

# Handbook of Maintenance Management and Engineering

Mohamed Ben-Daya • Salih O. Duffuaa  
Abdul Raouf • Jezdimir Knezevic • Daoud Ait-Kadi  
Editors

# Handbook of Maintenance Management and Engineering

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Mohamed Ben-Daya, Prof.  
Salih O. Duffuaa, Prof.  
King Fahd University of Petroleum  
& Minerals (KFUPM)  
Department of Systems Engineering  
Dhahran 31261  
Saudi Arabia  
bendaya@ccse.kfupm.edu.sa  
duffuaa@ccse.kfupm.edu.sa

Ježdimir Knezević, Prof.  
Mirce Academy  
Longbrook Street  
Exeter  
Hems Mews  
EX4 6AP  
United Kingdom  
mirce@mirce.net

Daoud Ait-Kadi, Prof.  
Université Laval  
Faculté de Sciences et de Génie  
Département de Génie Mécanique  
1314E Pavillon Adrien-Pouliot  
Sainte-Foy, QC G1K 7P4  
Canada  
daoud.aitkadi@gmc.ulaval.ca

Abdul Raouf, Prof.Dr.  
University of Management  
and Technology  
C-2 Johar Town  
Lahore-54600  
Pakistan  
abdulraouf@umt.edu.pk

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## Preface

To be able to compete successfully both at national and international levels, production systems and equipment must perform at levels not even thinkable a decade ago. Requirements for increased product quality, reduced throughput time and enhanced operating effectiveness within a rapidly changing customer demand environment continue to demand a high maintenance performance.

In some cases, maintenance is required to increase operational effectiveness and revenues and customer satisfaction while reducing capital, operating and support costs. This may be the largest challenge facing production enterprises these days. For this, maintenance strategy is required to be aligned with the production logistics and also to keep updated with the current best practices.

Maintenance has become a multidisciplinary activity and one may come across situations in which maintenance is the responsibility of people whose training is not engineering. This handbook aims to assist at different levels of understanding whether the manager is an engineer, a production manager, an experienced maintenance practitioner or a beginner. Topics selected to be included in this handbook cover a wide range of issues in the area of maintenance management and engineering to cater for all those interested in maintenance whether practitioners or researchers.

This handbook is divided into 6 parts and contains 26 chapters covering a wide range of topics related to maintenance management and engineering.

Part I deals with maintenance organization and performance measurement and contains two chapters. Chapter 1 by Haroun and Duffuaa describes the maintenance organization objectives, the responsibilities of maintenance, and the determinants of a sound maintenance organization. In Chapter 2, Parida and Kumar address the issues of maintenance productivity and performance measurement. Topics covered include important performance measures and maintenance performance indicators (MPI), measurement of maintenance productivity performance and various factors and issues like MPI and MPM systems, MPI standard and MPIs use in different industries.

Part II contains an overview and introduction to various tools used in reliability and maintenance studies and projects. In Chapter 3, Ben-Daya presents basic statistical concepts including an introduction to probability and probability distributions, reliability and failure rate functions, and failure statistics. In Chapter

4, Ben-Daya provides an overview of several tools including failure mode and effect analysis, root cause analysis, the Pareto chart, and cause and effect diagram.

Part III contains three chapters related to maintenance control systems. Chapter 5 by Duffuaa and Haroun presents the essential elements and structure of maintenance control. Topics included cover required functions for effective control, the design of a sound work order system, the necessary tools for feedback and effective maintenance control, and the steps of implementing effective maintenance control systems. Cost control and budgeting is the topic of Chapter 6 by Mirghani. This chapter provides guidelines for budgeting and costing planned maintenance services. Topics covered include overview of budgeting and standard costing systems, budgeting framework for planned maintenance, a methodology for developing standard costs and capturing actual costs for planned maintenance jobs, and how detailed cost variances could be generated to assess the cost efficiency of planned maintenance jobs. The final chapter in this part is Chapter 7 by Riane, Roux, Basile, and Dehombreux. The authors discuss an integrated framework called OPTIMAIN that allows maintenance decision makers to design their production system, to model its functioning and to optimize the appropriate maintenance strategies.

