LILIANE PINTELON & FRANK VAN PUYVELDE

ASSET MANAGEMENT

THE MAINTENANCE PERSPECTIVE

acco

Preface

Our first book on maintenance management was written in 1995, quite a pioneering project, as maintenance still was an awakening management function back then. In 1997 the book was translated in English. A serious update came in 2006 with Maintenance Decision Making. A book, which is now replaced by this one, Asset Management: The Maintenance Perspective. The title hints indeed that maintenance has come a long way, it even listens to a different name, asset management. However the asset management we speak of is only a part of what is generally understood by asset management. Here we refer to physical asset management, hence the subtitle, the maintenance perspective. There are – by now – many books on maintenance related subjects. There are the oldies such as the books by Barlow, Proschan and Hunter which provided the foundations for quantitative reliability engineering and the book by Cox on renewal theory. Since that time (60s-70s) quite some books – a first only a few, later more and more – on maintenance subjects have been written. The question is then: why this book? We believe this book fills a gap, because it presents a holistic view on maintenance management. It is not a book on reliability theory or on MRO or on auditing or ... It is less and more. It doesn't offer a very deep and involved discussion of either of these topics, but it gives a sound introduction to all of them. Moreover it links all these topics together in an integrated, holistic view on maintenance/asset management. This approach is not common for most books on the market, they rather tackle only one aspect. Compared to the few books which offer a broader view, this book stands out because of the many illustrations, both numerical examples and real-life case studies – mostly from a Belgian context. Although the majority of these examples come from industry, its use is by no means limited to the industry. All environments relying on technical equipment can benefit from the concepts and techniques outlined here. Think e.g. of applying reliability engineering to wind mill farms or in a healthcare context.

The book consists of six parts. It begins by defining maintenance management in its business context (Part I) and by looking at failure statistics and RAMS (Part II). Part III continues with a discussion of decision support models, including TPM, RCM and more recent evolutions, as well as optimization models and planning tools. In Part IV, management of maintenance resources, personnel and spare parts is presented with special attention for outsourcing. Part V goes on to cover assessment with topics on performance reporting, auditing and benchmarking, and Part VI wraps up with a discussion on world-class maintenance. Note that the subjects covered are qualitative (e.g. lean maintenance) as quantitative (e.g. reliability computations) in nature. The same holds for the illustrations.

Although the book contains, for convenience structured chapter by chapter, over the two hundred references, it was not our intention to offer an exhaustive literature review on all of the topics covered. Rather, we aimed at providing a complete view on maintenance/asset management, with a selection of references. This selection exists of on one hand older text books (because these simply are the base of further developments) and some more recent ones. The latter were selected mostly because they cover the subjects discussed in this book into more detail. The interested reader can find more information there. Also a limited number of recent research papers, from academic journals or international conferences, were included to provide some insight in current research activities. We believe that the concept of this book makes it worthwhile for a double audience. On one hand we think that it is a sound introduction in the whole field of maintenance management, in all its exciting complexity, for the (engineering) student or beginning researcher. On the other hand, the book can also provide insights and interesting tools for the practitioner in industry or in a service organization because of its holistic approach.

The authors would like to thank anybody who contributed to the contents of this book: i.e. organizations who provided interesting case projects and the enthusiastic master students, PhD students and co-workers who carried out these projects. And last but not least, thanks to Judith and Astrid Van Puyvelde for the cartoons and their support.

