

DETERMINATION OF THE INSPECTION FREQUENCY

At first it must be decided whether the equipment will be monitored continuously or in an interval basis. In the latter case the interval between inspections has to be determined, so that the action can be taken in time to prevent failures. Too short intervals result in over inspection, while too long intervals increase the risk of failures.

INTERPRETATION OF THE DATA

For the better scheduling of the repair action, in case a fault condition is detected, it is necessary to predict as accurately as possible the time of the complete failure, where the equipment would unavoidably shut down. For this purpose it is necessary to have information about the time from failure mode initiation to complete failure, lead times for repairs and lead times for materials which must be ordered. However, the estimation of the time lag between the instance that the symptoms become detectable and the moment when failure occurs is very difficult and may be inaccurate (8).

Thus, extended statistical analysis should be carried, from historical data, in order to link the time of failure to the time when the fault was initiated or first detected.

What are the success factors?

The necessary conditions for a successful implementation process are the following:

Commitment

The staff must have commitment to the process and its new technologies as well as their use. The management must have commitment to procure adequate equipment and training for the staff.

Participation

All personnel must participate on the program. The organization must fully support the new maintenance policy to achieve success and the management must reinforce this expectation.

Software support

CBM is a rather sophisticated maintenance policy incorporating the use of advanced technology. Thus, it is important for CBM to be fully supported by an equally advanced CMMS program which will provide the necessary data and analysis as well as the mathematical tools for the optimization of the policy parameters.

Sustainability

Sustainability is important in order to ensure the long term benefits of the process. This includes the top management support to trust and maintain the program.

Continuous improvement

As CBM procedures are running, feedback can and should be used to optimize it. For example as the data base is enriched with more recent failure information the estimations concerning the failure time distributions with regard to the equipment condition can become more accurate.

Training

Since most Condition Monitoring Techniques are rather advanced and unknown to the employees, training is essential to provide information for the implementation and usage of each technique as well as for the anticipated benefits.

B/3.4 Case study - Condition Based Maintenance at Company A

COMPANY A

Company A is an oil refinery with leading role in the Greek market. Company A covers 25% of the domestic market and 50% of oil exports. The company is the second biggest refinery and lubricant producer in Greece.

VIBRATION ANALYSIS IN COMPANY A

Vibration analysis constitutes the most important diagnostic technique for the company. It is applied in the whole range of its rotating equipment (pumps, compressors and turbines) with very accurate failure predictions.

Vibration analysis is a non-catastrophic procedure and it aims at condition monitoring and diagnosis of the equipment without cease of production. The monitoring process is conducted using an accelerometer named Data Collector. All collected data are then transferred in a computer, which is equipped with the appropriate software for their further analysis, evaluation and storing.

Every rotating machine of the company is categorised as "critical" or "non – critical" and is inspected either every 20 days (critical) or every two months (non – critical), unless a fault conditioning suspicion exists. The exact monitoring points of every machine are well defined and fixed so as all measurement are comparable. The number of machines, categorised as critical and non – critical, as well as the total number of monitoring points are summarised in Table 1.

VIBRATION DATA	
Monitoring machines	**845**
Critical	**276**
Non - critical	**569**
Monitoring points	**3343**

Table 1: Vibration monitoring

The measurement evaluation is performed based on the observations regarding the acceleration of the vibration in certain frequency ranges. More specifically, the software provides scatter charts of the acceleration (Y – axis) against frequency (X – axis). From these charts information can be drawn concerning the exact working condition and the detection of a potential malfunction.

Whenever the acceleration value exceeds the predefined alarm limits, a problem has occurred. Moreover, the frequency where the

alarm is issued is a direct indication of the specific machine component that has suffered the problem. For example, out – of – control acceleration values for low values of frequency are related to **imbalance**, for medium values of frequency to **coupling** problems while for high values of frequency to **bearing** fatigue (Figure 1).

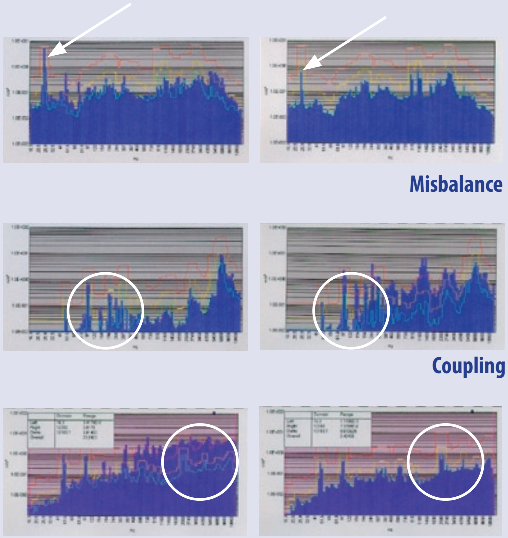

Figure 1

The most common malfunctions detected through vibration analysis in the company are:

1. **imbalance of rotating parts, due to irregular weight allocation which results in different rotating frequency of the machine**
2. **coupling problems among pumps and motors, due to misalignment**
3. **bearing fatigue, mainly due to imbalance, misalignment or bad assembly**

Misalignment is responsible for more than 50% of vibration problems in the company. The most common sources of misalignment are:

1. **Inappropriate supporting**
2. **Staff denial to adopt new alignment techniques**
3. **False tolerance setting**
4. **Difficulty in determining the increase in temperature**
5. **Inappropriate alignment equipment and tools**

Imbalance is also a major failure source in the company. Whenever imbalance is detected the mass allocation of the component is checked and corrected. Three steps are applied for this purpose; first the exact mass allocation is recorded, then it is corrected and finally the rotating unit is checked for any remaining imbalance. The most common sources of imbalance are:

1. **Bad assembly (e.g.. asymmetric addition of strings, chocks or screws)**
2. **Unfavourable operating conditions (e.g. corrosion, foreign parts, etc.)**

CONCLUSION

Both misalignment and imbalance can lead in enormous damage if not detected in time. Vibration analysis has contributed significantly for the early detection of these malfunctions greatly improving the efficiency of maintenance procedures in the company. The company reports that adopting CBM techniques has decreased maintenance related costs about 30%! But maybe the most important benefit of CBM was that it greatly decreased the need for periodic preventive maintenance (PM) procedures, which require the cease of production. More specifically, the company used to cease production every six months for PM purposes while now such PM activities are scheduled every 3 or 4 years!

B/3.5 Keywords

CBM: Condition Based Maintenance, PM: Preventive Maintenance, Condition Monitoring Techniques, ISO: International Standards Organization, CMMS: Computerized Maintenance Management System.

B/3.6 Glossary

Vibration: refers to mechanical oscillations about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road

Amplitude: is a nonnegative scalar measure of a wave's magnitude of oscillation, that is, the magnitude of the maximum disturbance in the medium during one wave cycle.

Velocity: is defined as the rate of change of position

Acceleration: is defined as the rate of change of velocity, or, equivalently, as the second derivative of position.

Ultrasonics: is a cyclic sound pressure with a frequency greater than the upper limit of human hearing, this limit being approximately 20 kilohertz (20,000 hertz).

Imbalance: loss of balance. Imbalance of an engine increases vibration and other stresses resulting in decreased performance, efficiency and reliability of the engine.

Misalignment: when some parts of a machine are not properly aligned.

B/3.7 Questions

1. Condition Based Maintenance differs from Predetermined Maintenance in that:

a. Condition Based Maintenance actions are performed earlier than Predetermine Maintenance actions.
b. Condition Based Maintenance is easier to implement.
c. Maintenance actions can not be scheduled in advance in a Condition Based Maintenance policy.
d. Predetermined Maintenance incurs lower maintenance - related costs.

(Answer: c)

2. What is the most important benefit of Condition Based Maintenance?

a. It is easier to implement than other maintenance policies.
b. It doesn't require expensive equipment to be performed.
c. It can be very effective in detecting 'anomalies' and preventing from failures.
d. It eliminates the necessity for Predetermined Maintenance.

(Answer: c)

3. Which of the following is not necessary for a Condition Based Maintenance policy?

a. A continuous monitoring mechanism.
b. A detectable symptom of degradation.
c. Threshold (alarm) values of the monitored parameter.
d. Staff training for the applied Condition Based Maintenance techniques.

(Answer: a)

4. Which of the following Condition Based Maintenance techniques is the most appropriate for the detection of piping cracks?

a. Thermography.
b. Ultrasonics.
c. Visual inspections.
d. Ferrography.

(Answer: b)

5. In what type of equipment is vibration analysis most commonly used?

a. Heat exchanger.
b. Punch press.
c. Fuel tank.
d. Turbine.

(Answer: d)

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B/ WORK AND MATERIAL

B/4 Spare Parts Management

B/4.1 Introduction

WHERE THE METHOD, TECHNIQUE AIMS?

Effective management of spare parts for maintenance purposes is a very critical factor in almost every production system. The main objective of a successful spare parts planning and control system is to fulfill the service requirements and avoid downtimes in the most efficient yet economic way.

WHAT ARE THE BENEFITS FOR THE COMPANY? (WHY TO USE IT?)

Developing the appropriate policy / strategy concerning the management of spare parts is crucial since lack of the right parts upon need either for scheduled or for emergency maintenance may have financially remarkable consequences. On the other hand stocking large numbers of expensive parts, the demand of which is sometimes extremely low and sporadic, can be very costly for the company.
Thus, it becomes obvious that it is very important for the maintenance managers as well as for the company itself to select the appropriate spare parts operating policy for their needs.

LEARNING OBJECTIVES FOR THE TRAINEES?

The scope of this chapter is to provide the maintenance managers with the basics for the correct choice, development and implementation of a spare parts planning and control policy. More specifically, the most important factors including criticality, specificity, value and demand of spare parts are analyzed and instructions

B/4.2 Theoretical Background

BASIC INFORMATION FOR THE MAINTENANCE PRACTICE, METHODOLOGY, TOOL

Management of spare parts is usually a very complicated procedure mainly because spare parts incur some special characteristics compared to other materials (4). More specifically, spare parts differ from other materials in several ways, the most important of which are the following:

a) **They are characterized by a more unpredictable demand. In fact, their demand may be extremely sporadic and irregular, making it very difficult to forecast.**

b) **The stock-out cost may be very high, since unavailability of parts directly impacts production and can cause costly downtimes. This, in turn, results in high service requirements.**

c) **The prices of some parts may be remarkably high.**

Thus, the choice of the appropriate planning and control policy is not a simple task and the decision maker has to take into account (apart from standard inventory characteristics) issues concerning spare parts importance and criticality as well.

However, in order to build a system for the management of spare parts there are still certain questions that must be answered; that is (a) how often should the inventory level be inspected, (b) when should parts be ordered and (c) in what quantity? These are typical questions in almost every inventory management system and thus before proceeding in the discussion of spare parts management techniques some basic characteristics of inventory control systems in general will be presented (see also 1).

FUNDAMENTALS OF INVENTORY CONTROL

The main objective of almost all inventory systems is to keep track of every item used and place an order for additional stock when inventories reach a predetermined level. The special characteristics that differentiate the several types of inventory systems are the following:

a) **Review process: Usually, the inventory levels are being reviewed either continuously or periodically. In the first case an order can be placed at any point in time, while in the latter an order can only be placed at review times.**

b) **Order quantity: The ordering policy is usually of one of the following types: (a) order up to some inventory level S, or (b) order a certain quantity Q. In any case, though, the choice of the exact values of S or Q should depend on some system parameters such as the inventory holding cost, the ordering cost and the mean value of demand.**

Probably the most common practice to derive the order quantity is the Economic Order Quantity (EOQ) model. According to this model the order quantity is derived by minimizing the total ordering and holding cost function, which is:

$$C=A\frac{D}{Q}+h\frac{Q}{2}$$

where A is the ordering cost, D is the mean demand per period and h is the holding cost per item per period. Thus from (1) the economically optimal order quantity is given by:

$$C=\sqrt{\frac{2AD}{h}}$$

c) **Reorder point:** The reorder point, denoted s, is the threshold inventory level where an order is placed. It must be high enough to satisfy any demand during replenishment time (order lead time) yet not too high because the holding cost would be greatly increased. In fact, the reorder point is directly related to the desired service level and it is derived as the mean value of demand during replenishment time plus some safety stock ss. That is:

$$C=\mu_L+ss$$

Safety stock is an additional stock needed as long as demand is a random variable and thus it may exceed its expected (mean) value during lead time; in other words ss is needed to prevent the system from stock outs. Typically, ss is derived so as to ensure with some probability (service level) that there is adequate inventory till order replenishment arrives. To determine the safety stock using the service level approach, it is necessary to know the probability distribution of the demand during lead time.

B/4.3 Implementation and Use

In maintenance inventory control systems, any parts required for routine maintenance should be readily available. The parts that must be controlled are those needed at nonscheduled times for non-routine maintenance. However, not all parts require the same degree of attention since some of them may be more expensive and/or more crucial for production. Thus, an initial classification of inventory items in terms of cost and criticality is strongly recommended.

CLASSIFICATION

a) Classification with respect to cost.

Classifying inventory items with respect to their cost is usually achieved with ABC analysis, which is a commonly applied technique based on Pareto's law. The main idea of ABC analysis lies on the fact that the significant items in a group usually constitute only a small portion of the total number of items in that group. Thus, the ABC approach classifies inventory into three categories (i.e. A, B and C) based on annual total inventory cost. In practice the following relationship between the percentage of inventory items and the percentage of annual total cost is observed (see also Figure 1):

1. **About 10% to 20% of total items are responsible for 60% to 80% of the total cost. These items constitute class A.**
2. **About 20% to 30% of total items are responsible for 20% to 30% of the total cost. These items constitute class B.**
3. **About 60% to 80% of total items are responsible for 10% to 20% of the total cost. These items constitute class C.**

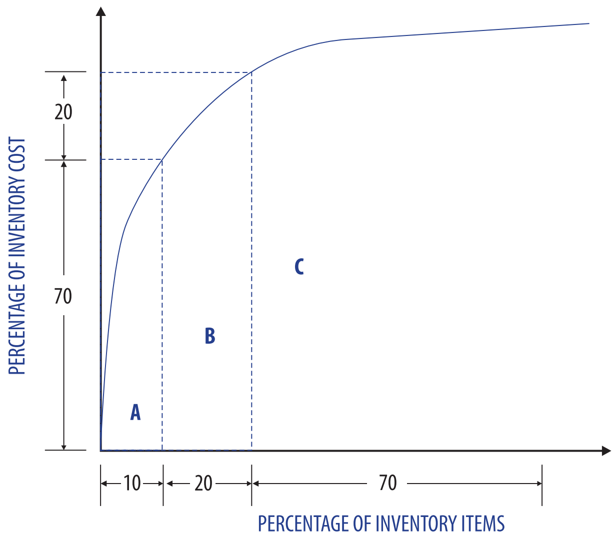

Figure 1: ABC analysis diagram

Thus, a step by step procedure for constructing an ABC analysis is as follows:

1. **Select a suitable time period, usually one year.**
2. **Calculate the cost of each item used in the selected period as a percentage of the total cost of inventory items.**
3. **Rank the items in descending order.**

4. **Plot the graph with percentage of item used on the X axis and percentage of its cost on the Y axis as shown in Figure 1**

5. **Group items based on the criteria established above.**

b) Classification with respect to criticality.
Criticality is probably the most important feature of spare parts (5). It is related to the consequences caused by the failure of a part in case replenishment is not readily available. In other words it is an indirect measure of the stock out cost.

Parts are usually classified in terms of their criticality using qualitative criteria. For example the following three categories could be used:

1. **Highly critical parts (class H): Parts that are absolutely essential for the operation of the equipment.**

2. **Moderately critical parts (class M): Parts that will have a moderate effect on the operation of the equipment.**

3. **Low critical parts (class L): Parts that hardly affect the operation of the equipment. Classification according to cost and criticality can be grouped together as shown in Table 1 (see also 2)**

	CRITICALITY		
Cost	H	M	L
A	1	1	2
B	1	2	2
C	3	3	3

Table 1: Classification of spare parts according to criticality and cost.

SELECTION OF INVENTORY SYSTEMS

After the classification of inventory items, control policies can be established associated with each group of items. More specifically:

Group 1 items: These are high-priority items and they must be tightly controlled. Thus, they must be continuously or frequently reviewed and orders must be placed based on calculations of the economic order quantities. Sometimes, it may be advisable that an item is ordered as soon as it is consumed; this type of inventory model is well known as (S-1, S) model and dictates that an order up to S must be placed as soon as the inventory level reaches S-1. This model is commonly used in cases of crucial and expensive equipment such as spare parts for aircraft machines.

Group 2 items: These are medium-priority items and they must be regularly controlled. They can be periodically reviewed and order quantities are usually larger than those of group 1 items. The EOQ model is commonly applied in this group of items as well.

Group 3 items: These are low-priority items and they must be minimally controlled. They are usually kept in stock in large quantities to ensure availability for considerably longer periods (sometimes up to six months), since they are generally low cost items.

In cases of extremely low volume demand but high value of some parts, it may be recommended that closely located companies cooperate in keeping some stock (probably one unit) for common use (4). This way, all sporadic demands faced by the companies are consolidated into a smoother one, which is easier to satisfy.