Part IV focuses on maintenance planning and scheduling and contains five chapters. Forecasting and capacity planning issues are addressed in Chapter 8 by Al-Fares and Duffuaa. Topics covered include forecasting techniques, forecasting maintenance workload, and maintenance capacity planning. Necessary tools for these topics are presented as well and illustrated with examples. Chapter 9 by Diallo, Ait-Kadi and Chelbi deals with spare parts management. This chapter addresses the problem of spare parts identification and provisioning for multi-component systems. A framework considering available technical, economical and strategic information is presented along with appropriate mathematical models. Turnaround maintenance (TAM) is the object of Chapter 10 by Duffuaa and Ben-Daya. This chapter outlines a structured process for managing TAM projects. The chapter covers all the phases of TAM from its initiation several months before the event till the termination and writing of the final report. Chapter 11 by Al-Turki gives hands on knowledge on maintenance planning and scheduling for planners and schedulers at all levels. Topics covered include strategic planning in maintenance, maintenance scheduling techniques, and information system support available for maintenance planning and scheduling. Chapter 12 by Boukas deals with the control of production systems and presents models for production and maintenance planning. The production systems are supposed to be subject to random abrupt changes in their structures that may result from breakdowns or repairs.

Part V addresses maintenance strategies and contain eight chapters. Chapter 13 by Ait-Kadi and Chelbi presents inspection models. Topics covered include models for single and multi-component systems, and conditional maintenance models. Chapter 14 by Kothamasu, Huang and VerDuin offers a comprehensive review of System Health Monitoring and Prognostics. Topics surveyed include health monitoring paradigms, health monitoring tools and techniques, case studies, and organizations and standards. Ito and Nakagawa present applied maintenance models in Chapter 15. In this chapter, the authors consider optimal maintenance

models for four different systems: missiles, phased array radar, Full Authority Digital Electronic Control and co-generation systems based on their research. In Chapter 16, Siddiqui and Ben-Daya provide an introduction to reliability centered maintenance (RCM) including RCM philosophy, RCM methodology, and RCM implementation issues. Total productive maintenance (TPM) is the subject of Chapter 17 by Ahuja. Topics include basic elements of TPM, TPM methodology and implementation issues. Maintenance is an important concept in the context of warranties. Chapter 18 by Murthy and Jack highlights the link between the two subjects and discusses the important issues involved. Topics covered include link between warranty and maintenance, maintenance logistics for warranty servicing, and outsourcing of maintenance for warranty servicing. Delay Time (DT) Modeling for Optimized Inspection Intervals of Production Plant is the title of Chapter 19 by Wang. Topics covered include DT models for complex plant, DT model parameters estimation, and related developments and future research on DT modeling. Intelligent maintenance solutions and e-maintenance applications have drawn much attention lately both in academia and industry. The last chapter in Part V, Chapter 20 by Liyanage, Lee, Emmanouilidis and Ni deals with Integrated E-maintenance and Intelligent Maintenance Systems. Issues discussed include integrated e-maintenance solutions and current status, technical framework for e-maintenance, technology integration for advanced e-maintenance solutions, some industrial applications, and challenges of e-Maintenance application solutions.

Part VI deals with maintainability and system effectiveness and contains one chapter by Knezevic. It covers topics related to maintainability analysis and engineering and maintainability management.

Part VII contains five chapters presenting important issues related to safety, environment and human error in maintenance. Safety and maintenance issues are discussed in Chapter 22 by Pintelon and Muchiri. This chapter establishes a link between safety and maintenance, studies the effect of various maintenance policies and concepts on plant safety, looks at how safety performance can be measured or quantified, and discusses accident prevention in light of the safety legislation put in place by governments and some safety organizations. In Chapter 23, Raouf proposes an integrated approach for monitoring maintenance quality and environmental performance. Chapter 24 by Liyanage, Badurdeen and Ratnayake gives an overview of emerging sustainability issues and shows how the asset maintenance process plays an important role in sustainability compliance. It also elaborates on issues of quality and discusses best practices for guiding decisions. The last two chapters deal with human error in maintenance. Chapter 25 by Dhillon presents various important aspects of human reliability and error in maintenance. Finally Chapter 26 by Nicholas deals with human error in maintenance – a design perspective.

