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Advanced Maintenance Modelling for Asset Management

Techniques and Methods for Complex Industrial Systems

Springer

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Foreword

It is humbling to write a foreword on a book edited by colleagues Adolfo Crespo Márquez, Vicente González-Prida Díaz and Juan Francisco Gómez Fernández, who have collated the wealth of experience of the research group SIM (Sistemas Inteligentes de Mantenimiento/Intelligent Maintenance Systems) at the School of Engineering, University of Seville, Spain.

Engineered assets make up our built environment, and include man-made equipment, infrastructure, plant, tools and physical systems that are deployed across all industry sectors of human endeavour. Industrial components, equipment, infrastructure and plant are becoming complex and more sophisticated underpinned by rapid advances in materials technologies, instrumentation and automation. Unprecedented advances in information and communications technologies coupled to globalization and sustainability imperatives are providing new tools and techniques for managing complex industrial systems.

Asset Management involves the strategic tenets of planning, decision-making and control of resources. Maintenance is a critical function for successful implementation of strategy for managing engineered assets. Maintenance is intertwined with operating complex industrial systems inasmuch as it informs the tactical aspects of managing engineered assets.

The emergence of big data analytics, Internet of things, and associated industry platforms and networks significantly accentuates the application of artificial intelligence techniques towards various models of the maintenance function. Such advanced models of the maintenance function are necessary to enhance the tactical and practical implementation of strategies for managing complex industrial systems.

This book extends an earlier publication by Adolfo Crespo Márquez in 2007. It covers recent research work of the SIM research group that focus on the demand for ever-increasing reliability and availability of industrial components, equipment,

plants, processes and systems. The numerous industrial case studies discussed in the book constitute an invaluable resource for practitioners, researchers, and academics.

January 2017

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Preface

Overview

The aim of this book is to continue with the development of a framework for maintenance and assets management that has been promoted by the SIM group over the years (the reader can find the seminal work regarding the referred management framework in Springer: Crespo Márquez 2007). To that end, this manuscript describes new advanced models, methods and techniques, which can be applied at different stages of the originally proposed management process, as well as their practical implementation. During the last 15 years, among other research activities, the SIM group has:

- Published 13 books (4 with Springer-Verlag and 2 with IGI Global, 2 in Chinese with Machinery Industry Press and National Defense Industry Press, 1 in Farsi with the University of Tehran, and 4 in Spanish with AENOR [2], INGEMAN and ETSI Sevilla), and coordinate other 3 books more (two from an international conference and other from the national research network on assets management)
- Authored 75 chapters in scientific books and 104 research articles of which 75 are articles in international journals and 45 are published in the JCR.
- Made more than 80 contributions in congresses of which 65 are international.
- Directed 11 Ph.D. works and over 150 Master Thesis.
- Opened international connections with many universities around the world.
- Evaluated research projects for national and international research agencies (Swedish, Canadian and Italian, among others).
- Developed research lines related to:
  - Asset Management
  - Maintenance Engineering and Management
  - Supply Chain Management and Logistics
  - Simulation and Analysis tools.

In the SIM group we realize that asset management, once considered a tactical area, is now a matter of strategy, given the implications it has for the proper

development of the business policy. In addition, the introduction of advanced manufacturing techniques and new production management systems, which lead to increased automation and reduced delivery times, has given great importance to asset management. In manufacturing, production, finance, etc., decisions are increasingly taken based on models or techniques which provide satisfactory, objective decision making, which guarantees improved competitiveness, reducing risk and uncertainty, and that can be justified to management. However, maintenance managers have taken decisions based only on their experience or supported by the advice of system sales staff or consultants. This lack of models and techniques in the area of asset management leads to underperforming maintenance departments characterized by a reactive approach, underutilized maintenance information systems, inaccurately managed costs, no scheduled maintenance hours, feedback on work quality not being provided, etc. Hence, this book looks to promote and address the application of objective and effective decision-making in asset management based on mathematical models and practical techniques that can be easily implemented in organizations.

Summary of Topics and Target Audience

The relevance of maintenance in organizations has increased considerably over the last two decades; this importance is linked to the introduction of a growing number of factors with an influence on the effective and efficient asset management. The existence of increasingly complex equipment and processes, the increase in the number of assets, the speed of technological change, the need to reduce costs in the modern world, together with increases in the level of excellence of commercial goals such as quality and delivery time, and concern for the safety of workers and the environment, make asset management an important source of benefits and competitive advantages for present and future world class enterprises. This book analyses these factors, which are divided into, although not limited to, the following categories:

- Maintenance policy selection.
- After-sales management.
- Knowledge management.
- Critical asset and infrastructure management.
- Asset life cycle management.
- Performance measurement system.
- Sensors and health monitoring systems.
- Reliability centred maintenance.
- Building information modelling.
- Advanced maintenance techniques.
- Set-up processes analysis.

Industrial and manufacturing engineers, managers and plant supervisor, academicians, researchers, advanced-level students (both postgraduate and doctoral),

technology developers and managers who take decisions in this field will find in this book a source of ideas, models and techniques which mark out a path for future research in this field and may also serve to encourage original ideas and in many cases practical application in business. This book is aimed at the above-mentioned target audience worldwide and because of the number of chapters it contains and the variety of the subjects analysed, it provides an in-depth look at current global concerns.