Liliane Pintelon and Frank Van Puyvelde (Heverlee, September 2013)

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Chapter 1

Maintenance/Asset Management

1.1 Definition

Maintenance has come a long way. For centuries maintenance meant only repairing what was broken. Since, say roughly World War II, maintenance and reliability engineering took off as new disciplines. Still a bit later, costs were brought explicitly into the picture and even more recently, the well-needed business context came into the picture. Nowadays, we speak of maintenance management, but also of asset management, or more precisely of physical asset management.
It may be a good idea to explore these terms 'maintenance management' and 'asset management' further by looking at some of the definitions given in literature. There are many, many definitions, which is not surprising seen the complexity and variety of activities and objectives covered. Some of the more interesting definitions are:

- '... all activities aimed at keeping an item in or restoring it to the physical state considered necessary for the fulfillment of its production function ...' (Geraerds [4])
- '... the engineering decisions and associated actions necessary and sufficient for the optimization of specified capability...' (MESA - Maintenance Engineering Society of Australia)
- '... all the activities of the management that determine the maintenance objectives or priorities (defined as targets assigned and accepted by the management and maintenance department), strategies (defined as a management method in order to achieve maintenance objectives), and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods including economical aspects in the organization ...' (Crespo Marquez[2])
- '... asset management can be defined as the systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated perfor-

mance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan...' (BSI:PAS 55 [1])

- '... maintenance management: all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics ...'

These are only a few examples of definitions, although they are not identitcial there is no discrepancy in their description of objectives and responsibilities of maintenance management/asset management. In the remainder of this book we will use the terms maintenance management and asset management interchangeably. By asset management we always refer to physical asset management (machines, equipment, installations, etc.) and not to financial, real estate, information or human assets, until stated differently.

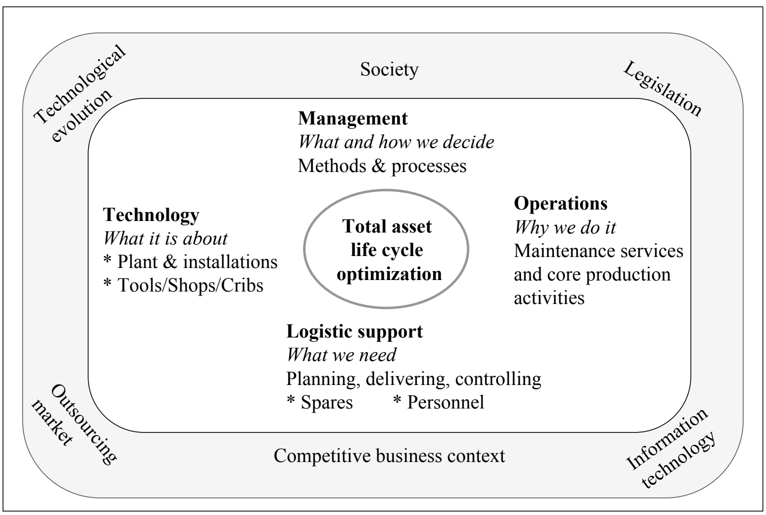

Figure 1.1: Asset/maintenance management defined

Here we give a practical definition of asset/maintenance management. The objective of *maintenance management* is *total asset life cycle optimization.* This could be rephrased as (Pintelon and Van Puyvelde [12]): maximizing of availability and reliability of the equipment in order to produce the desired quantity of products/services with the required quality specifications. Obviously, this objective must be attained in a cost-effective way and in accordance with environmental and safety regulations.
If we consider production equipment (power generation, automotive, CPI, etc), we clearly expect the equipment to be capable of producing product, as many as desired and in the required quality. Similar requirements hold for equipment in the services industries, which do manufacture tangible products, but e.g. distribute goods (think of an ATM) or provide assistance in medical diagnosis or treatment (think of scanners or infusion pumps). Both availability and reliability need to be high and consistent (see Chapter 5). Cost-effectiveness

refers to the optimum balancing between costs, risk and performance, not only in the short run, but also on long term horizon (life cycle, see Chapter 7). Obviously, occupational safety and environmental regulations have to be respected. Although not mentioned explicity, all this shows that maintenance/asset management is to be seen in an enterprise-wide setting and has to contribute to the given specific business context.