Maintenance professionals, students, practitioners, those aspiring to be maintenance managers, and persons concerned with quality, production and related areas will find this handbook very useful as it is relatively comprehensive when compared with those existing in the market.

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## List of Contributors

I.P.S. Ahuja,  
Punjabi University, India

Daoud Aït-Kadi,  
Université Laval, Québec, Canada

Hesham K. Alfares,  
King Fahd University of Petroleum & Minerals, Saudi Arabia

Umar M. Al-Turki,  
King Fahd University of Petroleum & Minerals, Saudi Arabia

Fazleena Badurdeen,  
University of Kentucky, USA

Olivier Basile,  
Faculté Polytechnique de Mon, Belgium

Mohamed Ben-Daya,  
King Fahd University of Petroleum & Minerals, Saudi Arabia

El-Kebir Boukas,  
École Polytechnique de Montréal, Canada

Anis Chelbi,  
École Supérieure des Sciences et Techniques de Tunis

Pierre Dehombreux,  
Faculté Polytechnique de Mon, Belgium

B.S. Dhillon,  
University of Ottawa, Canada

Claver Diallo,  
Dalhousie University, Canada

Salih O. Duffuaa,  
King Fahd University of Petroleum & Minerals, Saudi Arabia

Christos Emmanouilidis,  
CETI/ATHENA Research and Innovation Centre, Greece

Ahmed Haroun,  
King Fahd University of Petroleum & Minerals, Saudi Arabia

Samuel H. Huang,  
University of Cincinnati, Cincinnati, USA

Kodo Ito,  
Mitsubishi Heavy Industries, Ltd., Japan

Nat Jack,  
University of Abertay Dundee, UK

J. Knezevic,  
MIRCE Academy, UK

Ranganath Kothamasu,  
University of Cincinnati, Cincinnati, USA

Uday Kumar,  
Luleå University of Technology, Sweden

Jay Lee,  
University of Cincinnati, USA

Jayantha P. Liyanage,  
University of Stavanger, Norway

Mohamed Ali Mirghani,  
King Fahd University of Petroleum & Minerals, Saudi Arabia

Peter Muchiri,  
Katholieke University Leuven, Belgium

D.N.P. Murthy,  
The University of Queensland, Australia

Toshio Nakagawa,  
Aichi Institute of Technology, Japan

Jun Ni,  
University of Cincinnati, USA

Clive Nicholas,  
Mirce Academy, UK

Aditya Parida,  
Luleå University of Technology, Sweden

Liliane Pintelon,  
Katholieke University Leuven, Belgium

Abdul Raouf,  
University of Management and Technology, Pakistan

R.M. Chandima Ratnayake,  
University of Stavanger, Norway

Fouad Riane,  
Faculté Polytechnique de Mon, Belgium

Olivier Roux,  
Faculté Polytechnique de Mon, Belgium

Atiq Waliullah Siddiqui,  
King Fahd University of Petroleum & Minerals, Saudi Arabia

William H. VerDuin,  
Vertech LLC, Chagrin Falls, USA

Wenbin, Wang,  
University of Salford, UK

**Maintenance Organization**

# Maintenance Organization

Ahmed E. Haroun and Salih O. Duffuaa

## 1.1 Introduction

Organizing is the process of arranging resources (people, materials, technology *etc.*) together to achieve the organization's strategies and goals. The way in which the various parts of an organization are formally arranged is referred to as the organization structure. It is a system involving the interaction of inputs and outputs. It is characterized by task assignments, workflow, reporting relationships, and communication channels that link together the work of diverse individuals and groups. Any structure must allocate tasks through a division of labor and facilitate the coordination of the performance results. Nevertheless, we have to admit that there is no one best structure that meets the needs of all circumstances. Organization structures should be viewed as dynamic entities that continuously evolve to respond to changes in technology, processes and environment, (Daft, 1989 and Schermerhorn, 2007).