PREDICTION OF SPARE PARTS DEMAND

Regardless of the exact type of the inventory system in use there is usually a need for safety stocks. To determine the optimal safety stock level someone needs to predict as accurately as possible the demand distribution of spare parts. Since spare parts are usually required due to failure occurrences the demand for these parts can be described through the failure probability distribution of the equipment. Past experience and historical data should be used to describe the failure process and estimate the number of spares required for a desired service level.

GUIDELINES FOR EFFECTIVE SPARE PARTS STORING AND HANDLING (SEE ALSO 3)

For the maintenance staff:

- Provide the Storeroom with adequate time to pick parts for planned maintenance jobs.
- Notify the Storeroom of schedule delays.
- Assure that unused spare parts are returned to Storeroom.
- Notify the Storeroom of spare parts that will become obsolete to prevent surplus inventory.

For the Storeroom staff:

- Keep inventory orderly with parts easily identified and locatable.
- Maintain an (electronic) up-to-date catalogue listing parts and supplies in stock by location.
- Provide timely delivery of spare parts for planned maintenance jobs.
- Keep inventory records on which receipts are added and withdrawals are subtracted.

What are the success factors?

The necessary conditions for the successful implementation of a spare parts management system mainly lie on the following:

Data accuracy

The accuracy of historical data is of great importance, since both classification of items and forecasts of future demands will be based on them. In practice, the unavailability of accurate and usable data is probably the most important problem in building an inventory system for spare parts control.

Information Flow

The maintenance manager responsible for placing replenishment orders must be kept informed about the status of spare parts inventories, so that any orders are placed in time.

Software support

This factor is strongly related to the previous one, since the faster and more accurate way to update inventory records is by using an on-line software system where all maintenance related actions are directly recorded. It is very important that the CMMS used is built so as the inventory levels are directly updated as soon as a repair is recorded.

Reliability of suppliers

The reliability of suppliers highly influences the efficiency of the spare parts control system since the stock out costs may be severe especially for critical parts.

Review and improvement

No matter how well and accurately an inventory system has been designed it must be closely monitored and continuously improved. The inventory control system must be reviewed if needed and up-to-date data must be used.

B/4.4. Case study – Title Example: A spare parts control system at a refinery

This case concerns a study on spare parts at a major oil refinery in the Netherlands (6). The company keeps stock of a large number of spare parts related to equipment used in its petrochemical processes. Although these stocks are essential for the continuity of its operations, management was concerned with the savings opportunities at the process floor by having better inventory control of its spare parts, whose value was worth at the moment of the study more than 27 million euros. One major difficulty of the study was the limited demand history available.

PROBLEM DESCRIPTION

The company under study consists of a major petrochemical complex located in the Netherlands, which includes 60 different plants divided in chemicals manufacturing and oil refining. The complex dates from 1930, and many new installations have been added since then. A large part of it, however, stems from the 1960s. The procurement department offers service to all plants. There is one central warehouse owned by the company. At the moment of the study (2000), there were in total 130 thousand catalogued materials, of which only 43 thousand were kept on stock at the site, with a total value of more than 27 million euros. There are 22 additional small de-central storages on site, containing fast moving materials that can be directly used if needed. No stock registration is done for these items and they are replenished on a batch basis. Therefore, only a single stock echelon needs to be considered, being the warehouse as user of spares for equipment and not a producer of parts. In total there are 180 thousand requests of material per year, both for non-stock and stock materials. Requests for materials kept on stock are supplied from available stock. If there is shortage of a material an emergency replenishment order is generated.

Controlling 43 thousand materials represents a difficult task, especially because of the differences in types and consumption patterns associated with them. It also requires efficient use of the manpower available and of the information system at hand. Until 1997 an in-house developed information system for inventory control was used by the company. In 1997 they moved to the information system SAP R/3, which is a complete ERP-system, but not specific for inventory control. Almost the whole demand history before 1997 has been lost in the transfer to SAP. Within SAP, the company applied the MM (materials management) module for the control of its spare parts. Since SAP evolved out of MRP systems for the manufacturing and assembly industry, the MM module is very much based on the MRP planning philosophy. Demand is expressed by actual orders or by forecasts of demands. Next demand of end products is converted to demand for assemblies, components and parts. Stock control is performed in SAP on a periodic basis (so-called periodic review). Items are ordered when the MRP run is made. The SAP user can set the appropriate time interval, e.g. daily, weekly or monthly. At the company they run the MRP every week.

The actual stock control within SAP occurs in terms of equivalent to (s,S) policies (min–max levels), or MRP-type control based on lead times. Minor functionality is available in SAP to determine the minimum level s and the maximum level S. Safety stocks can be used to determine the reorder level s, and lot sizing methods are available to evaluate the difference between s and S. Before the project 90% of the control levels were set manually, and afterwards some 70%. As a result still many replenishment orders were checked manually before sending them out.

With respect to forecasting, several methods are available in SAP, like exponential smoothing and moving averages, both with trends and seasonality. It is however the intermittent nature of demand that makes the application of these methods particularly difficult to spare parts. For the determination of safety stock levels, the normal loss model is available which approximates the demand during the lead time with a normal distribution. This model works with the cycle service level as service level objective. However, no fill rate service levels can be defined within the MM module. A more striking aspect of SAP is that within its functionality no continuous review models can be implemented. Therefore the classical and much advised (S-1, S) model with Poisson distributed demand over the lead time cannot be applied.

DATA STRUCTURE

Statistical information for the consumption of spare parts was available for 5 years (the last year only until August). The demand information was recorded in monthly periods, so a total of 55 periods of demand information was available for the study. One important limitation of the demand set was that it did not specify whether demands were due to failures or preventive maintenance activities.

Different parts used by the company are divided in two main categories: materials related to a piece of equipment and the ones not related to any particular equipment, like protecting shoes, helmets, general-purposed electrical equipment and instrumentation. From the total of 43,000 materials in stock, 14,383 were spare parts, accounting for 80% of the total stock value. These spare parts are the focus of the case study. The parts related to equipment are classified according to criticality codes as follows:

- **High (H): Unavailability of these materials would result in expensive downtime or cause danger to the safety of the people and the environment. Risk taken in the process of ordering and stocking cannot be justified.**

- **Medium (M): Unavailability of these materials would result in significant loss of production, but does not endanger the safety of the people or the environment. A calculated risk can be taken in the process of ordering and stocking.**

- **Low (L): Unavailability of these materials would not result in serious effects on the processes or on the safety of the people and the environment.**

The previous classification is made on expert judgment and no quantitative methods are used to date. A further inspection of the materials with criticality code leads to a more refined classification: materials that are uniquely installed in a particular piece of equipment (60% of the materials related to equipment), and materials which are related to more than one piece of equipment of different criticality codes. That means that there are spare parts that have combined criticality codes (H/M/L, M/L) depending on whether they are installed in multiple piece of equipment of different criticality. The company used these codes to decide on the stock levels of the different parts. Thus, items identified as highly critical should be on stock since they require high fill rates, low critical ones destock, and medium critical ones on stock depending on cost-effective considerations. However, as no models are available in SAP that incorporate criticality considerations, these levels were set mostly by expert judgment.

CLASSIFICATION OF PARTS

A more refined analysis of the spare parts data revealed that important differences among them existed not only in terms of criticality codes but also with respect to demand and price. Therefore, the aim was to group them in different classes to see whether different stock control methods for different classes should be applied.

Below follows a description of the different classes considered in this case study.
Criticality classes. Based on the criticality codes, the following criticality classes were defined for the spare parts:

Criticality class 1: H

Criticality class 2: H/M/L or H/L

Criticality class 3: M

Criticality class 4: M/L

Criticality class 5: L

Criticality class 6: Not related to any particular piece of equipment

For the current policy used by the company, the service levels associated with high critical items is expected to be higher than the ones for low critical items.

Demand classes. The original data set consisted of more than 14,000 spare parts, for which a high variability in demand patterns was observed. For example some parts had only 0/1 demands while others experienced either few large demands or no realization of demands during 5 years. For other parts large negative demands due to returns was observed. Thus, a classification was needed for the spare parts based on consumption rates. For parts with total positive demand over the five-year period and some demand values higher than 1, two main groups were identified from a histogram: parts with relatively high total demand and parts with low total demand. Although the boundary between these two groups was not clearly identified in the histogram of demand, from a Pareto analysis it could reasonably established in 60 units. This also implies that at least in one month demand is at least 2. It was observed that 90% of the items had a demand below this value, and this contributed 25% of the total demand. At the same time, items with 0/1 demands also had a total demand of less than 60. According to this, the following demand classes for the parts were established:

Demand class 1: parts with only 0/1 demands.

Demand class 2: parts with total demand larger than 0 but less than 60, and not only 0/1 demands.

Demand class 3: parts with total demand higher than 60.

Demand class 4: parts with _1, 0, 1 demands. Parts with negative total demand or parts with no realizations of demand (all demands equal to zero) were excluded from the analysis.

Price classes. For the spare parts in the data set, five different price levels were identified in a histogram. Table 2 shows the different price classes for the spare parts. The parts recorded in SAP with a price of 0 euros are items not owned by the materials department (price class 1). Prices as low as 0.01 euros for some parts (price class 2) were observed and the most expensive ones had a price of 20,000 euros (price class 5).

with inventories: holding costs, ordering costs and stock-out costs. Holding costs represent the cost of capital tied up in the spare parts inventory. An annual fixed rate of 25% was used in the study. Ordering costs represent the cost associated with placing an order for a spare part, which includes the costs of telephone calls, inspection and handling of the incoming items, paying the bill and registration of the parts. This cost is independent of the number of parts included in the order. An ordering cost of 36 euros was used in the study. Since the objective is to evaluate the optimal balance between service levels and holding costs, in this case study stock-out costs are not incorporated.

Price class	1	2	3	4	5
Price (p) in euros	$p = 0$	$0 < p \leq 13.6$	$13.6 < p \leq 169$	$169 < p \leq 2112$	$p > 2112$
Spare parts (total = 14383)	10%	19%	33%	29%	8%

Table 2: Price classes of parts

Combined classes. Using the criticality, demand and price classes, each item was included in a combined class defined by three digits. Accordingly, an item in class "xyz" corresponds to an item with demand class x, criticality class y and price class z. This classification allows optimizing the system per class rather than for individual items. That is, once a service level is defined for the combined class, the parameters for the different inventory policies are evaluated for each item in the class. Then a simulation tool is used to evaluate the performance of the selected model of each individual item using its demand data. Finally total costs are aggregated across all items in the class. In this way the aim was to obtain an optimization rule for each combined class considered in the study.

COST STRUCTURE

In general, three types of costs are associated

METHODOLOGY

The historical demand data was divided into two sets, namely a fitting period and a testing period. The fitting period was used to estimate the lead time demand distribution (LTD) which was used in turn to determine the inventory policy parameters. The testing period was used to perform a simulation to evaluate the performances of the inventory policies selected and compare them with the performance of the current one.

RESULTS

The analysis showed that the suggested inventory control policies outperformed the current one of the company both in terms of cost and service levels. The resulting savings varied with respect to item class as well as with respect to the type of the suggested inventory model. In general, it could be stated that total savings of up to 6.4% in inventory costs can be achieved by using a more sophisticated inventory control system while the service levels can also be considerably improved.

B/4.5 Keywords

Economic Order Quantity (EOQ), Safety Stock, Reorder point, Demand distribution, Holding / Stock-out / Ordering cost, ABC analysis, Criticality.

B/4.6 Glossary

Spare parts: Parts that are kept in stock to support maintenance operations and to protect against equipment failures.

Inventory control: A systematic approach to monitor and control the inventory levels of all (or a part of) the items kept in stock by a company.

Service level: The achieved amount of service provided by a company to its customers, usually represented by the probability of satisfying any demand between replenishments.

B/4.7 Questions

1. What is the scope of an effective Spare Parts management policy?
a. To ensure that there always are spare parts available upon need.
b. To fulfil service requirements in the most economical way.
c. To minimize spare parts stocks.
d. To minimize failure occurrences.

(Answer: b)

2. When choosing the appropriate planning and control policy for spare parts you should also consider:
a. The cost of spare parts.
b. The criticality of spare parts.
c. Both the cost and criticality of spare parts.
d. None of the above.

(Answer: c)

3. What exactly is the reorder point of spare parts?
a. The threshold stock level where an order is placed.
b. The time period between consecutive orders.
c. The average stock level when an order arrives.
d. The order quantity of each replenishment.

(Answer: a)

4. Which of the following is not a special characteristic of spare parts?
a. Their demand is usually erratic.
b. Their stock out costs can be very high.
c. Sometimes they are very expensive.
d. Their demand is usually higher than that of other materials.

(Answer: d)

5. What type of spare parts is usually kept in stock in larger quantities?
a. The low-priority ones since they generally have low holding cost.
b. The high-priority ones since they incur high stock-out cost.
c. All spare parts must be kept in stock in equal quantities.
d. The expensive ones so that they will be always available.

(Answer: a)

B/4.8 List of References

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TRAINING MATERIAL IN MAINTENANCE MANAGEMENT

C/ MEASUREMENT AND IMPROVEMENT

C/ MEASUREMENT AND IMPROVEMENT

C/1 Availability Performance

C/1.1 Introduction

In today's competitive business environment, every conceivable advantage is being pursued by companies. In the first decade of the 2000's, many of them are shifting their focus to the optimization of their assets. Because the maintenance function has the greatest impact on the condition and, ultimately, the capacity of the asset, companies are searching for the best method of managing maintenance [3].

The question is: How can rapidly changing companies focus on improvements when there is no system to tell them if they are making progress? This question highlights the need for measurable and consistent performance indicators [3]. Availability performance is, among others, an indicator to measure the performance of assets.

Properly utilized, performance indicators, thus availability performance, should highlight opportunities for improvement within companies today. Performance measures should be used to highlight a soft spot in a company and then be further analyzed to find the problem that is causing the indicator to be low. Ultimately, they can point to a solution to the problem [3].

Objective of this module is to familiarize the reader with the basic terminology, evaluation and practices subject to availability performance. After all, objective of the maintenance is, as priority one, to create an availability performance which is suitable for production demands in the organization.

C/1.2 Theoretical Background

One of the main criteria according to which any maintenance management can define its maintenance strategy, is to ensure the availability of the item for the required function, often at optimum costs. The purpose of this paragraph is to define the generic terms used for maintenance management and specifically for availability performance [1]. The measures for each term are also provided [2].

AVAILABILITY PERFORMANCE
Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided [1].

NOTE 1 This ability depends on the combined aspects of the reliability, the maintainability and the maintenance supportability.

NOTE 2 Required external resources, other than maintenance resources, do not affect the availability of the item.

Availability performance is depended by reliability, maintainability and maintenance supportability as shown in figure 1. [2]

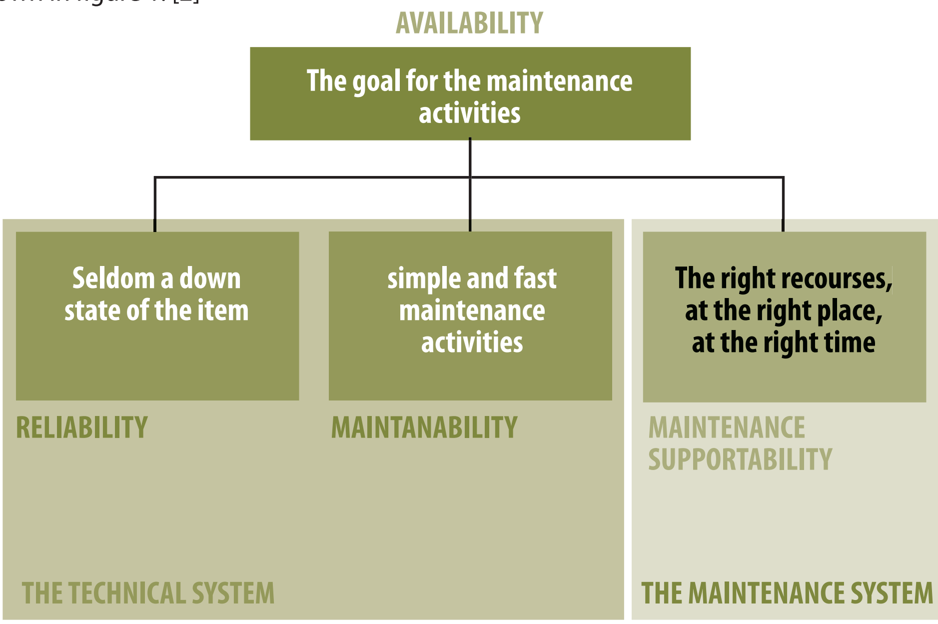

Figure 1: Relation between the terms for the Availability performance

A measure for the availability performance is AVAILABILITY [A]. Often the value for the availability is expressed as a percentage of a time interval during which the function of an item is (or has been) required to be in an up state [2].

RELIABILITY
Ability of an item to perform a required function under given conditions for a given time interval [1].

NOTE The term "reliability" is also used as a measure of reliability performance and may also be defined as a probability.

A measure for the reliability performance is MEAN TIME TO FAILURE [MMTF]. Another measure is FAILURE INTENSITY [Z], expressed as the mean number of failures for an item during a certain time interval [2].

$$MTTF=E(T)=\int_{0}^{x} t f(t)dt$$

Where f(t) is the failure probability density function. There are a number of well known probability density functions which have been found in practice to describe the failure characteristics of equipment and some of them are: Hyper exponential, Negative exponential, Normal and Weibull [4].