Figure 1.1 pictures the complexity of current maintenance management. Total asset life cycle management includes different aspects. *Management* is about "what to decide" and "how to decide"; i.e. methods and processes. *Technology* is "what it is all about". It refers to the plant and installations to be maintained. Closely related to this issue is the technology to support the maintenance technician, including tools, cribs and work shops. *Operations* refers to the "why". Maintenance services must be designed to optimally support the core production activities. *Logistic support* is about "what is needed"; i.e. about planning, delivering and controlling. As main support elements there are spare parts and personnel.
These different aspects will always be present, but their intensity and interrelationships will vary from situation to situation (e.g. elevator maintenance in a hospital vs plant maintenance in chemical process industries (CPI)). Besides the environment, other factors will be important like the competitiveness of the business context, societal structure and climate, legislation concerning environment, health and safety (EHS), technological evolution, outsourcing market and information technology (IT). The two latter are expected to influence current and future maintenance management considerably.

The definition given by Higgins [6] is a suitable way to conclude this section on the definition of maintenance management. Higgins introduces the complexity of maintenance management in a nice way; he states: '... maintenance *is a science* since its execution relies, sooner or later, on most or all of the sciences. It is *an art* because seemingly identical problems regularly demand and receive varying approaches and actions and because some managers, foremen and mechanics display greater aptitude for it than other show or even attain. It is above all *a philosophy* because it is a discipline that can be applied intensively, modestly, or not at all, depending upon a wide range of variables that frequently transcend more immediate and obvious solutions'. Although decades old, still very true ...

1.2 Historical perspective

1.2.1 What has happened?

Although man has been using tools and equipment for centuries, maintenance only became a management concern after World War II. Figure 1.2 illustrates the evolution in maintenance during the last decades. Maintenance started out as a necessary, not-manageable evil, an activity which only costed money. Later on maintenance was considered as a purely technical function, emphasis was put on aspects like materials and techniques used and also work procedures and planning. This - luckily - evolved in to a broader view on maintenance as a business function, i.e. a potential profit contributor. Nowadays, maintenance is a mature partner for production; external partnerships are an interesting opportunity seized by many companies. For the years to come, e-maintenance in all its facets will surely be one of the main issues in maintenance management.

In the remainder of this paragraph the main changes in the *playing field of the maintenance manager* wil be addressed.

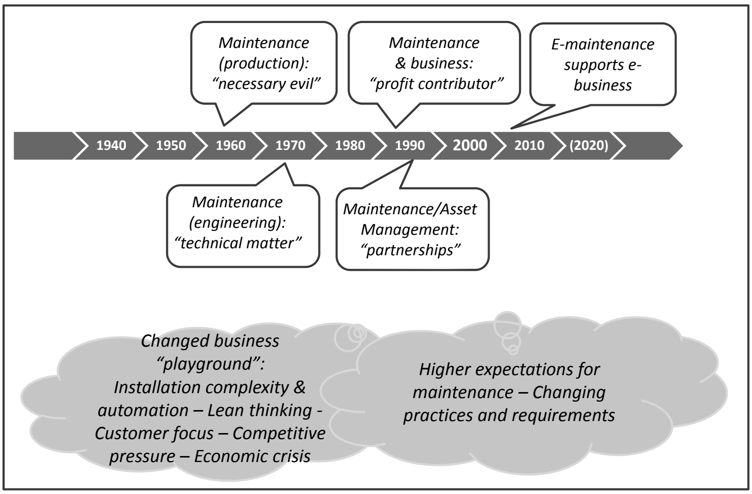

Figure 1.2: Historical perspective on maintenance management

The last century was marked by a *technological (r)evolution*, which greatly influenced industrial practice. At the start of the 20th century, installations were hardly or not mechanized, had a simple design, worked in a stand-alone configuration and often had considerable overcapacity. Nowadays, installations are highly automated and technologically very complex. Often these installations are part of an integrated production line and right-sized in capacity. Moreover, lean manufacturing, 6σ, JIT (just-in-time) and the like have led to minimum logistic buffers (work-in-process (WIP) and stocks of finished goods) against equipment problems such as breakdonws and quality problems. The installations thus not only became more complex, they also became more vulnerable, i.e. critical in terms of reliability and availability. Built-in redundancy is expensive and only considered for very critical components, e.g. a critical - in terms of safety hazards - pump in the CPI. For very expensive installations like e.g. flexible manufacturing systems (FMS), special modular design ensures minimal downtime during maintenance. Also condition monitoring and e-maintenance offer great potential here (see Chapter 3), as such offers the technological (r)evolution not only new challenges but also new opportunities.