Frederick W. Taylor introduced the concept of scientific management (time study and division of labor), while Frank and Lilian Gilbreth founded the concept of modern motion study techniques. The contributions of Taylor and the Gilbreths are considered as the basis for modern organization management. Until the middle of the twentieth century maintenance has been carried out in an unplanned reactive way and for a long time it has lagged behind other areas of industrial management in the application of formal techniques and/or information technology. With realization of the impact of poor maintenance on enterprises' profitability, many managers are revising the organization of maintenance and have developed new approaches that foster effective maintenance organization.

Maintenance cost can be a significant factor in an organization's profitability. In manufacturing, maintenance cost could consume 2–10% of the company's revenue and may reach up to 24% in the transport industry (Chelson, Payne and Reavill, 2005). So, contemporary management considers maintenance as an integral function in achieving productive operations and high-quality products, while maintaining satisfactory equipment and machines reliability as demanded by

the era of automation, flexible manufacturing systems (FMS), “lean manufacturing”, and “just-in-time” operations.

However, there is no universally accepted methodology for designing maintenance systems, *i.e.*, no fully structured approach leading to an optimal maintenance system (*i.e.*, organizational structure with a defined hierarchy of authority and span of control; defined maintenance procedures and policies, *etc.*). Identical product organizations, but different in technology advancement and production size, may apply different maintenance systems and the different systems may run successfully. So, maintenance systems are designed using experience and judgment supported by a number of formal decision tools and techniques. Nevertheless, two vital considerations should be considered: strategy that decides on which level within the plant to perform maintenance, and hence outlining a structure that will support the maintenance; planning that handles day-to-day decisions on what maintenance tasks to perform and providing the resources to undertake these tasks.

The maintenance organizing function can be viewed as one of the basic and integral parts of the maintenance management function (MMF). The MMF consists of planning, organizing, implementing and controlling maintenance activities. The management organizes, provides resources (personnel, capital, assets, material and hardware, *etc.*) and leads to performing tasks and accomplishing targets. Figure 1.1 shows the role organizing plays in the management process. Once the plans are created, the management’s task is to ensure that they are carried out in an effective and efficient manner. Having a clear mission, strategy, and objectives facilitated by a corporate culture, organizing starts the process of implementation by clarifying job and working relations (chain of command, span of control, delegation of authority, *etc.*).

In designing the maintenance organization there are important determinants that must be considered. The determinants include the capacity of maintenance, centralization *vs* decentralization and in-house maintenance *vs* outsourcing. A number of criteria can be used to design the maintenance organization. The criteria include clear roles and responsibilities, effective span of control, facilitation of good supervision and effective reporting, and minimization of costs.

Maintenance managers must have the capabilities to create a division of labor for maintenance tasks to be performed and then coordinate results to achieve a common purpose. Solving performance problems and capitalizing on opportunities could be attained through selection of the right persons, with the appropriate capabilities, supported by continuous training and good incentive schemes, in order to achieve organization success in terms of performance effectiveness and efficiency.