MAINTAINABILITY
Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources [1].

NOTE The maintainability is also used as a measure of maintainability performance.

A measure for the maintainability performance is MEAN TIME TO REPAIR [MTTR], expressed as the mean time for repair activities of an item. Even the expression MEAN TIME TO RESTORATION is often used [2].

$$MTTR=\frac{\sum_{n=1}^{N} t_n}{N}$$

MAINTENANCE SUPPORTABILITY
Ability of a maintenance organization of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant of time or during a given time interval [1].

A measure for the maintenance supportability is MEAN TIME WAITING [MTW], expressed as the mean time waiting for maintenance resources [2].
MTW is also estimated with help of historical data.

Operational Availability Performance
There is a difference between:

- the requirement from the production for an item to perform a required function during a given time interval (Operational Availability), and
- the ability of the maintenance activities to have the item in a state to perform the required function (Equipment Availability). [2]

OPERATIONAL AVAILABILITY PERFORMANCE

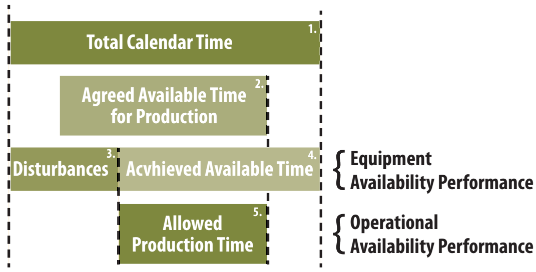

Figure 2: Operational Availability Performance

To satisfy the wishes of the production (high operational availability), the time interval (5) should be equal to the time interval (2). Note, that the time interval (4) can be longer than the time intervals (5) or (2). However, that is not enough if the time interval (4) does not cover the required time interval (2).

Formulas for Availability Performance

1. Ai = MTTF / (MTTF + MTTR)

2. Aa = MTTF / (MTTF + MTTR + MTW)

Ai = Inherent Availability (e.g. an availability only depending upon the technical system.)
Aa = Achieved Availability (e.g. an availability depending upon both the technical system and the maintenance organization.)

NOTE: In the two formulas above the availability is only taking into account faults and corrective maintenance. The total availability, depending upon corrective as well as preventive maintenance, e.g. the Operational Availability, has got this formula:

3. Ao = MTTM / (MTTM + M + MTW)

Ao = Operational Availability
MTTM = Mean Time To Maintenance (Maintenance = preventive and corrective maintenance actions)
M = Mean Maintenance Time (Time for preventive and corrective maintenance actions)

NOTE: In the calculation of the Ao, only those maintenance actions which will cause stoppage time for the operational use of the technical system will be included.

Comments
The measure Ai is used by manufactures and suppliers of the technical systems, as these companies have no control regarding the maintenance activities by the user of the technical system.
Maintenance organisations normally are using the measure Ao as it reflects the practical reality.

Mean Time Between Failure, MTBF
Mean Time Between Failure is the most common way to determine a maintenance interval. It indicates the time from a components failure to its next failure. This time include MDT (Mean Down Time) and MTTF (Mean Time To Failure).

MTBF = MDT + MTTF

C/1.3 Implementation and Use

Effective implementation of availability performance requires the following steps:

1. We need a thorough understanding of all the failure modes which are likely to cause each loss of function in order to be able to design, operate and maintain an asset in such a way that the effectiveness expectations which we have of each function will be achieved.

2. It is unreasonable to hold the maintainer of an asset alone accountable for the achievement of any continuity (availability/ reliability) targets for any asset or any function of any asset. The achievement of these targets is also a function of how it is designed, built and operated. Accountability for achieving the associated targets should be divided jointly between the people responsible for all of these functions. (In other words, 'maintenance' effectiveness is not only a measure of the effectiveness of the maintenance department. It measures how effectively everyone associated with the asset is playing their part in doing whatever is necessary to ensure that it continues to do what its users want it to do.)

3. When measuring maintenance performance, we are not measuring equipment effectiveness - we are measuring functional effectiveness. The distinction is important, because shifting emphasis from the equipment to its functions helps people - maintainers in particu1ar - to focus on what the equipment does rather than what it is.

4. Even quite simple assets have a surprisingly large number of functions. Each of these functions has a unique set of performance expectations. Before it is possible to develop a comprehensive maintenance effectiveness reporting system, we need to know what all these functions are, and we must be prepared to establish what the user thinks is acceptable or otherwise in each case.

   This means that it is not possible to list a single continuity statement for an entire asset, such as "to fail not more than once every two years" or "to last at least eleven years". We need to be specific about which function must not be lost more than once every two years or must not fail for at least eleven years (or more precisely, which functional failure must not occur more than once every two years, or which functional failure must not occur before eleven years).

5. There is often a tendency to focus too heavily on primary functions when assessing maintenance effectiveness. This is a mistake, because in practice apparently trivial secondary functions often embody bigger threats to the organization if they fail than primary functions. As a result, every function must be considered when setting up maintenance effectiveness measures and targets [6].

6. Decide what the required availability for every function is. This can be done in three stages:

   a. Ask what probability the organization is prepared to tolerate for the failure of the device (e.g. less than 1 in 1000 in any one year),

   b. Determine the probability that the device will fail in the period under consideration (e.g. 1 in 10 years)

c. **Determine what availability the device must achieve to reduce the probability of the failure to the desired level (e.g. unavailability= 1/1000x10=1%, thus availability= 99%) [6].**

7. Determine the Preventive maintenance task intervals for the device. This can be achieved by calculating FFI (Failure Finding Intervals), using availability and reliability only.
   FFI= 2 x unavailability x MTBF

For people who are uncomfortable with mathematical formulae, formula above can be used to develop a simple table, as follows:

Availability we require for the function	**99,99%**	**99,95%**	**99,9%**	**99,5%**	**99%**	**98%**	**95%**
Failure-finding interval (as a % of the MTBF)	**0,02%**	**0,1%**	**0,2%**	**1%**	**2%**	**4%**	**10%**

(e.g. to achieve availability 99%, someone would need to carry out a failure finding task, -in other words, check that it is fully functional- at an interval of 2% of its MTBF. Records might show that the device has MTBF of 8 years-or about 400 weeks- so the failure finding task frequency should be:
2% of 400 weeks = 8 weeks = 2 months).

SUCCESS FACTORS

1. Recognize the need for availability performance indicator by identifying new challenges (e.g. lost sales opportunities resulting from high levels of downtime, unnecessary expenditures for capital equipment, or weak competitive position of the company in general). By committing the organization to good maintenance policies and practices, management can reduce equipment downtime. The result is more throughput, and more throughput enables the company to get more products or services from assets, resulting in lower production costs and higher return of assets [5].

2. Ensure top management support and commitment by actively involving them in the development of the new indicator. Their communication should involve the need for the performance indicator. They should be directly invo1ved with the implementation team.

3. Create an implementation team that can develop and communicate a common under-standing of the company's strategic direction. The team should actively solicit input from all levels of the company and be able to refine the input into a cohesive plan. The indicator should then be cascaded throughout the corporation.

4. Define the supporting activities that will have the largest impact on the department's strategies. These activities will deal with deployment and other issues that impact the department's efficiency and effectiveness and, ultimately, its financial contribution to the corporate strategies.

5. Determine who will be tracking the indicator, how the information shou1d be tracked, tracking frequency, and the performance targets.

6. Estab1ish the underlying technology (typically a CMMS) necessary for the availability perfor-mance indicator. Consider what is required, the 1eve1 of detail, frequency of reporting, the amount of data required, and its source. This step is critical because most companies do not utilize their CMMS/EAM systems sufficiently to allow for high 1eve1 of confidence in the data. Without accurate data from the CMMS/EAM system, the performance indicator will not be accurate.

7. Reevaluate the reward and recognition system to insure that it is consistent with the new performance indicator system. This will insure that all employees are focused on supporting the company and departmental strategies.

8. Ensure continuous improvement by updating the system, keeping in mind that the business needs of the company and what is critical to competitiveness may change. The availability performance indicator should always be aligned with any updated strategies [3].

C/1.4 Case study – How PA Company applied availability performance techniques

PA Company is one of the most influential aluminium manufacturing industries in Greece. PA was established in 1975 with main object to produce aluminium profiles for architectural use. From the first moment that the Company went into operation, its constant aim was to manufacture high quality and aesthetically attractive products.

To achieve its objectives, the Company relied on two factors: human resources and high efficiency of the machinery. Today PA possesses leading place in the extrusion field, constituting an ultramodern but also dynamically evolving of production and electrostatic coating of extrusion products unit, with 450 specially trained employees.

The main production plant consists of three departments:

- **Extrusion department: with three modern extrusion presses with a capacity of 24.000 tn.**
  - PE1420
  - PE2000
  - PE2200
- **Dye-shop: with three electrostatic coating production lines (1 horizontal and 2 vertical)**
- **Warehouse: with an automatic robot system**

At the late '90's the Maintenance Department faced a great problem with the Production Department, which insisted that low productivity was due to continuous breakdowns of the production lines. It was then that Maintenance Department decided to set specific maintenance indicators to substantiate its work performed.

Previously, the only measure at PA was the number of tonnes of profile produced. This did not show whether this was met with overtime work or higher productivity could be achieved. PA set new Availability performance indicators which focused on the effectiveness of maintenance, such as:

1. $$\text{Percentege of Breakdowns Hours} = \frac{\text{Breakdown Hours}}{\text{Production Hours}} \times 100$$

where:
Breakdown Hours: the hours spent for repairing breakdowns
Production Hours: the net production hours

2. $$\text{Availibility} = \frac{\text{Maintenance Hours}}{\text{Available Production Hours}} \times 100$$

where:
Maintenance Hours: the hours spent for repairing breakdowns and executing preventive maintenance programs
Available Production Hours: the total production hours available except weekends (for example the available production hours in a week are: 24 hours x 5 days=120 hours)

MARCH 2003				
DATE	DOWN TIME	PE 1420	PE 2000	PE2200
3/3	26		1	
3/3	22			1
4/3	12	1		
4/3	26		1	
5/3	5	1		
7/3	8		1	
11/3	10	1		
11/3	3		1	
11/3	3		1	
12/3	8	1		
13/3	5	1		
13/3	3			1
14/3	9		1	
17/3	5	1		
17/3	3	1		
17/3	5		1	
18/3	15	1		
19/3	40	1		
19/3	28		1	
20/3	3		1	
21/3	11	1		
21/3	20			1
24/3	7		1	
24/3	10			1
26/3	6	1		
26/3	12			1
27/3	10		1	
27/3	15		1	
27/3	5		1	
31/3	8			1
TOTAL	5,72	2,00	2,47	1,25
DOWN TIME (%)	0,69	0,58	0,79	176
PRODUCTION HOURS	832	342	314	176
	TOTAL HOURS			

The indicators were formed monthly by the Maintenance Department using spreadsheets to record the data concerning breakdowns and production hours.

The indicators were firstly tracked for the critical machines, such as presses and then for all the machines at Extrusion department, Dye-Shop and Warehouse.

The target for availability at the beginning was set to 90%.

Figure 3: Spreadsheet used for data recording

At year 2003 PA started to implement a CMMS so as to have more accurate data necessary for the availability performance indicators. The maintenance department started to record every single breakdown, and execute preventive maintenance programs through the CMMS. PA was then more confident for the data and the accuracy of the performance indicators.

The results of the indicators were presented to the General Management of the plant in a monthly basis. Together, they reevaluated the maintenance policies for the equipment and the machines, and new preventive maintenance programs were developed to maximize the availability of the machines.

Today, all employees, both from the production and maintenance department, are focused on supporting the company and departmental strategies concerning availability indicators and bonus rewards are connected with the achieved performance of the machines.

PA's Maintenance Department is continuously updating the system aiming at continuous improvement. It is very significant to comment that today the target for the availability of the machines is up to 99%.

AVAILIBILITY: Extrusion Department

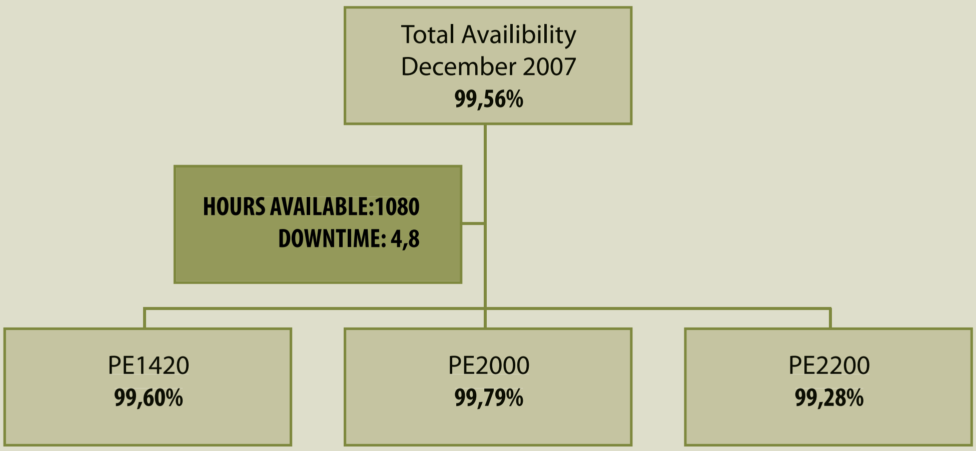

Figure 4: Availability per month and press at Extrusion department

C/1.5 Keywords

Availability performance, Reliability, Maintainability, Maintenance Supportability, Performance indicator

C/1.6 Glossary

Failure mode: A single event that causes a functional failure

Function: What the owner or user of a physical asset or system wants to do

Desired performance: The level of performance acceptable to the owner or user of a physical asset or system

C/1.7 Questions

1. Which of the following performance indicators is the most general (i.e. it combines the other three)?

a. Reliability
b. Availability
c. Maintainability
d. Maintenance supportability

(Answer : b)

2. Decreasing the MTTF results:

a. Only in increased maintainability
b. Only in increased reliability
c. Both in increased maintainability and availability
d. Both in increased maintainability and reliability

(Answer : c)

3. Which of the following definitions better describes reliability?

a. Ability of an item to perform a required function under given conditions for a given time interval
b. Ability of an item to be restored to a state in which it can perform a required function
c. Ability of a maintenance organization to have the right maintenance support for the required maintenance activity at a given time
d. A combination of the above

(Answer : a)

4. Why is it important to monitor availability performance?

a. Because it provides information for the maintenance (company) effectiveness
b. Because it can be used as a motive for further improvement
c. Because it can be used to detect problems
d. All of the above

(Answer :d)

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C/ MEASUREMENT AND IMPROVEMENT

C/2 Key Performance Indicators

C/2.1 Introduction

Measuring the performance of an organisation is a complex task, but measuring the performance of maintenance process in an organisation is even MORE COMPLEX due to the multi-disciplinary nature of the process and also multiplicity of inputs to and outputs from the maintenance process.

The Key Performance Indicators shall support management in achieving excellence and utilize technical assets in a competitive manner. The majority of these indicators which are described in this module apply to all industrial and supporting facilities (buildings, infrastructure, transport, distribution, networks, etc).

After reading this module you will be able to understand how to choose applicable key performance indicators for usage in your company.

C/2.2 Theoretical Background

"If you can't measure it, you can't manage it." If companies are to survive and prosper in information age competition, they must use measurement and management system derived from their strategies and capabilities. A performance measurement system is defined as the set of metrics used to quantify the efficiency and effectiveness of actions. Key Performance Indicators, also known as KPI, helps an organization to define and measure progress toward achieving the organizational goals. Once an organization has analyzed its mission, identified all its stakeholders, and defined its goals, it needs a way to measure the progress toward those goals. KPI is needed to be defined for each element of a strategy plan, which can break down to the performance indicator (PI) at the basic shop floor or operational level. KPIs are quantifiable measurements, identified and decided beforehand, that reflect the critical success factors of an organization. They will differ from organization to organization, depending on the business activities and stake holder's need. For example, a Customer Service Department may have as one of its KPIs, in line with overall company KPIs, as the percentage of customer calls answered in the first minute. A KPI for a social service organization might be number of clients assisted during the year. Whatever KPIs are selected, they must reflect the organization's goals, they must be key to its success, and they must be quantifiable (measurable). KPIs usually are long-term considerations. The definition of what they are and how they are measured do not change often. The goals for a particular KPI may change as the organizations goals change, or as it get closer to achieving a goal.

The indicators should be used to:

- Measure status
- Compare (internal and external benchmarks)
- Diagnose (analysis of strengths and weaknesses)
- Identify objectives and define targets to be reached
- Plan improvement actions
- Continuously measure changes over time

Measurement and analysis of the indicators can help management to:

- Set objectives
- Plan strategies and actions
- Share the results in order to inform and motivate people

C/2.3 Implementation and Use

The KPIs can be used:

- **On a periodic basis, for instance by preparing and following-up a budget and during performance assessment**

- **On a spot basis, for instance with the framework of specific audits, studies and/or benchmarking**

The period of time to be considered for measurement depends on the company policy and management approach.

The traceability of each input and their corresponding contribution towards output from the process and also towards total business goals are non linear and difficult to model and measure. However, in recent past many researchers have tried to develop means and measures to measure the performance of maintenance using various types of KPIs. One of the results is the European standard CEN EN 15341.