Customer focus became more and more explicit: customers want better products, also they want them cheaper and faster and they require more choice. The technological evolution combined with this ever-increasing customer focus causes a shortening of the economic lifetime of installations. The stronger customer focus also partly determines the above-mentioned criticality: the required flexibility due to the varying custom demands calls for well-maintained and reliable installations. The same goes for the logistic requirements (shorter lead times and higher lead time reliability) and the quality requirements (high and consistent quality).

The *business environment* has changed as well. Competition has become fierce and - due to the globalization - has become worldwide. The latter does not only imply that competitors are located all over the world, but also that the decision to move production activities from a non-efficient site (e.g. due to high operations and maintenance costs) to another site is quickly taken, even if that other location is on another continent. Companies try to cope with these dynamics by adopting management concepts like MRP (material requirements planning), MRPII (manufacturing resources planning), theory of constraints (TOC), just-in-time (JIT), total quality management (TQM), time-based competition (TBC), business process reengineering (BPR), supply chain management (SCM), customer relationship management (CRM), enterprise resources planning (ERP), etc. These popular letter words not only represent another general management focus or reorientation, but also have their impact on the perception of maintenance. Many companies are critically evaluating their value chain and often decide to reorganize it drastically. This results in focussing on the core business and consequently the outsourcing of given activities (also maintenance) and/or the creation of new partnerships and alliances.

Societal expectations concerning technology and its impact also create boundary conditions for maintenance management. The attention paid to sustainability (the so-called $3P$ (people, profit, planet), short for societal, economic and environmental demands) is made on any organization nowadays. This calls a fortiori for a strict respecting stringent legislation on occupational safety and environmental standards.

Note that most of the above mentioned industrial trends can be easily translated for the **service sector**: e.g. automated warehouses in distribution centers, medical technology in hospitals, building utilities and smart building systems, automated teller machines (ATM) in the bank sector, security equipment at airports, etc.

1.2.2 How did this change maintenance management?

Maintenance management has changed drastically over the past decades. The rapidly changing technological evolution and the corresponding increasing complexity of installations make quick and correct diagnosis of a machine problem more challenging and more difficult. A *continuously updated knowledge* is required, preferably supported by state-of-the-art monitoring technology embedded in an e-maintenance decision environment. Repairing and maintaining these installations requires better and more sophisticated skills. The fact that maintenance has become more critical implies that a thorough insight in the impact of maintenance interventions (or the omission of them) is indispensable. Good maintenance means optimally allocating resources (personnel, spares, etc.). Limited (or no) maintenance may seem a saving in the short run, but in the long run it is likely to generate more costs due to more unexpected failures, longer repair times, accelerated wear, etc.

The installation life cycle can be improved and extended through an optimized maintenance program. Operational costs (e.g. energy) can be decreased by better maintenance. The perception on which *maintenance policy* is 'right', i.e. the maintenance policy optimization, has changed a lot during the last