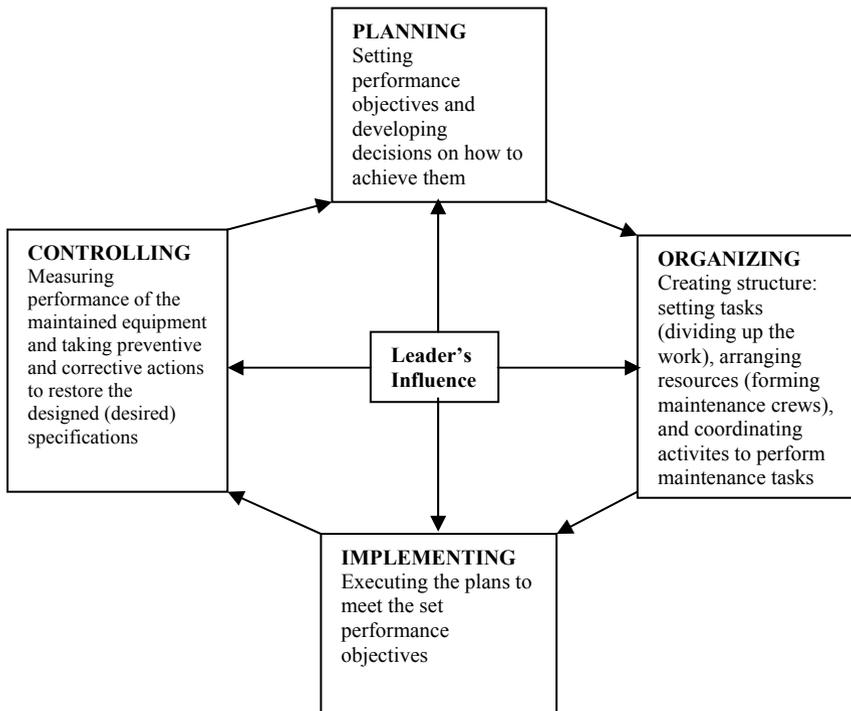
This chapter covers the organizational structure of maintenance activities. Section 1.2 describes the organization objectives and the responsibilities of maintenance, followed by the determinants of a maintenance organization in Section 1.3. Section 1.4 outlines the design of maintenance organization and Section 1.5 presents basic models for organization. The description of function of material and spare parts management is given in Section 1.6, and Section 1.7 outlines the process of establishing authority. The role of the quality of leadership and supervision is presented in Section 1.8 followed by the role of incentives in

Section 1.9. Sections 1.10 and 1.11 present education and training, and management and labor relations, respectively. A summary of the chapter is provided in Section 1.12.

## 1.2 Maintenance Organization Objectives and Responsibility

A maintenance organization and its position in the plant/whole organization is heavily impacted by the following elements or factors:

- Type of business, *e.g.*, whether it is high tech, labor intensive, production or service;
- Objectives: may include profit maximization, increasing market share and other social objectives;
- Size and structure of the organization;
- Culture of the organization; and
- Range of responsibility assigned to maintenance.



**Figure 1.1.** Maintenance organizing as a function of the management process

Organizations seek one or several of the following objectives: profit maximization, specific quality level of service or products, minimizing costs, safe and clean environment, or human resource development. It is clear that all of these

objectives are heavily impacted by maintenance and therefore the objectives of maintenance must be aligned with the objectives of the organization.

The principal responsibility of maintenance is to provide a service to enable an organization to achieve its objectives. The specific responsibilities vary from one organization to another; however they generally include the following according to Duffuaa *et al.* (1998):

1. Keeping assets and equipment in good condition, well configured and safe to perform their intended functions;
2. Perform all maintenance activities including preventive, predictive; corrective, overhauls, design modification and emergency maintenance in an efficient and effective manner;
3. Conserve and control the use of spare parts and material;
4. Commission new plants and plant expansions; and
5. Operate utilities and conserve energy.

The above responsibilities and objectives impact the organization structure for maintenance as will be shown in the coming sections.

### **1.3 Determinants of a Maintenance Organization**

The maintenance organization's structure is determined after planning the maintenance capacity. The maintenance capacity is heavily influenced by the level of centralization or decentralization adopted. In this section the main issues that must be addressed when forming the maintenance organization's structure are presented. The issues are: capacity planning, centralization vs decentralization and in-house vs outsourcing.

#### **1.3.1 Maintenance Capacity Planning**

Maintenance capacity planning determines the required resources for maintenance including the required crafts, administration, equipment, tools and space to execute the maintenance load efficiently and meet the objectives of the maintenance department. Critical aspects of maintenance capacity are the numbers and skills of craftsmen required to execute the maintenance load. It is difficult to determine the exact number of various types of craftsmen, since the maintenance load is uncertain. Therefore accurate forecasts for the future maintenance work demand are essential for determining the maintenance capacity. In order to have better utilization of manpower, organizations tend to reduce the number of available craftsmen below their expected need. This is likely to result in a backlog of uncompleted maintenance work. This backlog can also be cleared when the maintenance load is less than the capacity. Making long run estimations is one of the areas in maintenance capacity planning that is both critical and not well developed in practice. Techniques for maintenance forecasting and capacity planning are presented in a separate chapter in this handbook.