The European standard CEN EN 15341 describes a system for managing KPIs to measure maintenance performance in the framework of the influencing factors such as economical, technical and organisational aspects, to appraise and to improve efficiency and effectiveness to achieve excellence in maintaining technical assets.

Maintenance performance depends on both external and internal factors such as: location, culture, transformation and service processes, size, utilization rate and age. Maintenance performance is an outcome of complex activities which can be evaluated by appropriate indicators to measure both the actual and expected results.

The figure 1 below, illustrates the external and internal factors that influence the maintenance performance and consequently the three groups of KPIs.

EXTERNAL INFLUECING FACTORS

Location
Society, Culture
National Labour
Cost, Market Situation,
Laws Regulations
Sector/Branches

INTERNAL INFLUECING FACTORS

Company Culture
Process Severity
Product Mix,
Plant Size
Utilization Rate
Age of Plant
Criticallity

INDICATOR GROUPS	Indicator Level		
	LEVEL1	LEVEL2	LEVEL3
ECONOMIC INDICATORS	E1 E2 E3 E4 E5 E6	E7 E8 E9 E10 E11 E12 E13 E14	E15 E16 E17 E18 E19 E20 E21 E22 E23 E24
TECHICAL INDICATORS	T1 T2 T3 T4 T5	T6 T7	T8 T9 T10 T11 T12 T13 T14 T15 T16 T17 T18 T19 T20 T21
ORGANISATIONAL INDICATORS	O1 O2 O3 O4 O5 O6 O7 O8	O9 O10	O11 O12 O13 O14 O15 O16 O17 O18 O19 O20 O21 O22 O23 O24 O25

Figure 1: Maintenance influencing factors and Maintenance KPIs

External factors are variable conditions outside of the company management control. Internal factors are referred to the group, company, factory or plant outside of the maintenance management control but inside of the company management control.

When using the KPIs, it is important to consider these influencing factors as prerequisites to avoid misleading evaluations and comparisons due to not having homogeneous conditions.

Each of the numbered KPIs in the figure represents a defined KPI in the standard. These numbers are used for identification and not to indicate the importance.

Most indicators can be used at different levels depending on whether they are used to measure the performance of plant production, one production line, or given equipment or item. The different levels could also be used to identify KPIs to be used by management, supervisors and technicians within the maintenance organisation.

When calculating the indicators (denominator and numerator) factors shall be referred to the same activity/item and to same period of time (year, quarter, month, etc.).

METHODOLOGY FOR THE SELECTION AND USE OF KPIS FOR MAINTENANCE

Here is a suggested step by step procedure:

- Define the objectives which characterise the maintenance management process
- Select the relevant indicators
- Define and collecting the necessary basic data
- Calculate the indicators and select the type of presentation
  - Frequency of calculating the indicators
  - Type of presentation
  - Test and validation
  - Analysis of the results and take the required actions
- Make sure that the results are understood by everybody involved, and that the results of the required actions are presented when they have been implemented

C/2.4 Case Study

Here are some examples of case studies.

This is a result from a work shop, in which the present maintenance managers, with different backgrounds, selected the most relevant KPIs according to their opinion.

	TOP MANAGEMENT	MAINTENANCE MANAGEMENT	MAINTENANCE TECHNICIANS
ECONOMICAL INDICATORS	Total Maintenance Cost / Asset Replacement Value	Total Internal Personnel CostSpent in Maintenance / Total Maintenence Cost	Cost of Training in Maintenance / Number of Maintenance Personnel
TECHICAL INDICATORS	Achieved up time During Require time / Require time = Op. Availability	Total Operating Time / Total Operating Time + Downtime related to failures	Total Operating Time / Number of Failures = MTTF
ORGANISATIONAL INDICATORS	Planned and Scheduled Maintenance Man -hours / Total Maintenance Man -hours Available	Production Operator Maintenance Man-hours / Total Production Operator Maintenance Man-hours	Preventive Maintenance Man-hours / Total Maintenance Man-hours

Here below are some results from work shops with contribution from 12 companies from Slovenia, Croatia, Ireland and Denmark.

PHARMACEUTICAL BUSINESS - MAINTENANCE AVERAGE VALUES BASED ON 12 COMPANIES		
Workshop Results - October/November 2005		
I:01 Maintanance costs as a % of Plant replacement value	3,2	%
I:02 Stores investment as a % of Plant replacement value	0,9	%
I:03 Contactor costs as a % of Maintenance costs	29,2	%
I:04 Preventive maintenance costs as a % of Maintenance costs	36,9	%
I:05 Preventive maintenance man-hours as a % of Maintenance man-hours	36,6	%
I:06 Maintanance costs as a % of Turnover	2,2	%
I:07 Training Man-hours as a % of Maintenance man-hours	4,6	%
I:08 Immediate Corrective maintenance man-hours as a % of Maintenance man-hours	18,4	%
I:09 Planned and Scheduled man-hours as a % of Maintenance man-hours	60,0	%
I:10 Required Operating Time as a % of Required operating time	78,5	%
I:11 Actual Operating time as a % of required operating time	87,2	%
I:12 Actual Operating time/ Number of immediate corrective maintenance events	176,2	HOURS
I:13 Immediate corrective Maintenance time/ Number of immediate corrective maintenance events	2,6	HOURS
T1 Availability Related to Maintenance	96,0	%
T2 Operational Availibility	95,3	%

Results compiled by EFNMS, Tom Svantesson

C/2.5 Keywords

Maintenance performance measurement, Key performance indicator (KPI), Maintenance influencing factors

C/2.6 Glossary

Maintenance Performance
The activity of using resources to retain an item in, or restore it to, a state in which it can perform its required function. It can be expressed as an achieved or expected result.

Maintenance costs
Maintenance costs only include costs related to maintenance activities and do not include costs for modification activities, even if those are performed by the maintenance personnel.

The total Maintenance Costs includes costs referred to:

- Wages, salaries and overtimes for managerial, supervision, support staff and direct staff,
- Payroll added costs for the above mentioned persons (Taxes, Insurance, Legislative contributions),
- Spares and material consumables charged to maintenance (including fright costs),
- Tools and equipment (not capitalized or rented),
- Contractors, rented facilities,
- Consultancy services,
- Administration costs for maintenance,
- Education and training,
- Costs for maintenance activities carried out by production people,
- Costs for transportation, hotels, etc,
- Documentation
- CMMS (computerized maintenance management system)
- Energy and utilities,
- Depreciation of maintenance capitalized equipments and workshops, warehouse for spare parts.

Asset Replacement Value
The Asset Replacement Value (ARV) is defined as the estimated amount of capital that would be required to build the Asset.
ARV is an estimate of the current costs to replace in kind what now exists.
(In industries the ARV is usually the Plant Replacement Value. ARV can be equivalent to the insurance value.)

C/2.7 Questions

1. When can a Maintenance Key Performance Indicator not be used?

a) To define targets to be reached
b) To become information for planning strategies
c) On a spot basis for studies
d) To specify the measurement for condition based maintenance

(Answer : d)

2. What is included in the total maintenance cost?

a) The costs for changing the function of an item
b) The total purchasing cost for the stored spare parts
c) The costs for the building of a new work shop for maintenance
d) The education and training for maintenance personnel

(Answer : a)

3. What are technical indicators influenced by?

a) Asset Replacement Value
b) Total maintenance man-hours available
c) The age of the plant
d) The total maintenance cost

(Answer : c)

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C/ MEASUREMENT AND IMPROVEMENT

C/3 Measure and Analyze Results

C/3.1 Introduction

Where the method, technique aims?
Measurement and analysis of maintenance performance help management to identify the current performance status with respect to target values and set new realistic goals. At the same time performance measures are a very powerful tool in motivating and driving actions for further improvement.

What are the benefits for the company? (why to use it?)
When maintenance measures are properly analyzed they provide valuable information concerning maintenance performance which can be used as a feedback for improvement actions. This way, the effectiveness of maintenance procedures can be further increased and the overall system performance can be remarkably improved.

Are there any preconditions, limitations?
In order to draw reliable and useful conclusions performance measures must depend on a sufficient amount of accurate data; thus a dependable data source must exist.

Learning objectives for the trainees?
In this chapter the most important maintenance performance measures are presented and useful guidelines for their analysis and assessment are provided. Certain analysis tools and techniques are discussed in detail and the necessity of statistical evidence for the resulting conclusions is emphasized.

C/3.2 Theoretical Background

Various measures of performance for the evaluation of maintenance effectiveness and efficiency exist, the most important of which are related to availability, reliability, maintainability, process effectiveness and cost.

UTILIZATION

Utilization (U) is a measure of production capacity and it is expressed as the ratio of the scheduled production time over calendar time:

$$Availibility = \frac{Scheduled\ production\ time}{calendar\ time}$$

AVAILABILITY

Availability performance is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided.

Availability (A) is a measure of uptime or, conversely, downtime duration and it is expressed as the ratio of scheduled time minus all delays over the scheduled time:

$$Availibility = \frac{Scheduled\ production\ time - downtime}{Scheduled\ production\ time}$$

The percentage of downtime, I_d, is derived as follows:

$$I_d = 1 - Availibility$$

RELIABILITY

Reliability of an item is its ability to perform a required function under given conditions for a given time interval. Thus, lower equipment reliability means higher need for maintenance.
The most common measures of reliability are the following:

a) Reliability function (R(t)): $$(R(t)): R(t) = 1 - F(t) = 1 - \int_{0}^{t} f(t)\, dt$$

where F(t): cumulative distribution function
f(t): failure density function.

b) Hazard rate (h(t)): $$h(t) = \frac{f(t)}{R(t)}$$

c) Mean time to failure (MTTF):

$$MTTF=\int_0^\infty tf(t)\,dt=\int_0^\infty R(t)dt.$$

Mean time between failures is in fact a measure of failure frequency defined as the ratio of running time over the number of failures.

MAINTAINABILITY

Maintainability of an item is its ability under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

The most common measures of maintainability are the following:

a) Maintainability function:

$$M(t)=\int_0^t f_R(t)\,dt$$

where
$f_R(t)$: probability density function of the repair time.

b) Mean time to repair (MTTR):

$$MTTR=\left(\sum_{i=1}^{k}\lambda_i CMT_i\right)\Big/\sum_{i=1}^{k}\lambda_i$$

where
k: number of items

λ_i: failure rate of item i

CMT_i: corrective maintenance/repair time required to repair item i.

Mean time between repairs is in fact a measure of the duration of repair time defined as the ratio of downtime over the number of failures.

c) Mean preventive maintenance time (MPMT):

$$MPMT=\left(\sum_{i=1}^{m}FPM_i\cdot ETPMT_i\right)\Big/\sum_{i=1}^{m}FPM_i$$

where
m: total number of preventive maintenance tasks

FPM_i: frequency of preventive maintenance task i

$ETPMT_i$: elapsed time for preventive maintenance task i.

d) Mean maintenance downtime (MMD):

$$MPMT = MAMT + LTD + ATD$$

where
MAMT: mean active maintenance time or mean time needed to perform preventive and corrective maintenance-associated tasks.

LDT: logistic delay time

ADT: administrative delay time.

PROCESS RATE

Process rate (PR) is a measure of the cycle time of the equipment defined as the ratio of the ideal cycle time over the actual cycle time or, alternatively, as the ratio of the actual throughput rate over the ideal throughput rate:

$$\text{Process rate}=\frac{\text{Ideal cycle time}}{\text{Actusl cycle time}}=\frac{\text{Actual througput rate}}{\text{Ideal throughput rate}}$$

QUALITY RATE

Quality rate (QR) is a measure of the process or equipment precision, defined as the ratio of total throughput minus net rejects over total throughput. Net rejects include the loss for recycled, rejected, scrapped or downgraded product:

$$\text{Quality rate} = \frac{\text{Total throughput} - \text{Net reject}}{\text{Total throughput}}$$

OVERALL EQUIPMENT EFFECTIVENESS

Overall equipment effectiveness (QEE) is the product of availability, process rate and quality rate:

$$OEE = A \times PR \times QR$$

MAINTENANCE COST PER UNIT TIME

Maintenance cost per unit time is a measure that is independent of the machine operating time and it is necessary in comparing machines with different running times. It is calculated as the ratio of total maintenance cost over the running time of the machine:

$$\text{Maintenance cost per unit time} = \frac{\text{Total maintenance cost}}{\text{Running time}}$$

C/3.3 Implementation and Use

Measurements of maintenance performance are very useful for two reasons: a) they provide information about the progress of the process effectiveness over time and b) they can be used for comparisons among companies (benchmarking). Thus, maintenance performance measures are a powerful tool for motivating and driving actions for improvement and should be combined with continuous improvement techniques.

In any case maintenance performance measures should fulfill certain requirements such as:

a) **they must be informative and describe the performance behavior of the process**

b) **they must be simple and easily understood and implemented**

c) **they must be sensitive to changes in maintenance performance**

d) **they must not be easily influenced by disturbing factors.**

As soon as maintenance performance has been measured it should be judged whether the measured performance is good, bad or indifferent. There are several ways to assess the current performance comparing it with some kind of standard:

HISTORICAL PERFORMANCE STANDARDS

Historical standards are used to compare current performance against previous performance. Historical performance standards are effective in judging whether maintenance procedures are improved over time but they give no indication as to whether performance should be regarded as satisfactory.

TARGET PERFORMANCE STANDARDS

Target performance standards are usually set arbitrarily to reflect some level of performance which is considered as appropriate.

COMPETITOR PERFORMANCE STANDARDS

Competitor performance standards are used to compare the achieved performance of maintenance procedures with that of the company's competitors. These standards are very useful since they provide information concerning the company's position within the competition.

Regardless of the exact type of the standards used for comparisons the final conclusions must be drawn after systematic analysis of the numerical results. The most common tools and methodologies applied to this end are the following:

1. Statistical comparisons

Different values of maintenance performance measures may be explained by the natural variation of the process. Thus, in order to distinguish the statistically important differences, hypothesis testing between the compared measures should be applied. This way, it is investigated whether there is strong statistical evidence for the observed differences preventing from misleading conclusions. Confidence intervals and control charts can also be used to determine whether there is a significant change in the value of some performance measure. A typical control chart is shown in Figure 1 where the values of a measured parameter are periodically compared to the upper and lower control limits. Points falling outside the limits are considered to be indications of a change in the true value of the monitored parameter that cannot be attributed to natural variability.

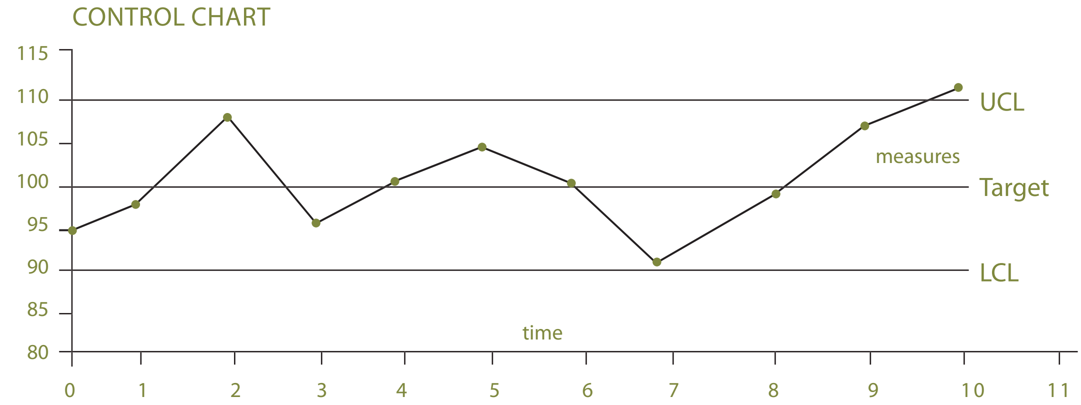

Figure 1: Graphical illustration of measurements monitoring using a control chart.

1. Trend analysis

In cases where the evolution of performance measures over time is examined, trend analysis techniques can be applied. Through trend analysis measures of performance are studied with respect to time or sequence in order to spot a pattern or trend in the collected data. Again, the existence and type of a pattern should be statistically tested (through linear or non-linear regression techniques) to ensure that it can not be attributed to natural variation. A trend line fitted in a series of measurements along with the resulting mathematical expression is illustrated in Figure 2.

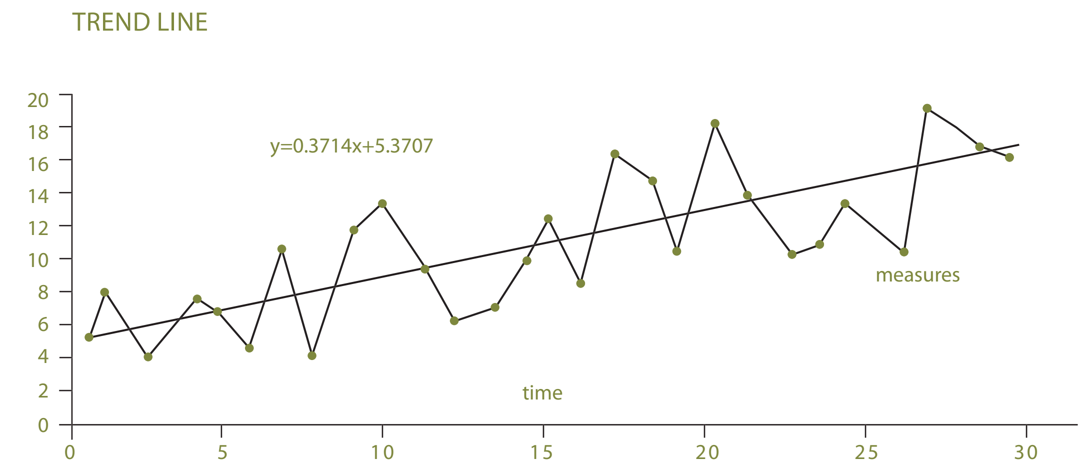

Figure 2: Trend line analysis on a series of measurements.