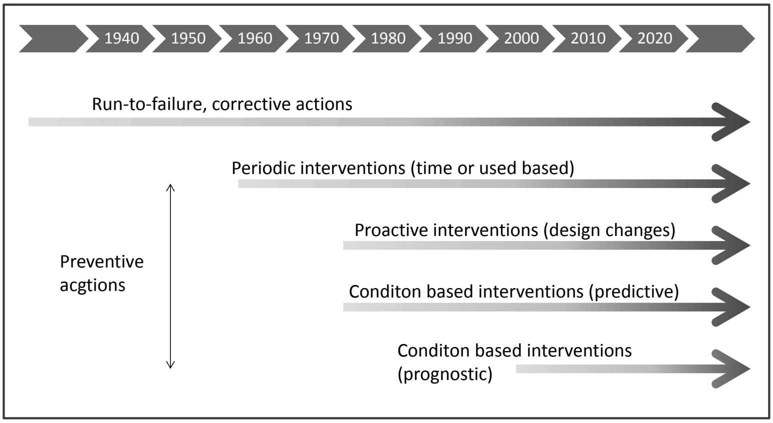

Figure 1.3: Evolution in maintenance policy implementation

decennia (Figure 1.3):

- In the 50s almost all maintenance was corrective maintenance. Maintenance was considered as an annoying and unavoidable cost, which could not be managed. In the 60s many companies switched to preventive maintenance programs. It was accepted that preventive actions could avoid some of the breakdowns and would lead to cost savings in the long run.

- In the late 70s and early 80s, preventive maintenance was considered more carefully. A concern about 'over-maintaining' grew. This meant a gradual, though not complete, switch to condition based maintenance. Of course this was limited to those applications where this was both technically and economically acceptable. Supportive to this trend was the fact that condition-monitoring equipment became more accessible and cheaper (before that time these techniques were reserved to high risk applications, like e.g. airplanes and nuclear power plants). A further step in this direction is e-maintenance, gaining a lot of research attention lately. An example of this evolution is tele-maintenance, the diagnosis and (limited) possibility to repair installation from a remote location using IT and sophisticated control and knowledge tools.

- Taking condition monitoring one step further introduces e-maintenance (see Chapter 3), which offers opportunities for a better follow-up and more efficient and effective maintenance of installed equipment. It also opens new horizons in product support, which allows the equipment manufacturer to remotely monitor the equipment installed at the customer's site (e.g. elevator, photcopier, etc.) and to intervene when problems are expected, even before the customer is aware of pending difficulties.

- Another evolution is the attention paid to design-out-maintenance (DOM), where equipment modifications are geared either at increasing the reliability (increasing mean time between failures (MTBF)) or at decreasing the maintainability (decreasing mean time to repair (MTTR)), as such improving the equipment availability. Often these DOM projects are combined with efforts to increase occupational safety or increase production capacity (e.g. set up reduction programs).

Finding the *right mix of maintenance interventions* for the installations is a huge challenge. Some companies go about in a rather ad hoc way based on experience. Others recur to maintenance concepts to help with this issue. Literature provides us with a lot of maintenance concepts, new maintenance concepts are developed, old ones are updated and methodologies to design customized maintenance concepts are created. Typical examples of maintenance concepts are TPM (total productive maintenance), RCM (reliability centered maintenance), LCC (life cycle costing) and BCM (business centered maintenance).

1.2.3 What exactly is expected?

It is clear that this whole evolution was based not solely on technical but rather on techno-economic considerations. Clearly maintenance cannot be managed as a purely technical and technological function only. Business economics (cost-benefit considerations) and business context (installation performance requirements) play an important role. A good maintenance manager needs starting from an indispensable technical background to have an eye for the ***big picture*** (i.e. no silo thinking) and not loose any aspect out of sight. Besides financial insights to manage the maintenance budget, maintenance logistics skills are in order. These concern managing resources like spares and personnel. Finding the optimum trade-off between the advantages of the high spare parts availability and the disadvantages of the corresponding stock investments is one of the challenges in spare parts management. As maintenance is still a very labor-intensive function, people management and communication are of utmost importance.

The decisions expected from the maintenance manager are complex and sometimes far reaching. He/she is (partly) responsible for *operational, tactical and strategic aspects* maintenance management of the company. This involves the final responsibility for operational decisions like the planning of the maintenance jobs and tactical decisions concerning the long-term maintenance policy to adopt. More recently, maintenance managers are also consulted in strategic decisions, e.g. purchases of new installations, design choices, personnel policy, etc.