### 1.3.2 Centralization vs Decentralization

The decision to organize maintenance in a centralized, decentralized or a hybrid form depends to a greater extent on the organization is philosophy, maintenance load, size of the plant and skills of craftsmen. The advantages of centralization are:

1. Provides more flexibility and improves utilization of resources such highly skilled crafts and special equipment and therefore results in more efficiency;
2. Allows more efficient line supervision;
3. Allows more effective on the job training; and
4. Permits the purchasing of modern equipment.

However it has the following disadvantages:

1. Less utilization of crafts since more time is required for getting to and from jobs;
2. Supervision of crafts becomes more difficult and as such less maintenance control is achieved;
3. Less specialization on complex hardware is achieved since different persons work on the same hardware; and
4. More costs of transportation are incurred due to remoteness of some of the maintenance work.

In a decentralized maintenance organization, departments are assigned to specific areas or units. This tends to reduce the flexibility of the maintenance system as a whole. The range of skills available becomes reduced and manpower utilization is usually less efficient than in a centralized maintenance. In some cases a compromise solution that combines centralization and decentralization is better. This type of hybrid is called a cascade system. The cascade system organizes maintenance in areas and what ever exceeds the capacity of each area is challenged to a centralized unit. In this fashion the advantages of both systems may be reaped. For more on the advantages and disadvantages of centralization and decentralization see Duffuaa *et al.* (1998) and Niebel (1994).

### 1.3.3 In-house vs Outsourcing

At this level management considers the sources for building the maintenance capacity. The main sources or options available are in-house by direct hiring, outsourcing, or a combination of in-house and outsourcing. The criteria for selecting sources for building and maintaining maintenance capacity include strategic considerations, technological and economic factors. The following are criteria that can be employed to select among sources for maintenance capacity:

1. Availability and dependability of the source on a long term basis;
2. Capability of the source to achieve the objectives set for maintenance by the organization and its ability to carry out the maintenance tasks;

3. Short term and long term costs;
4. Organizational secrecy in some cases may be subjected to leakage;
5. Long term impact on maintenance personnel expertise; and
6. Special agreement by manufacturer or regulatory bodies that set certain specifications for maintenance and environmental emissions.

Examples of maintenance tasks which could be outsourced are:

1. Work for which the skill of specialists is required on a routine basis and which is readily available in the market on a competitive basis, *e.g.*,:
  - Installation and periodic inspection and repair of automatic fire sprinkler systems;
  - Inspection and repair of air conditioning systems;
  - Inspection and repair of heating systems; and
  - Inspection and repair of main frame computers *etc.*
2. When it is cheaper than recruiting your own staff and accessible at a short notice of time.

The issues and criteria presented in the above section may help organizations in designing or re-designing their maintenance organization.

## **1.4 Design of the Maintenance Organization**

A maintenance organization is subjected to frequent changes due to uncertainty and desire for excellence in maintenance. Maintenance and plant managers are always swinging from supporters of centralized maintenance to decentralized ones, and back again. The result of this frequent change is the creation of responsibility channels and direction of the new organization's accomplishments *vs* the accomplishments of the former structure. So, the craftsmen have to adjust to the new roles. To establish a maintenance organization an objective method that caters for factors that influence the effectiveness of the organization is needed. Competencies and continuous improvement should be the driving considerations behind an organization's design and re-design.

### **1.4.1 Current Criteria for Organizational Change**

Many organizations were re-designed to fix a perceived problem. This approach in many cases may raise more issues than solve the specific problem (Bradley, 2002). Among the reasons to change a specific maintenance organization's design are:

1. Dissatisfaction with maintenance performance by the organization or plant management;
2. A desire for increased accountability;