3. Benchmarking techniques

Performance benchmarking is a process used to compare and evaluate the levels of achieved performance in a company against those of the best company within the same sector. Thus, benchmarking aims not only at judging the effectiveness of maintenance procedures but also at setting realistic performance standards and most importantly at motivating the development or adoption of new ideas and practices. Benchmarking can be considered as a continuous process strongly related to continuous improvement techniques. In other words, benchmarking maintenance is a way to identify the best result gained by a competitor which uses approximately the same machinery. This may ultimately lead to the adoption of a more cost effective maintenance policy and consequently to a considerable improvement in the effectiveness of the manufacturing process.
Typical steps of a maintenance benchmarking methodology are the following:

i) **Identify other companies that have similar machinery**

ii) **Identify companies that are leaders in the area**

iii) **Survey companies for measures and practices**

iv) **Visit the "best practice" companies to identify leading edge practices**

v) **Implement new and improved maintenance practices**

WHAT ARE THE SUCCES FACTORS?

A succesful maintenance performance mea-surement system should have the following features:

Small number of measures
The number of performance measures used should be small to avoid accumulation of useless data that add no extra value in the analysis. Moreover performance measures should definitely be representative and easily understood

Accuracy and adequacy of data
The dependability of the resulting conclusions lies significantly in the number and accuracy of relevant measures. Consequently, special emphasis must be laid in order to ensure that all measures are reliable and all conclusions are adequately supported by the existing data.

Target values
The main reason of measuring performance is to see whether a progress is made towards specific goals. Thus, it is essential that clearly understood target values of performance are set.

Awareness of the natural variability
Every process is characterized by a certain degree of natural variability. It is very important that this variability is taken into account in analyzing performance data. Otherwise, misleading conclusions may be drawn regarding the effect of external actions on the process performance and valuable time may be wasted in useless interventions.

Linkage to improvement actions
Maintenance performance measurements can only have a positive effect on maintenance procedures when the results and conclusions are used for further improvement. That is, certain improvement actions dictated by the analysis of measured data should exist so that the desired performance will eventually

be achieved.

In brief, the key elements of an effective maintenance measurement, analysis and improvement process are graphically presented in Figure 3.

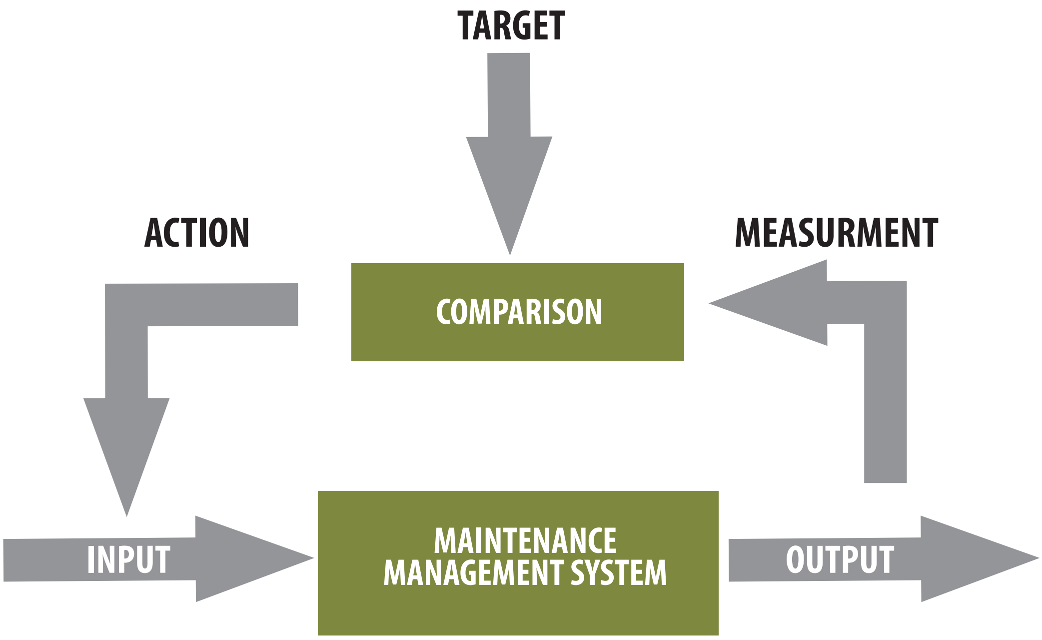

Figure 3: Key elements of an effective maintenance measurement, analysis and improvement process.

C/3.4 Case Study

OF is a furniture manufacturer which sells office furniture in several dealers in Northern Greece. The company has about 50 employees and its yearly turnover is about 4 million euros.

From previous data maintenance actions in OF were found to be about 90% based on corrective maintenance and only 10% on preventive maintenance. Moreover, according to OF maintenance policy all PM actions used to be outsourced since 2004. The company in an effort to reduce production costs, increase product quality and improve at the same time the share of PM actions, has decided to take control of all PM actions starting from the beginning of 2005.

The maintenance department of OF keeps records concerning stoppage times, availability measures, reworked and rejected parts due to lack of quality and maintenance related costs. The manager of maintenance department has decided to compare the monthly availability measures prior to 2005 with those after the PM procedures have been shifted to OF. Table 1 summarizes the measured availability values during the period 2004-2005.

	2004			2005		
	Stoppage time (h)	Operating time (h)	Availability	Stoppage time (h)	Operating time (h)	Availability
January	86.3	400	0.784	68.8	384	0.821
February	69.5	368	0.811	69.5	384	0.819
March	75.1	384	0.804	85.4	416	0.795
April	82.8	384	0.784	78.3	400	0.804
May	87.9	416	0.789	79.1	416	0.81
June	82.2	400	0.795	81.6	400	0.796
July	70.6	368	0.808	65.8	352	0.813
August	45.7	240	0.81	44.9	208	0.784
September	84.4	416	0.797	77.7	400	0.806
October	88.2	416	0.788	86.5	416	0.792
November	78.7	400	0.803	83.8	416	0.799
December	79.3	368	0.785	72.7	352	0.793
Average Availability			**0.7965**			**0.803**

Table 1: Availability measures in OF for 2004-2005 time period.

At the end of 2004 the average monthly availability of the equipment was calculated and found equal to 0.7965. As soon as the first data of 2005 became available the availability of January 2005 was also calculated and found equal to 0.821. The maintenance manager was really happy with this value since it was proving that shifting PM actions to the OF maintenance department had resulted in an increase of equipment availability. However, in the progress of time he was very disappointed since the next months of 2005 did not confirm his impression. Why did this happen to OF? What went wrong after the first two months of 2005?

The manager of maintenance department decided to proceed in a more comprehensive analysis of availability data to explain this behaviour. For this purpose, except for the average availability of 2004 the observed variability of the measures was also calculated, since there is some natural and acceptable variability in stochastic data. He then constructed the upper and lower control limits (95% confidence limits – the limits within which the 95% of measures are expected to lie) of availability and put all availability measures of period 2004-2005 in a typical control chart, shown in Figure 4. In fact, the limits in Figure 4 represent the natural variability of the process which means that any variation within the limits is due to the process itself rather that any external action.

Figure 4: Control chart for availability monitoring in OF

From Figure 4 it is obvious that all availability measures lie within the upper and lower control limits of availability. That is, despite the impression of the maintenance manager any observed change could be attributed to the natural variability. None of the measures in the chart indicates that there was statistical evidence that equipment availability has indeed increased.

As a conclusion it can be stated that understanding and quantifying the natural variability of measures under study is very important in preventing from misleading conclusions.

C/3.5 Keywords

Availability, Maintainability, Reliability, Key Performance Indicators

C/3.6 Glossary

Confidence Interval: An interval estimate of a measured parameter that is very likely to include the true (but unknown) parameter value.

Control chart: A tool used to determine whether the value of a measured parameter has been changed.

Trend Analysis: A method where a trend line is fitted on the values of some parameter depicting the general direction in which the parameter is headed.

Benchmarking: A management procedure used to evaluate various process results in relation to the best practice of other companies or organizations usually within the same sector.

C/3.7 Questions

1. Which of the following statements is not true?

a. Availability increases as mean time to repair (MTTR) increases.
b. Reliability does not depend on maintainability.
c. Mean time to failure (MTTF) decreases as failure rate increases.
d. Overall equipment effectiveness (OEE) increases as downtime decreases.

(Answer :a)

2. The mean time to failure (MTTF) of a machine is 100h and the mean time to repair (MTTR) for the same machine is 10h. What is the value of its expected availability considering that downtimes are only due to failure repairs?

a. $A = \frac{MTTF - MTTR}{MTTF} = 0.9.$

b. $A = \frac{MTTF}{MTTF + MTTR} = 0.909.$

c. $A = \frac{MTTF - MTTR}{MTTF + MTTR} = 0.818.$

d. none of the above

(Answer :b)

3. In which case is trend analysis the most appropriate tool?

a. For benchmarking.
b. For comparisons between two measures.
c. For the examination of some measure over time.
d. For the estimation of the natural variation of a measure.

(Answer :c)

4. If the total maintenance cost (for corrective and preventive maintenance actions) of machine A was 40€ during March 2008 while the respective cost of machine B for the same time period was 30€, can you claim that machine B generally incurs lower maintenance costs than machine A?

a. Yes, it is obvious.
b. Yes, as long as the cost measures are accurate.
c. No, the cost difference is too small.
d. No, the cost difference may be due to natural variability.

(Answer :d)

5. What should the scope of measuring maintenance performance be?

a. To prove that maintenance is more effective than other production procedures.
b. To minimize maintenance related costs.
c. To motivate further improvement.
d. To supervise maintenance staff.

(Answer :d)

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C/ MEASUREMENT AND IMPROVEMENT

C/4 Fault Finding and Learning from Failures

C/4.1 Introduction

Where the method, technique aims?

The methods and techniques covered here aim at developing a closed loop design methodology of feeding information from maintenance to design. This is achieved through analysis of failures and generation of lessons that can prevent such failures from re-occurring. The emphasis will be on generic lessons that can be applied to other similar cases.

What are the benefits for the company? (why to use it?)

The main benefits of such approach are that it will help to improve design of systems and artifacts as well as improved working practice. Currently maintenance domain is an environment of rich data related to failures. There seems to be no formal methods of feeding back this data to the designers of the systems. This module will help users to appreciate different Case Studies related to failures in both maintenance and design functions, and discuss lessons learnt

Are there any preconditions, limitations?

It provides cases from some industries. However, it doe not cover all industries.

Learning objectives for the trainees?

After reading this module you will be able to analyze failure using advanced techniques in maintenance and reliability in order to extract lessons for prevention and improvement.

C/4.2 Theoretical Background

According to the European Standards,
Maintenance as a term can be defined as *"Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function"*.

Availability is defined as *"the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided"*.

Reliability is defined as the *"ability of an item to perform a required function under given conditions for a given time interval"*.

Maintainability is defined as *"the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources"*

Maintenance Supportability is defined as *"the ability of a maintenance organization of having the right maintenance support at the necessary place to perform the required maintenance Activity at a given instant of time or during a given time interval".* (CEN EN 13306).

Therefore the three terms that define availability are reliability (measured by Mean Time between Failures), maintainability (measured by Mean Time To repair) and maintenance supportability (measured by Mean Waiting Time).

Where:

- **MTBF (Mean Time between Failures): Which is a functional reliability measure that relates to the technical system or the machine, and the objective is to maximise the value of this term.**

- **MTTR (Mean Time To Repair): Which is a maintainability measure that also relates to the technical system or the machine, but the objective is to minimise the value of this term.**

- **MWT (Mean Waiting time): Which is a supportability measure. It relates to the maintenance system (way of doing things), and the objective is to minimise the value of this term. This term tends to be ignored as companies perceive it as fact of life.**

Factors that can affect the MTBF could be ccondition monitoring, the design, redundancy, choice of equipment or components. Whereas factors that can affect the MTTR could be the organisation structure, the information systems used, routines employed, education of workforce, and their training. Factors that affect the MWT could be accessibility to different parts of the machine, built in test, fault indication, staff's knowledge, and staff's motivation.

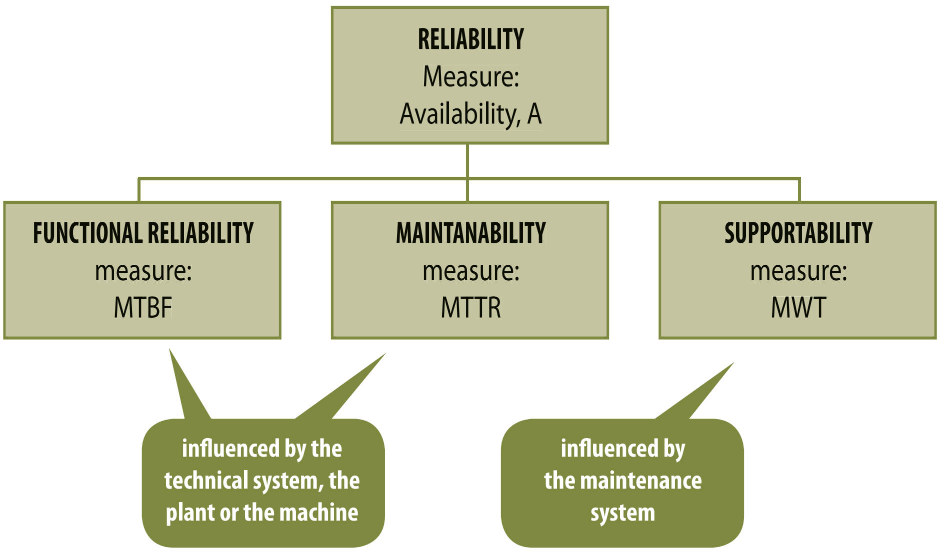


Figure 1: THEORETICAL BACKGROUND: Fault Finding in the Total Picture

Examples of tools and techniques used for analyzing failures are:

1. **Fault Tree Analysis (FTA).**
2. **Reliability Block Diagrams (RBD).**

FAULT TREE ANALYSIS:

A fault tree is a logical diagram which shows the relation between system failure, i.e. a specific undesirable event in the system as well as failures of the components of the system. The undesirable event constitutes the top event of the tree and the different component failures constitute the basic event of the tree. For example, for a production process the top event might be that the process stops, and one basic event is that a certain motor fails.