These expectations incur a sharp need for *decision support techniques* of various nature: statistical analysis tools for predicting the failure behavior of equipment, decision schemes for determining the right maintenance concept, mathematical models to optimize the maintenance policy parameters (e.g. preventive maintenance frequency), decision criteria concerning e-maintenance, decision aids for outsourcing decisions, etc.

- The computerized maintenance management systems or enterprise asset management systems (CMMS/EAM) nowadays available offer many opportunities here, both concerning data availability and decision modeling. These systems evolved a lot since the early solely administrative maintenance software.

- OR/MS (Operations Research/Management Science) offers many models for this decision modeling. Lately the initial gap between the academic research and industrial decision making needs has been closing rapidly. The first mathematical models developed for maintenance purposes were often too much focused on mathematical tractability rather than on practical relevance. This has changed, more and more academics become interested in maintenance and start working on theoretically sound, but practically useful models that then are adopted by industry. E-maintenance decision algorithms strongly depend on advanced computational techniques in stochastics and optimization.

- Also more financially oriented models and concepts regarding life cycle optimization receive a lot of attention. These relatively complex models try to take into account all aspects of the life cycle (from inception till disposal), this from the point of view of costs (both direct and indirect) as well as from the point of view of utilization (availability, reliability) as well as from the point of view of time (life cycle duration). Making the maintenance component in these models as realistic as possible is a complex undertaking due to the many existing maintenance alternatives and their impact on e.g. operating costs and life cycle duration. The recent interest in sustainable business management has given the interest in life cycle optimization a new boost (e.g. low investment cost for a cheap machine which will have to be dumped after a short time and replaced by a new one or higher investment cost for a more expensive but durable machine with a longer lifetime and reusable components?). Note that also the business context (e.g. traditional sector versus rapidly evolving high-tech sector) plays a role here.

A side constraint which should not be forgotten in the current industrial organization is the often *quickly changing organizational structure* due to flexibilization and delayering (IT impact), take-overs and mergers, alliances and partnerships, etc. An example: where as in the past most companies were using traditional outsourcing, nowadays more and more companies turn towards the cooperative or even the transformational outsourcing alternative (see further). The rather disruptive character of and the painful experience of possible backsourcing decisions make the decision concerning the latter two forms very critical. Here also decision support concepts are available from literature. The outsourcing market has increased dramatically the last few decennia, this concerning consultants as well as maintenance firms executing maintenance jobs. These maintenance firms range from all-rounder, over specialists focussing on a small market segment or a given activity to integrators aiming at taking over the whole maintenance department.

1.3 Wrapping things up and getting ready to explore further

1.3.1 Drivers and dillemmas

From the above it becomes clear that there are a few very important drivers for maintenance management. Obviously, there is the *asset utilization* issue. As stated in the definition for maintenance management: there is a need for reliable and available equipment, delivering the required output in terms of quantity and quality. There is also the need for *cost* management. Maintenance budgets can be pretty steep and represent a fair share of the production cost. A sound cost control is needed. This includes many different components: wages, contracts, materials, inspections, etc. *Optimization* will lead to a better ratio of indirect vs direct maintenance people, a more clever management of the MRO (maintenance, repair and operating supplies) store, the selection of the right outsourcing formula, the implementation of the right amount of IT for support, etc. Next there is also *society*, expressing concerns about environmental impact of activities, occupational safety, societal safety in industrial areas, etc. Having these different drivers already hints a potential problem, namely the problem of conflicting interests.