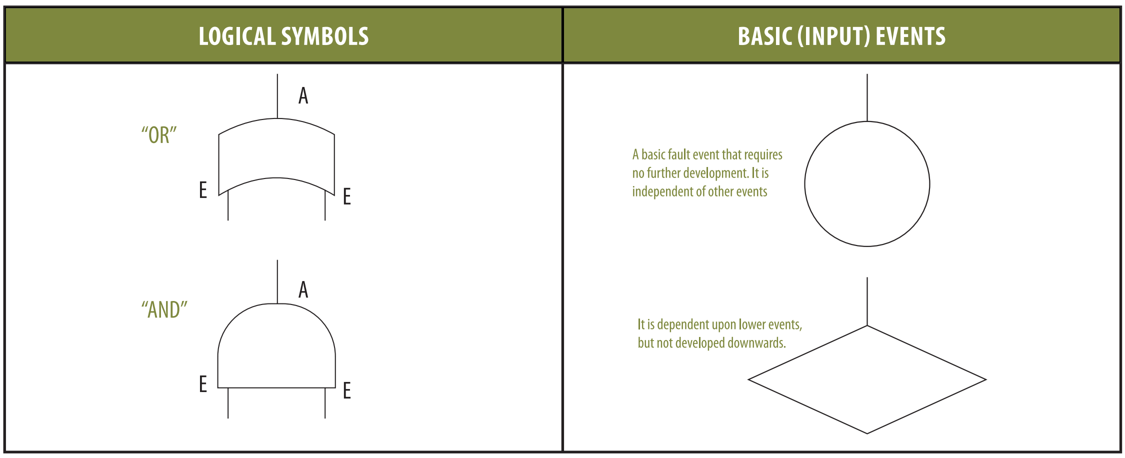


Figure 2

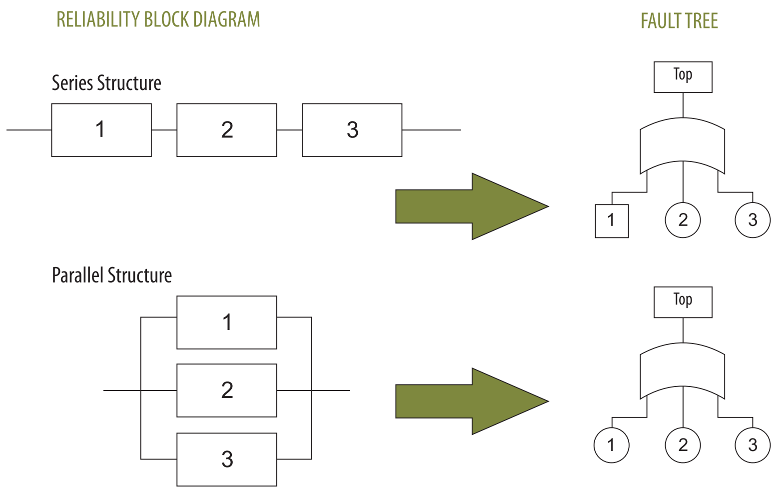


Figure 3: Fault Tree Analysis: Connection to reliability

EXAMPLE: STORAGE TANK

The figure 4 shows an open container for preliminary storage of fluid for use in the production process.The consumption of fluid is not constant. Filling the tank is automatically controlled and can be described as follows:

- **When the the liquid level reaches a certain height - "normal level", then the Level Switch High (LSH) will be activated and send a closure signal to the valve v1.The fluid supply to the tank then stops.**
- **If this mechanism does not function and the liquid level continues to increase to "abnormal level", then the Level Switch High High (LSHH) will be activated and send a closure signal to valve V2. The fluid supply to the tank then stops. At the same time the LSHH send an opening signal to valve V3 so that the fluid is drained.**

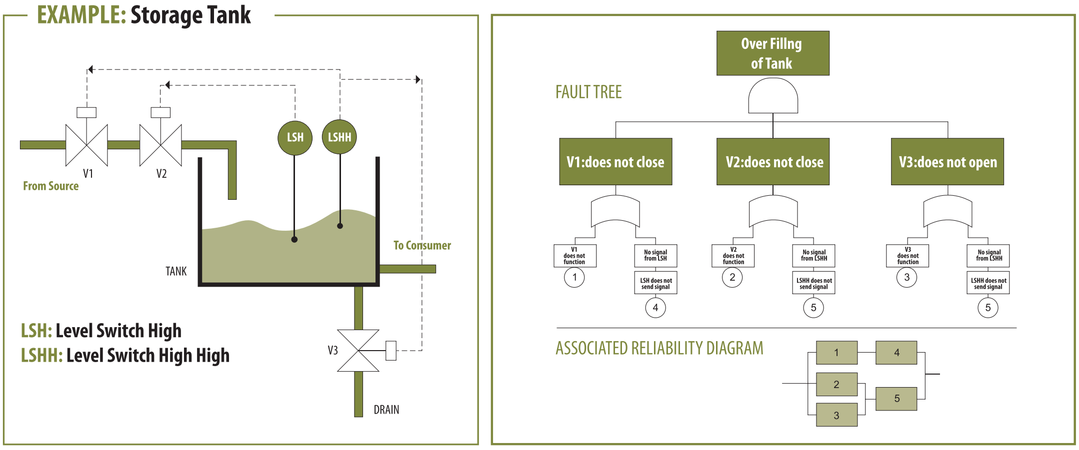
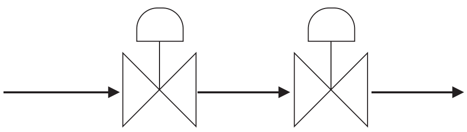


Figure 4

RELIABILITY BLOCK DIAGRAMS:

Systems can be arranged either in series or parallel structure or a combination. For a series system, for loss of supply, reliability of system is probability that valve A does not fail and valve B does not fail.

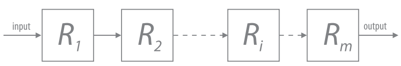


From the multiplication rule:

$$R_{ab} = R_a R_b$$

and, in general:

$$R_{an} = R_a R_b ...., R_n$$

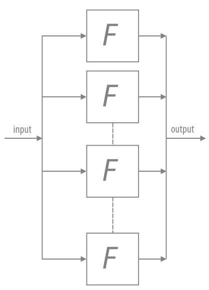


$$R_{SYST} = R_1 R_2 ...., R_1 ....R_m$$

$$R_{SYST} = \prod_{i=1}^{m} R_1$$

Notice that reliability of series system is less than the worst element

For a Parallel System (usually for a system with redundancy), we consider unreliability (F), where R+F = 1.



$$F_{SYST} = F_1 F_2 ...., F_j ....F_n$$

$$F_{SYST} = \prod_{j=1}^{n} F_j$$

$$F_{SYST} = 1 - F_{SYST} = 1 - \prod_{j=1}^{n} F_j$$

Comparing equations we see that for series systems, system reliability is the product of element reliabilities, whereas for parallel systems, system unreliability is the product of element unreliabilities.

Example (Tutorial)

Consider a system that consists of three components in parallel. The probabilities of the three components being operational are 0.9, 0.8, 0.75. Determine the reliability of the system.

Solution:

Reliability of the system can be obtained by using equation in previous equation:

$$R = 1 - \prod_{i=1}^{n} F_i$$

$$R=1-(1-0.90)(1-0.80)(1-0.75)=0.995.$$

C/4.3 Implementation and Use

Failure loss prevention is fundamental to the maintenance function. When dealing with this issue, one looks at learning from failures through analysis of the causal effects that have lead to certain events such as accidents or disasters. This then produces knowledge that can lead to elicitation of generic lessons learnt from those events.

All cases are analyzed using the following steps:

- Consequence of failure (what happened?).
- The technical cause of failure (Why did it happen?).
- Design improvements / lessons learned (How can it be prevented?)

What are the success factors?

- **An understanding of maintenance and reliability tools and techniques and means of applying them.**
- **Understanding of technical issues regarding details of the system and its failure modes.**
- **Ability to apply techniques to the chosen case.**

C/4.4 Case Study - Title Example: What can we learn from the Titanic Disaster?

What Happened? Consequence of failure:

- The Ship Hit The Iceberg At Such High Speed That Caused The Resulting Failure Of The Superstructure To Be Catastrophic
- The Iceberg Caused A Rip To The Hull Of The Ship And Damaged 5 Of 16 Watertight Compartments
- Titanic Sank After 2 Hours And 40 Minutes After The Crash
- On Board Was 2,228 Between Passengers And Crew
- Human Loss 1,300 People
- Loss Of Ship $7.5m
- Massive Insurance Premium Increase

Why did it happen? The technical cause of failure:

- Wrong Decisions Made (Human Factor)
- Low Visibility Condition (Lack Of Technology And Equipment)
- Material Weakness / Metal Failure (Technology Not Available For Quality Control And Testing)
- Inefficient Evacuation Procedure And Insufficient Life Boats (The Life Boats Capacity Was Only 1.178 People)
- Too Much Belief On The Unsinkable Ship
- Lack Of Technology And Equipment -Limited Resources. But What Was Available Was Insufficient For Detection Of Iceberg
- Poor Design – Manufacturing Process And Materials Used. Material Weakness / Metal Failure (Technology Not Available For Quality Control And Testing)
- Poor Safety Factor And Procedures If Major Failure Occurred (Insufficient Of Life Boats)
- Lack Of FMECA Study And Criticality Of Failure

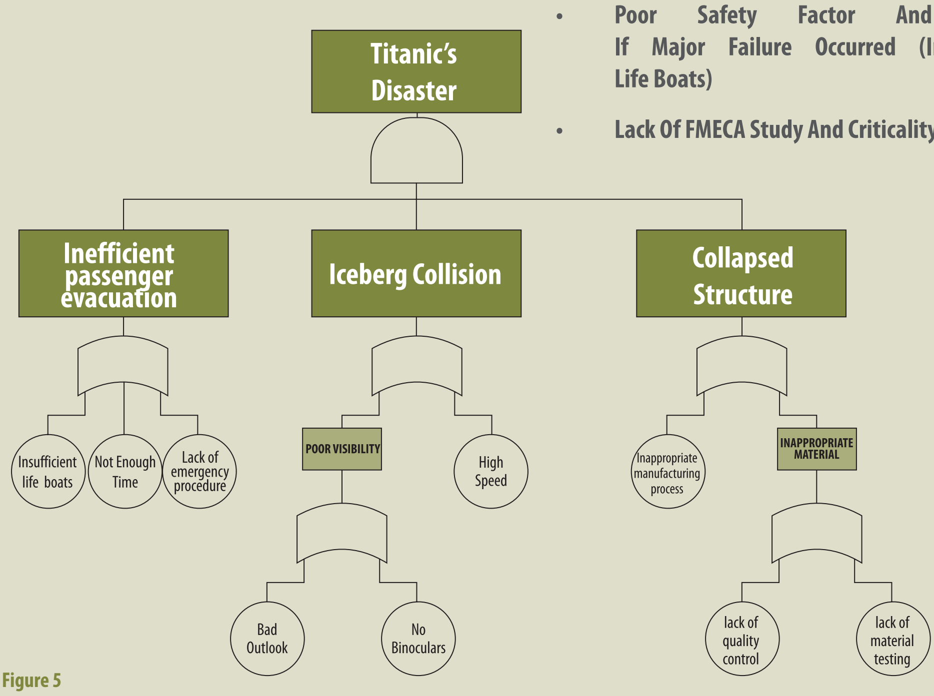


Figure 5

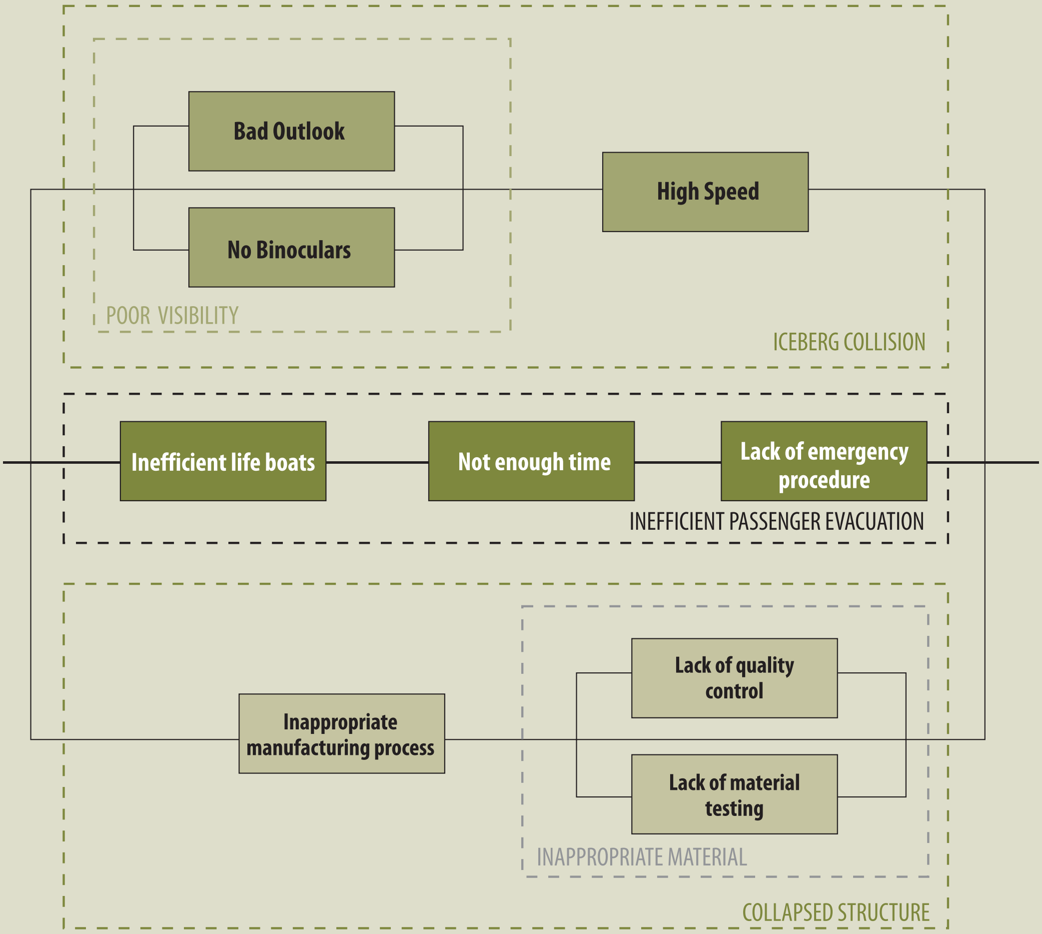


Figure 6

How can it be prevented? - Design improvements / lessons learned:

- Human – Adherence To Safety Procedures. Concurrence Of Decisions Made. Train The People
- Use of Technology And Equipment Available - Real Time Observation And Safe Running Speed
- Poor Design. Re-design Ship To Remain Afloat After Major Impact. Review Best Available Technologies.
- Re-design Ship Superstructure – Concurrent Engineering Methodology Should Be Applied
- Multiple Criteria For Re-design.

C/4.5 Keywords

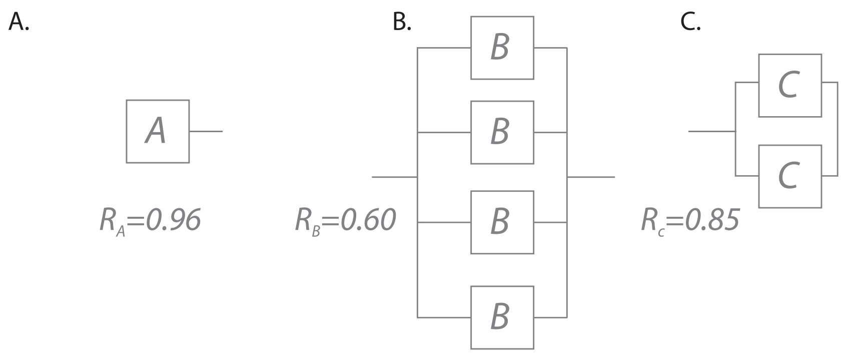
Loss Prevention, Technical failure analysis, Generic lessons

C/4.6 Glossary

Fault Tree Analysis (FTA).
Reliability Block Diagrams (RBD).

C/4.7 Questions

1. **A system designer has to choose one of the three configurations shown, in the form of Reliability Block Diagram in Fig (1). If his/her objective is to achieve maximum reliability, which system should she/he select?**



(Answer : c)

2. **Which of the following is influenced by the technical system, the plant or the machine?**
   a) MTBF and MTTR
   b) MTTR and MWT
   c) MTBF and MWT
   d) MTBF, MTTR, and MWT

(Answer : a)

3. **Which of the following is influenced by the Maintenance system?**
   a) MTBF
   b) MTTR
   c) MWT
   d) MTBF and MWT

(Answer : c)

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C/ MEASUREMENT AND IMPROVEMENT

C/5 Improvement Techniques

C/5.1 Introduction

Where the method, technique aims?

Improvement techniques such as continuous improvement, fale-safeing and error – proofing focus on improving customer satisfaction through continuous and incremental improvements to processes, elimination of waste and prevention from errors.

What are the benefits for the company? (why to use it?)

Improvement techniques are daily activities that contribute to the development of effective production processes and usually they result in significant increase of performance in the long run.

Are there any preconditions, limitations?

The precondition of appropriate problem - sourcing and fault - finding techniques is very important for the success of any improvement attempt. Moreover, it is of major importance that all employees involved in an improvement program are convinced for its usefulness and are willing to support it.

Learning objectives for the trainees?

In this chapter the general concept of improvement techniques in maintenance is presented and the most important improvement tools are described. The information provided here is of great interest for maintenance technicians since a detailed framework is provided for the implementation of the proposed methods.

C/5.2 Theoretical Background

Basic information for the maintenance practice, methodology, tool

There are two particular improvement strategies which to some extent represent opposing philosophies. These are breakthrough improvement and continuous improvement (2, 3).

BREAKTHROUGH IMPROVEMENT

Breakthrough improvement considers a major and dramatic change in the way the operation works. The impact of breakthrough improvements is relatively sudden, abrupt and represents a step change in practice. Such improvements are usually expensive and frequently involve changes in the product or process technology. The improving performance over time under a breakthrough strategy is illustrated in Figure 1.

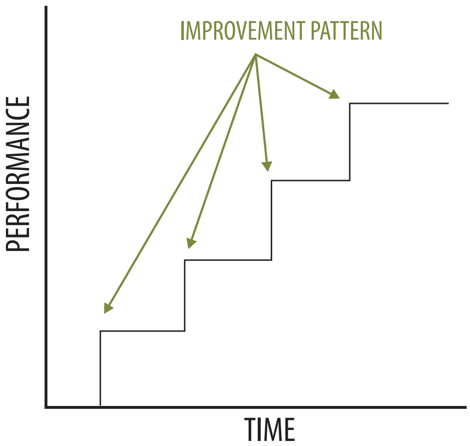

Figure 1: Improvement pattern under a breakthrough strategy

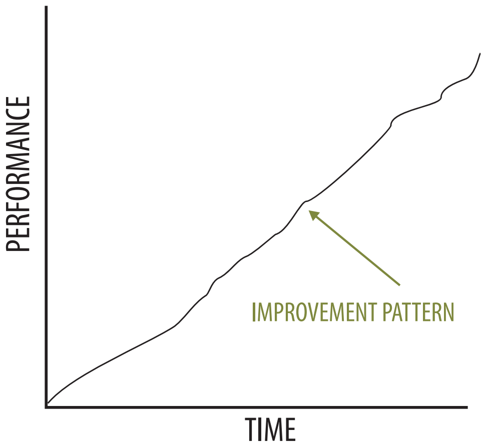

Figure 2: Improvement pattern under a continuous strategy

CONTINUOUS IMPROVEMENT

Continuous improvement adopts an approach with smaller and more incremental improvement steps. While there is no guarantee that such small steps towards improvement will be followed by other steps, the whole philosophy of continuous improvement attempts to ensure that there will be. The main advantage of smaller steps over large ones is that they can be followed rather painlessly by other small improvements. Continuous improvement is also known as kaizen; a Japanese word for improvement. In continuous improvement it is not the rate of improvement that is important but the continuality. The improving performance over time under a continuous strategy is illustrated in Figure 2.