Indeed viewpoints on maintenance related issues can be very different. Some illustrations of potential conflicts are given below. *Production*, customer of maintenance, tries to maximize throughput and minimize downtime. When business grows, production will be reluctant to "give" the installations to maintenance, while still requiring installations to operate without any problems. Production is not always aware of the fact that postponing maintenance can have a disastrous impact on the installation life time in the long run. When business slows down, the pressure on maintenance will be less in terms of service, but higher in terms of cutting costs. *Materials management* is concerned with managing the MRO store. They sometimes focus on quantity discounts not realizing that for slow moving items this may not be the main concern. *Engineering* is not always very keen on taking into account maintenance considerations in their design. They often go for custom-made, technologically sophisticated equipment, forgetting about issues like e.g. standardization (which can reduce MRO investments) or maintainability. Society keeps a close look at environmental and safety issues. Violating legislation in this respect can lead to high fines or even result in loss of the license to operate. *Financial managers* (and many top managers) are only concerned about money. The maintenance budget being a big chunk of the operations budget is a popular target, especially in times where business slows down. Cutting costs by canceling a big revision or postponing a renovation project may free up some money in the short run, but often jeopardizes the future useful life of the installations concerned. The *maintenance manager* has to try to cope with these dilemmas. He has to derive from there some objectives and add to these own objectives. All managerial decision levels will need to be considered and integrated: a giant task requiring a holistic view to determine strategy and the right skills to implement it and make it work. The philosophy of lean manufacturing is also applicable to maintenance, i.e. doing the right things, doing the things right, at the right time, while minimizing any waste and being flexible and open to change.

1.3.2 Critical success factors for maintenance today and (the day after) tomorrow

It is obvious that trends in industry - and note that a similar story can be told for the service industry: think e.g. about hospitals, bank or distribution centers, where reliability and availability of equipment and monitoring and control systems is very important - have shaped current maintenance management. Maintenance clearly has become more critical and more complex. Also the expectations for maintenance management have changed as described above. In summary the critical success factors (CSF) for professional and sustainable maintenance management are: a sound *technical and technological background* (the technical component in maintenance remains of course extremely important), combined with *management skills* (e.g. concerning human resource management, maintenance optimization, spare parts management and planning) and *flexibility* to cope with the opportunities and threats for the maintenance department (e.g. the growing outsourcing marke and the organizational changes due to mergers). Supporting management tools are available: old tools like e.g. key performance indicators (KPI) and OR/MS tools and new ones like e.g. e-maintenance. Paying attention to the evolutions in the field and in industry as a whole is helpful as well as the insight that maintenance management is not an isolated function, but needs to be integrated in a business context.

1.4 Selected further reading

For the reader interested in the history of maintenance management the articles of Geraerds [3] and Luxhoj et al. [9] may be of interest, as well as some chapters in the books of Mann [10], Kelly [8], Matyas [11], Jardine and Campbell [7] and Hawkins and Kister [5] may be of interest.

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Physical asset management - maintenance management - is of increasing concern in industry for all-day operations of existing plants, as well as in the design of innovative new technology and in service organizations providing high-quality and highly reliable services. Scarce resources and competition make maintenance an issue of utmost importance.

This book provides a holistic approach to maintenance management. Theoretical insights and concepts are provided in a structured way. Maintenance strategy is related to the business context and translated into tactical and operational decisions. Some of the theory is more qualitative in nature (e.g., discussion on e-maintenance), whereas other parts of it are quantitative (e.g., reliability computations). Many numerical examples and real-life case studies are included, making the book unique and interesting for students, researchers and practitioners.

The book consists of six parts. It begins by defining maintenance management in its business context (Part I) and by looking at failure statistics and RAMS (Part II). Part III then continues with a discussion of decision support models, including TPM, RCM and more recent evolutions, as well as optimization models and planning tools. In Part IV, management of maintenance resources, personnel and spare parts is presented with special attention for outsourcing. Part V goes on to cover assessment with topics on performance reporting, auditing and benchmarking, and Part VI wraps up with a discussion on world-class maintenance.

Asset Management. The Maintenance Perspective is the updated and expanded version of *Maintenance Decision Making* (2006).

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