Differences between breakthrough and continuous improvement

Breakthrough improvement places a high value on creative solutions. It encourages free thinking and individualism. Continuous improvement on the other hand is less ambitious, at least in the short term. It stresses adaptability, teamwork and attention to detail.

C/5.3 Implementation and Use

IMPLEMENTATION

The materialization of improvement greatly depends on the improvement strategy adopted.

Continuous improvement case

The concept of continuous improvement implies a never-ending process of repeatedly actions. The repeated and cyclical nature of continuous improvement is summarized by what is called the PDCA cycle. The PDCA cycle is the sequence of activities which are undertaken on a cyclical basis to improve operation.

The cycle starts with the P (for plan) stage which involves an examination of the current method so as to formulate a plan of action. The next step is the D (for do) stage, which is the plan implementation stage. Next comes the C (for check) stage where the new implemented solution is evaluated to see whether it has resulted in the expected performance improvement. Finally comes the A (for act) stage where the change is consolidated or standardized if it has been successful.

The most important thing about the PDCA cycle is that as soon as it is finished the cycle starts again.

Breakthrough improvement case

Typical approach of breakthrough improvement is the business process re-engineering method (BPR). In specific, BPR is a blend of ideas such as Just-in-time, process flow charting, critical examination in method study and customer-focused operations. It implies process rethinking and redesigning focusing on the outcomes of the process rather than on the tasks themselves.

IMPROVEMENT SUPPORTING TOOLS

No matter what improvement strategy is adopted there are some basic tools that support the improvement process (6). Mainly, these are tools that aim at describing a process and identifying problem areas as well as possible problem sources. The most important of these tools are presented in more detail in what follows but it must be noted that there are various other techniques that could be used for improvement purposes as well.

1. Input – output analysis

The input-output analysis aims at recognizing any improvement opportunity and understanding the context an operation is set. Input- output analysis usually consists of three steps:

a) identifying the inputs and outputs of a process

b) identifying the source of inputs and thedestination of outputs

c) clarifying the requirements to the suppliers of the process as well as the requirements of the customers that are served by the outputs of the process.

2. Flow charts

A flow chart is a more detailed tool of input-output diagrams in giving a useful overview of the process (see Figure 3). It records actions and stages and provides information for any flow that occurs in the process. Its purpose is to ensure that all stages in the flow processes are included in the improvement process as well as to highlight problem areas.

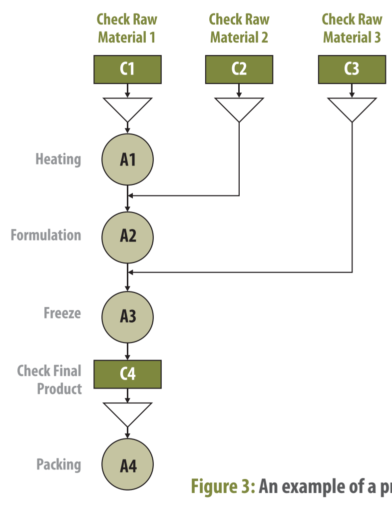

Figure 3: An example of a process flow chart

3. Scatter diagrams

Scatter diagrams are a simple method of identifying whether a connection between two sets of data exists (see Figure 4); for example the failure frequency of a part and the temperature. Scatter diagrams can be also treated in a more sophisticated way by quantifying how strong the observed relation between the sets of data is. However, note that even when a relationship is identifying there is no proof that it is a cause effect relationship.

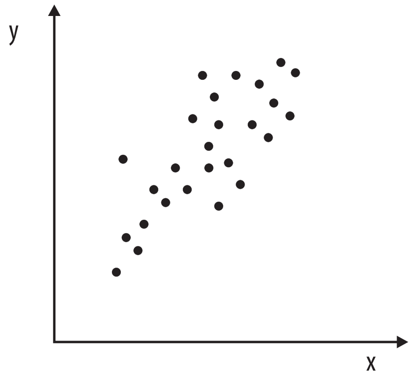

Figure 4: A typical scatter diagram.

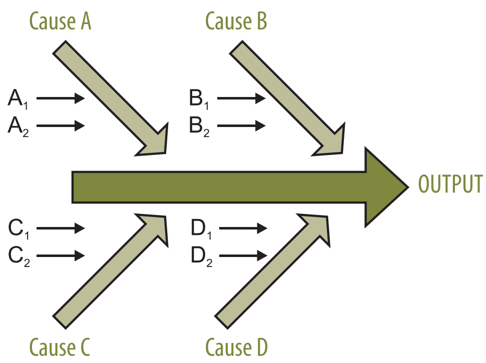

Figure 5: The structure of a cause-effect diagram.

4. Cause-effect diagrams

Cause-effect diagrams are a particularly effective tool on searching for the root causes of problems. They are also known as fish-bone diagrams. Their objective is to present graphically all possible causes of a problem categorized in some main branches of the diagram, such as machinery, manpower, materials etc (see Figure 5).

5. Pareto diagrams

In any improvement process it is important distinguishing what is more important and what is less. This distinction can be achieved with the use of a Pareto diagram where all problems or problem causes are ranked according to their order of importance (see Figure 6). Thus the few most important can be easily derived.

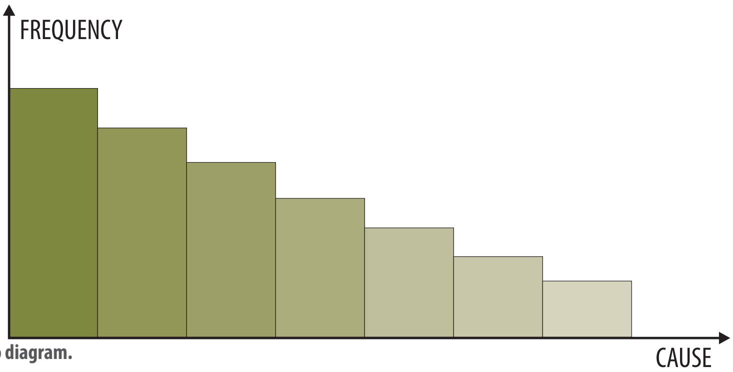

Figure 6: A typical Pareto diagram.

6. Why-why analysis

Why-why analysis is a simple but effective technique in understanding the reasons for problem occurring. The technique starts by stating the problem and asking why that problem has occurred. Once the major reasons have been identified the same question is asked for each one of them and so on.

All the above mentioned tools can greatly help a maintenance manager to understand where and why failures are usually occurring. Once this is done, the next thing is to find ways of either reducing the chances for failures or minimizing their consequences. In that sense, prevention actions such as building redundancy into the operation and fail-safeing techniques are essential for improvement.

REDUNDANCY

Building in redundancy to an operation means having back-up systems or components in case of failure. It is usually an expensive solution to reduce the likelihood of failure and thus it is used when the breakdown could have a critical impact. Redundancy means doubling or even tripling some of the components in a system so that these redundant elements can come into action when one component fails. Typical example of redundant equipment is the aircraft engines.

FAIL-SAFEING

The concept of fail-safeing has emerged in Japan and it is also known by the Japanese word poka-yoke (4). The idea is based on the principle that human mistakes are to some extent inevitable and thus it is important to prevent them becoming defects. Poka-yokes are simple and usually inexpensive devices which are incorporated into a process to prevent inadvertent operator mistakes resulting in a defect. Typical example is a limit switch on machine which allows the machine to operate only if the part is positioned correctly.

WHAT ARE THE SUCCESS FACTORS?

The necessary conditions for a successful improvement process are the following:

Recognition of improvement opportunities
Fault finding techniques and performance indicators can be proved to be very useful for this purpose indicating where room for improvement exists.

Staff participation
It is very important that all employees involved in an improvement program are convinced for its usefulness and are willing to support it.

Measures of improvement
To ensure continuality of improvement it must be proved to be effective. Thus, the resulting performance improvement must be measured by representative indicators and communicated to all participants so that they can see that their efforts were not worthless.

Top management support
Applying improvement techniques can be considered a strategic decision and as such it must be fully supported by management. In the case of breakthrough improvement, in particular, the staff must be encouraged to think free and creative ideas must be promoted.

C/5.4 Case Study - Problem identification and improvement at Hewlett-Packard

Hewlett-Packard is proud of its reputation for high-quality products and services. Because of this it was especially concerned with the problems that it was having with its customers returning defective toner cartridges. About 2000 of these were being returned every month. The UK team suspected that not all the returns were actually the result of a faulty product, which is why the team decided to investigate the problem. The cause-effect diagram which they generated is shown in Figure 7.

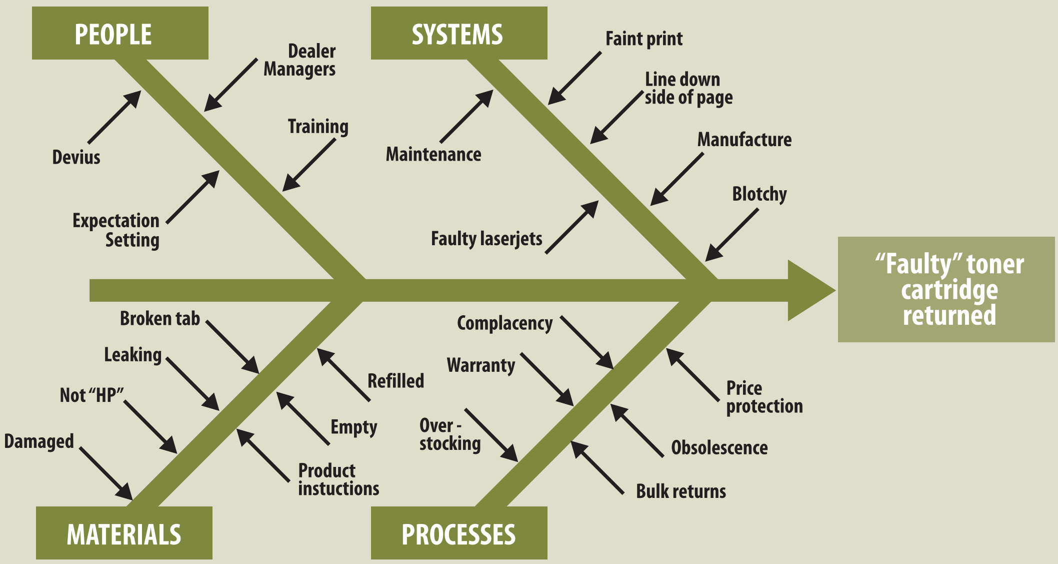

Figure 7: Cause-effect diagram for Hewlett-Packard's toner analysis

Three major problems were identified. First, some users were not as familiar as they should have been with the correct method of loading the cartridge into the printer, or in being able to solve their own minor printing problems. Second, some of the dealers were also unaware of how to sort out minor problems. Third, there was clearly some abuse of Hewlett-Packard's 'no-questions-asked' returns policy. Empty toner cartridges were being sent to unauthorized refilling companies who would sell the refilled cartridges at reduced prices. Some cartridges were being refilled up to five times and were understandably wearing out. Furthermore, the toner in the refilled cartridges was not up to Hewlett-Packard's high quality standards. The team went on to use the PDCA sequence of problem solving and made suggestions which tightened up on their returns policy as well as improving the way in which customers were instructed on how to use the products. The results were impressive. Complaints in almost all areas shrank to a fraction of what they had been previously.

C/5.5 Keywords

Breakthrough / continuous improvement, improvement supporting tools, Fail-safeing technique.

C/5.6 Glossary

Improvement techniques: All techniques that focus on maximizing a company's performance, such as increasing process efficiency, eliminating waste, preventing errors etc.

C/5.7 Questions

1. **What should the first step of a Continuous Improvement process be?**
   - a. Planning of improvement actions.
   - b. Why-why analysis.
   - c. Identification of problem areas.
   - d. Building redundancy.

(Answer : c)

2. **What is poka-yoke?**
   - a. The Japanese word for Continuous Improvement.
   - b. A cause-effect diagram.
   - c. A device which prevents human mistakes becoming defects.
   - d. A fault-finding technique.

(Answer : c)

3. **Which of the following tools is more appropriate for ranking problem causes according to their importance?**
   - a. Pareto diagram.
   - b. Scatter diagram.
   - c. Cause-effect diagram.
   - d. Input-output analysis.

(Answer: a)

4. **Which of the following statements better describes the philosophy of Continuous Improvement?**
   - a. Continuous Improvement encourages free thinking and individualism.
   - b. Continuous Improvement results in remarkable performance improvement in the short run.
   - c. Continuous Improvement implies a never-ending process of repeatedly actions.
   - d. Continuous Improvement implies process rethinking and redesigning.

(Answer : c)

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TRAINING MATERIAL IN MAINTENANCE MANAGEMENT

D/ COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM

D/1 CMMS

D/ COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM

D/1 CMMS

D/1.1 Introduction

In today's environment, maintenance costs are rising faster than production costs. Some surveys have shown that, at many plants, typical management goals for maintenance – such as 95% or better equipment availability and reliability, 99% product quality, reduced maintenance overtime hours, reduced contract labor hours, and improved record keeping on repairs – are not being met. Maintenance has tended to be viewed as a "black hole" where too much money goes with little measurable return. But as most companies find themselves looking for ways to reduce cost and increase productivity, management is beginning to realize that maintenance offers real opportunities in both areas.

Maintenance can account for as much as 60% of controllable plant operating costs. Because maintenance costs can be not only controlled, but often substantially reduced, efficient management of maintenance can influence the bottom line much more than is usually realized [3, page 1].

There are many factors to consider in determining whether a CMMS can benefit your operation. The most important factors relate to reduced cost, but you also need to consider such results as better organizational methods, reduced paperwork, and improved communications. From a cost standpoint, if planned maintenance work is less than 90% of the total maintenance work load, if craft productivity is less than 80% of capacity, or if craft overtime is more than 10%, a CMMS can help you. If the maintenance inventory cost, including holding cost, is more than 30% of the annual maintenance budget, a CMMS can help you [3, page 3] [1, page 252].

D/1.2 Theoretical Background

A CMMS is an integrated set of computer programs and data files designed to provide its user with a cost effective means of managing massive amounts of maintenance actions, inventory control, and purchasing data [3, page 13].

A CMMS consists of four sub-modules (Figure 4.1) [2, page 3]:

a. The System basic data
b. The Actions management
c. The Preventive maintenance management
d. The Spare parts management

The three sub-modules (b, c, d) are splitted in 3 parts:

1. **Basic data**
2. **Daily work**
3. **Analysis**

The total CMMS structure is represented in Figure 4.1. All entities in Figure 4.1 are marked with bold in the following text.

A. SYSTEM BASIC DATA SUB-MODULE

The System basic data sub-module contains the common information which is used to build the other sub-modules. It consists, mainly, of the Machines and the Technicians entities.

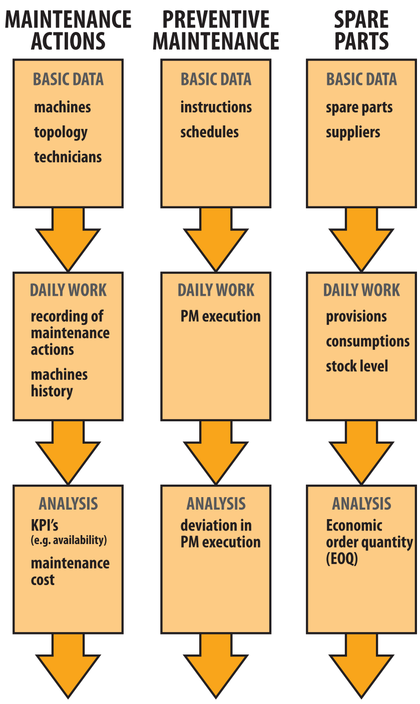

Figure 1: CMMS sub-modules

Machines
The Machines (except their code & description) must be characterized by two important information, which are their Topology, which determines where each machine is located, and their Category, which is helping machines grouping. The Topology information can be used i) to find out quickly the location of the machine, ii) to allocate maintenance cost per cost centre, iii) into machines code generator (gives automatically machine codes, grouped by topology). The Category information can be used i) into machines code generator (gives automatically machine codes, grouped by category), ii) to declare machines technical characteristics, which are common per machines category, iii) to be able to analyze information (e.g. breakdowns) per machines category and not per individual machine.

Technicians
Regarding the technicians, except their code and name, it can be recorded their Trade, which is used in Preventive Maintenance budgeting, their hourly rate, and their training.

B. ACTIONS SUB-MODULE

The Actions sub-module is used to record all maintenance activities. Each one of these activities belongs to a specific type. The most common maintenance actions types are related to breakdowns, corrective actions and preventive maintenance (generated by the preventive maintenance sub-module).

b1. Actions basic data
In order to start working the Actions sub-module, there must be recorded the Actions codes (fault codes for the breakdowns), which should be in a tree format. The Actions codes are used to group analyze Actions being recorded into the CMMS.

In order the engineers to be able to easily identify the machines, each one of them must have a Label on it. The labels can be i) metal, ii) plastic, or iii) just painted on the machines.

External engineers (suppliers) must be recorded. These engineers are called when special knowledge is needed and their cost is accumulated on the total maintenance cost.

b2. Actions daily work
The maintenance actions requests, initiated, by production personnel (breakdowns or corrective actions) are executed by the technicians, who are recording the Description of their work, the Action code, their Names (Technicians) and their Hours spent.

As a result of maintenance actions being recorded, Machines history is generated. Machines history must be frequently analyzed by searching the worst machines (most breakdowns, higher maintenance cost) and the most frequent faults on them. This analysis should have as a result amendments on the existing Preventive maintenance schedules.

b3. Actions analysis
Further the frequent Machines history analysis, periodically more advanced analysis must be performed:

- **Key Performance Indicators (KPIs)**
  Once the CMMS is implemented, it must be made sure that the savings documented in realization are being realized. KPIs must be set in order to monitor and control the progress (e.g. 90% availability, 90/10 planned versus emergency actions [1, page 119]). These KPIs should be a driving force concerning maintenance department management.

- **Replace or repair decision**
  Based on machine market value and the annual operational and maintenance cost, the optimal time for replacing a machine can be calculated [1, page 84].

- **Optimum inspection frequency**
  Based on the actions (breakdowns) being recorded, the optimum frequency of preventive maintenance can be calculated. In order to extract accurate results, several breakdown data of the same fault should exist.

- **Total maintenance cost**
  Taking into consideration all different CMMS sub-modules, the total maintenance cost is calculated. The maintenance cost consists of Technicians cost, Spare parts cost, Lost production cost (for breakdowns), and External technicians cost. All these costs can be splitted into the different maintenance action types (breakdowns, corrective, preventive, etc).

C. PREVENTIVE MAINTENANCE (PM) SUB-MODULE

The PM sub-module is managing PM schedules which are used to keep equipment in good condition.

c1. PM basic data

A PM schedule consists of Instructions, Spare parts, Drawings, Trades & hours required, and Frequency (calendar time (e.g. monthly) or run time (e.g. hours, miles) based).

A good practice when generating PM schedules is to create a Schedules library which can be used for common machines. This feature is helpful for schedules future maintainability.

c2. PM daily work

To execute PM, it is very important to give work orders, so every time the same and the correct instructions are followed. A continuous adjustment on the instructions should exist. After the execution of the PM work orders, the information must be recorded into the CMMS to know what (instructions, spares replaced) has been executed compared to the planned one.

Regarding CMMS, PM execution is the first priority to be incorporated into company's ISO. All PM work orders executed is proposed to be signed by production personnel to have a verification of their execution.

c3. PM analysis

There are many ways to analyze PM execution compared the planned one. Some of them are the following:

- Deviation in execution time (execution day of PM compared to planned day of PM), to find out delays in PM execution.

- Budget compared Results of PM. PM budgeting can be done regarding hours (or hours per trade) needed, spare parts cost and total cost.

D. SPARE PARTS SUB-MODULE

The Spare parts sub-module manages all spare parts provisions, current stock and their location, and consumptions.

d1. Spare parts basic data

The data needed in order to work the spare parts module are the Suppliers, the Spare parts categories and the Spare parts.

An important point is to decide Spare parts categories, in a manner that statistics about spare parts stock or consumptions are the maximum meaningful.

d2. Spare parts daily work

The two main transactions of the spare parts daily work are Provisions and Consumptions. Having an accurate recording of provisions and consumptions, the Spare parts stock level will be known.

Another option is to record, per Supplier and Spare part, the different part code, price and discount. This is helping to minimize provisions time and avoid mistakes.

Spare parts Consumptions must be linked with an Action (work order). This way, three targets are succeeded: a) accurate stock level, b) each machine spare parts cost, and c) automatic update of machines bill of materials.

Usually the (spare parts) provisions are part of company's ISO. In addition suppliers evaluation can be performed.

Tool tip for successful implementation: Initial Inventory process must be done when Provisions & Consumptions procedures are smoothly "running". Otherwise, initial Inventory process might be wasted until any difficulties are solved into Provisions & Consumptions procedures.

TOOL TIP FOR SUCCESSFUL IMPLEMENTATION:
Initial Inventory process must be done when Provisions & Consumptions procedures are smoothly "running". Otherwise, initial Inventory process might be wasted until any difficulties are solved into Provisions & Consumptions procedures.

d3. Spare parts analysis

The most important issue of the spare parts is to have in stock the right spares on the right stock level. So, the Economic Order Quantity (EOQ) model to find the optimum minimum stock level and the optimum reorder quantity.

A common issue in spare parts management is the existence of spares which are no longer needed. As long as the bill of materials of the machines is recorded into the CMMS, the unneeded spares can be easily found.

TOOL TIPS FOR SUCCESSFUL IMPLEMENTATION:

1. **During the implementation period, data entry (e.g. like machines bill of materials and machines technical characteristics) should be as minimum as possible and the main emphasis should be given on the procedures of the system and the results of them.**

2. **During the implementation period, all procedures must first work on a pilot phase (e.g. only 2-3 preventive maintenance schedules to be generated). This will help to check that all procedures are properly working and they are covering company's needs.**

   If 1 & 2 are followed, we'll succeed to save time (from data entry and implementing procedures to their full extend) and test as many procedures as possible during the implementation period (when CMMS personnel are near to us, to train us and make any modifications to the software).

C/1.3 Implementation and Use

Following, the implementation procedure, in a step-by-step process is described [1, page 197]:

FORMULATION OF A TEAM

The first step is to establish a team, which would consist of the plant engineer, maintenance manager, maintenance employees and representatives of IT. It should be reinforced that IT is a facilitator of the solution and not the driver.

Involving employees in the implementation process enables to break down their resistance to the change and build enthusiasm for CMMS as a tool to facilitate their work.

Systematic, periodic reports should be submitted to upper-level management keeping them informed of progress, or lack of it.

The maintenance manager should assign one person as the project leader responsible for implementing the CMMS. His role should be to keep all activities coordinated and the team motivated.

MANAGEMENT COMMITMENT

Upper-level management must be totally committed to the CMMS project. This commitment must include allocation of manpower and resources needed to complete the project successfully.

SCOPE OF PROJECT

First, the existing workflow must be reviewed to decide the changes which should be made. Next the CMMS modules to be implemented should be decided. Then, it must be decided which equipment to implement first; all of them or the crucial ones first to start with. Same concept applies to inventory parts. Opportunities to interface the CMMS to other systems, such as purchasing, should be reviewed as well.

Once the scope of the project has been reviewed, the overall time frame must be also determined.

PLANNING

In the planning phase the ‘what’, ‘why’, ‘who’, and ‘how’ concerning equipment data, preventive maintenance, labour, spare parts inventory, purchasing, backup procedure, key performance indicators, and training must be defined.

INSTALLATION AND CONFIGURATION

It must be taken sure that necessary hardware and software, other than CMMS, is in place. For example, a need for new hardware or need to upgrade memory might exist.

TRAINING

Training consists into two parts, application training and internal training.

Application training can be done in two different phases, initial training to get the system up and running, and advanced training after spending a period of time with CMMS. It is important that training is coordinated with implementation and not being done too early.

Internal training is also important because CMMS users must be trained with internal procedures. Examples of this could be equipment numbering scheme, inventory part description, or repair descriptions. Proper and consistent job description training is important in order to follow common rules all members of the implementation team.

While training may initially seem an expensive proposition, in the long run it will not only prove beneficial, but very cost effective. Also, it must be pointed out that as users leave, their replacements must be trained as thoroughly as if they had been original users.

DATA GATHERING

Before gathering any data, it must be checked if there're already data in electronic format. It may be possible to transfer this data electronically without retyping.

If there're no existing data, then we must go through the process of collecting the data. Data collection and entry are critical to a successful implementation.

DATA ENTRY

First a prototype must be developed. A few records must be initially entered into the CMMS and we must go through the whole cycle of generating work orders, completing work orders, generating work histories, and so forth. In case any problems encountered, there should be resolved with the CMMS vendor. When everything is working according to the standards being set, enter all the data to the CMMS.

FOLLOW-UP/MONITOR

Merely keeping the system running smoothly is not enough to justify its continuing existence. It must produce something useful. To ensure that goal, make sure that the CMMS continues to serve the purpose for which it was purchased.

CONTINUOUS IMPROVEMENT

Most systems have a great deal of growth potential built into them. Much of that potential can remain unused throughout the life of the system because the users are not aware, or have forgotten that it is there. A recent survey shows that only 6 percent of companies are using their CMMS to its fullest capacity. In some cases, using those untapped recourses can eliminate the need to upgrade. The key is to know what the system's capabilities are and use them as required.

Success factors

To be able to reach a CMMS implementation to each full extend, the following factors should be taken into consideration [1, page 195]:

Management support: The major element necessary to the success of any large undertaking is commitment to the project and support by upper-level management.

Acceptance of employees: Employees may accept the computerization enthusiastically or become hostile to the idea. Management may look at the CMMS as a tool to help employees in their work, and in turn enhance the bottom-line. In fact, radical change in the human factor must be made in order to succeed the expected results [3, page 129]

Correct selection of CMMS: This is one of the most important factors. The CMMS must be selected based on the real needs and requirements. Relative to this is the adequacy of the CMMS supplier support. CMMS vendors are very good at developing software programs that will store massive amounts of data, manipulate the data, automate recurring tasks, and generate standard reports, but they do not provide the real management tools needed to have an effective maintenance organization [3, page 125].

Implementation of accompanying changes: Many organizations never realize that the simple installation of computers, networks, and software is only a small part of CMMS implementation. Full implementation of all the accompanying changes needed in work methods, procedures, organization, employee attitude, skills, and other critical areas will ensure the success [3, page 129].

Involvement: Almost every plant or facility has some level of internal politics that prevents effective coordination and cooperation among and within its functions. In the case of a CMMS, the major adversarial relationship will develop between maintenance, information systems, procurement, finance, and production. During the implementation phase, there should be a team consisting of at least one representative from each affected organization. A senior management person should act as arbitrator to resolve differences the team can not resolve [3, page 129].

Stability of employees: A key member or members of a project team may resign, be terminated, or transferred. With a sophisticated project like the CMMS, continuity is a key factor in its success. In order to establish that continuity, and maintain it in the event of personnel changes, each step of the project should be fully and accurately documented.

Adequate training during implementation: Users should know how to use the software effectively [3, page 7].

Adequate follow up and monitoring: This is related to upper management commitment. Proper follow-up to ensure the continuity of the project is important.

D/1.4 Case Study

Company A is one of the biggest steelwork companies in domestic equipment. The company was founded in 1971, while today it possesses a significant place in the sector of exports, with a percentage of more than 90% of total sales.

Maintenance in Company A

Maintenance department is particularly critical for Company A, since it is responsible for the maintenance of over 200 machines, of different types and particular requirements, which operate in 3 shifts. Today, the department is staffed by 12 persons, whose activities are: fixing breakdowns, preventive maintenance and machines setup.

CMMS in Company A

For maintenance people didn't take a lot to understand that a CMMS constitutes a precious tool for department's daily function.

Every machine has its own record, where all data (technical characteristics, spare parts, drawings, expire of guarantee, constructor, history of movements, etc), that craftsmen need for the reliable maintenance of the equipment, is assembled.

Machines search is done very rapidly, since for their unique code, topology characteristics have been used, avoiding thus awkward codes of accountant type. Total measurements of technical characteristics can be received immediately, like the installed power per production department.

The history of the machines is completely monitored through the CMMS. Today, after four and even more years of full operation of the CMMS (since 2003), the precise history of all the equipment exists, being evaluated and investigated in order to continuously improve preventive maintenance schedules.

Important is the contribution of the CMMS in the organisation of preventive maintenance. The implementation of preventive maintenance schedules has already been methodized, materialising each time concrete instructions, publishing drawings that have been incorporated in the schedules and determining the spare parts that are required for the implementation of preventive maintenance.

The CMMS constitutes a strategic tool in the hands of management, from which it draws information of complete cost accounting per machine and cost centre, it monitors indicators on maintenance department performance, rendering possible its evaluation.

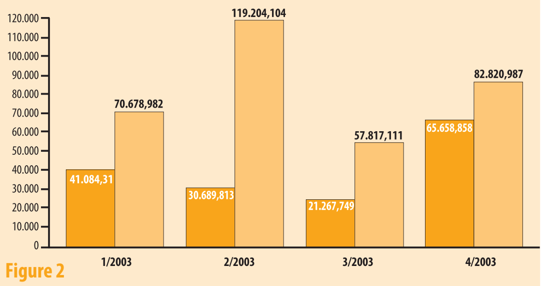

Figure 2

Company B was founded in 1979 as a paper sheet-plant, in order to produce corrugated board boxes, dividers and separators. In its continuous effort to improve the productive process as well as the optimization of the human and material resources, it has advanced in investments on infrastructure and productive equipment during last years.

CMMS in Company B

A CMMS was chosen in order to upgrade the level of organization and the effectiveness of the maintenance department, satisfying the following processes:

1) Organizing and monitoring Preventive Maintenance
2) Recording of breakdowns and analysis of machines history
3) Spare parts management
4) Cost accounting of maintenance, department and machine level
5) Monitor & evaluation of Key Performance Indicators (KPIs)

CMMS operates completely in both manufacturing units of the company, supporting all 16 craftsmen of the maintenance department and roughly 150 machines of high complexity. After 2 years of systematic work on the collection of data from the daily interventions, maintenance personnel are now locating "problematic" machines, analyzing repeated breakdowns and proceeding in their radical confrontation.

Important was the assistance offered by the CMMS in the organisation and follow-up of preventive maintenance. For the first time completed preventive maintenance schedules were formed with specific maintenance instructions (many of which resulted from machines breakdowns and problems analysis) and the relevant spare parts. The reliable PM schedules execution has led to perceptible reduction of breakdowns.

Characteristically, the indicator of technicians time percentage per work type declares the effort of the department to go from emergency to preventive maintenance. In 2004 the technicians dedicated 23,89% of their time in the preventive maintenance against 50,86% in 2005, an increase of 112%. At the same period, the time of technicians on breakdowns decreased by 20%.

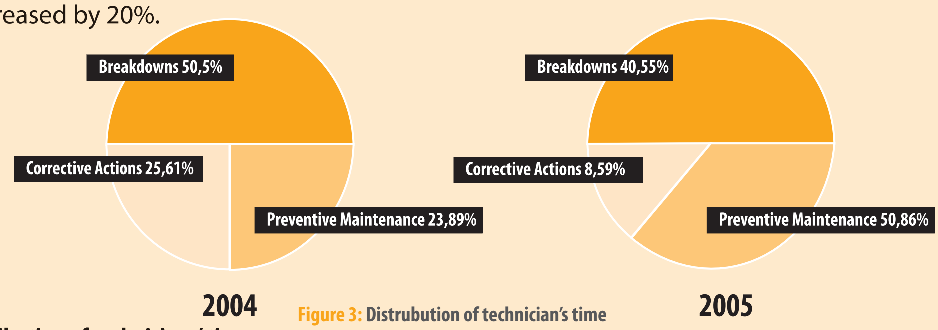

Figure 3: Distrubution of technician's time

Distribution of technicians' time

In spare parts warehouse hundreds of spare parts have been coded and assigned a stock location. At the same time, all warehouse management processes have been supported, like spare parts requests, offers and provisions, decreasing drastically the bureaucracy and the administrative cost of these functions. The craftsmen know henceforth with precision spare parts stock level, a fact that has led to the obliteration of shortage phenomena, to stock reduction and generally to management functional cost reduction.

The CMMS henceforth constitutes a tool in management hands for pumping critical information concerning the maintenance department. For the first time the factory's management can watch and oversee the output and the effectiveness of the department via KPI's, and set concrete objectives for the next year.

D/1.5 Keywords

CMMS: Computerised Maintenance Management System, EAM: Enterprise Asset Management.

D/1.6 Glossary

Actions (Work orders): Manages actions for correcting faults or improving equipment's condition. Basic action information on the desired job might include the equipment number to be worked on, a description of the problem or work to be done, who requested the work, when they wanted it completed, the job's priority, and the date issued. Planning and scheduling of the actions may be useful.

Preventive maintenance (PM): Manages actions for predefined scheduled jobs in order to preserve good equipment condition. Jobs done under PM usually include inspections, lubrications and changes of finite-lifetime items such as filters or seals. An important assignment of PM is discovering needed corrective actions, which results in generating the needed actions.

Spare parts (Inventory Control): Recordkeeping of maintenance parts and other materials received, stocked, and disbursed as well as their location in the stockroom. Data is provided showing what items are to be ordered, what are available, and what are on order. The data so provided is directly supportive of the planning and scheduling effort.

D/1.7 Questions

1. Which of the following CMMS modules is splitted in 3 parts: basic data, daily work and analysis?

a. Actions Management
b. Preventive Maintenance Actions
c. Spare Parts Management
d. All the above

(Answer : d)

2. Which data entry strategy should a company follow, during the CMMS implementation period?

a. As minimum as possible
b. As maximum as possible
c. Enter only the known information
d. As fast as possible

(Answer : a)

3. Which method will help a company to check that all the procedures are properly working during the CMMS implementation period?

a. Run all the procedures simultaneously
b. Run a pilot phase
c. Spend a great amount of time on procedures fault detection
d. There is no need to perform such a method

(Answer : b)

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