Background Material and Origin of Each Chapter

The content of the book is divided into seven parts. Briefly, each part deals with the following matters:

- The first part is an introduction to the topic and to the manuscript.
- The second part presents new possible evolutions in the current assets management framework, according to new standards, techniques and technologies.
- The third part contains advanced tools to improve effectiveness of management, especially under modern dynamic scenario considerations.
- The fourth part includes methods for the improvement of management efficiency, which benefit of a more affordable online information availability regarding assets' conditions.
- The fifth part present innovative techniques to easy management control, providing also a more practical approach to maintenance activities accountability.
- The sixth part compiles new efforts in continuous improvements using artificial intelligence tools mixed with advanced interoperability of the information systems. At the same time explore advance analysis of different operational possibilities to improve assets management.
- Finally, the seventh part is devoted to summarize conclusions and to infer future developments.

Different research results of the SIM group, over the last 5 years, are serving as the main basis and background for the mentioned parts.

Table 1 explicitly mentions the publication linked to each book chapter.

At the same time, each chapter has been developed by a group of authors (some belonging properly to the SIM Research Group, and other assiduous collaborators with the group), whose relevance in the field of asset management has been manifested for years. A brief biographical note of each one of them is shown in the section List of Contributors. Additional information about the contributions in the book can be found in the Intelligent Maintenance Systems Group (SIM) web site (University of Seville) at http://taylor.us.es/sim.

Table 1 Link between chapters and published references

Chapter	Title	Original reference
1	On the Family of Standards UNE-ISO 55000 and How to Effectively Manage Assets	Sola Rosique et al. (2015)
2	A Maintenance Management Framework Based on PAS 55	López-Campos and Crespo Márquez (2011)
3	The Integration of Open Reliability, Maintenance and Condition Monitoring Management Systems	López-Campos et al. (2013)
4	Prognostics and Health Management in Advanced Maintenance Systems	Guillén et al. (2016a)
5	A Framework for Effective Management of CBM Programs	Guillén et al. (2016b)
6	Criticality Analysis for Maintenance Purposes	Crespo Márquez et al. (2015)
7	AHP Method According to a Changing Environment	González-Prida et al. (2014)
8	Reliability Stochastic Modelling for Repairable Physical Assets	Viveros et al. (2016)
9	Economic Impact of a Failure Using Life-Cycle Cost Analysis	Parra et al. (2012)
10	Online Reliability and Risk to Schedule the Preventive Maintenance in Network Utilities	Crespo et al. (2013)
11	Customer-oriented Risk Assessment in Network Utilities	Gómez et al. (2016a)
12	Dynamic Reliability Prediction of Asset Failure Modes	Gómez et al. (2016b)
13	A Quantitative Graphical Analysis to Support Maintenance	Barberá et al. (2012)
14	Case Study of Graphical Analysis for Maintenance Management	Barberá et al. (2013)
15	A Graphical Method to Support Operation Performance Assessment	Viveros et al. (2015)
16	Value-Driven Engineering of e-maintenance Platforms	Macchi et al. (2014)
17	Assistance to Dynamic Maintenance Tasks by Ann-Based Models	Olivencia et al. (2015)
18	Expected Impact Quantification Based on Reliability Assessment	Kristjampoller et al. (2016)
19	Influence of the Input Load on the Reliability of the Grinding Line	Barberá et al. (2014)

The a.m. references are detailed in Chapter "On the Family of Standards UNE-ISO 55000 and How to Effectively Manage Assets"

Conclusions

As introduced at the beginning of this preface, this book looks to promote and address the application of objective and effective decision-making in asset management based on mathematical models and practical techniques that can be easily implemented in organizations. This comprehensive and timely publication aims to be an essential reference source, building on the available literature in the field of asset management while providing for further research breakthroughs in this field. This text provides the necessary resources for managers, technology developers, scientists and engineers to adopt and implement optimum decision-making based on models and techniques that contribute to recognizing risks and uncertainties and, in general terms, to the important role of asset management to increase competitiveness in organizations.

Seville, Spain

Adolfo Crespo Márquez
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Reference

Crespo Márquez A (2007) The maintenance management framework. Models and methods for complex systems maintenance. Springer Series in Reliability Engineering. ISBN: 978-1-84628-820-3

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The 5th of April 2016, Professor Marco Garetti passed away. Marco was Full Professor of Industrial Technology at the Department of Management, Economics and Industrial Engineering of Politecnico di Milano, Italy. As a visionary in the area of asset management and maintenance, he devoted a great deal of effort to the creation of an international community of scholars and researchers in this area. Marco was always a person very close to our research group in Spain and helped very significantly in the international dimension of our work, which can be appreciated in this book. At the time of publishing this book we want to leave in writing our deep recognition of Marco's professional work and effort, and our profound appreciation for his exceptional support and friendship for so many years.

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To all of them, thanks.

Contents

Editors and Contributors

About the Editors

Adolfo Crespo Márquez is currently Full Professor at the School of Engineering of the University of Seville, and Head of the Department of Industrial Management. He holds a Ph.D. with Honours in Industrial Engineering from this same University. His research works have been published in journals such as Reliability Engineering and System Safety, International Journal of Production Research, International Journal of Production Economics, European Journal of Operations Research, Omega, Decision Support Systems and Computers in Industry, among others. Prof. Crespo is the author of eight books, the last five with Springer-Verlag (2007, 2010, 2012, 2014) and Aenor (2016) about maintenance, warranty, supply chain and assets management. Professor Crespo is Fellow of ISEAM (International Society of Engineering Assets Management) and leads the Spanish Research Network on Assets Management and the Spanish Committee for Maintenance Standardization (1995–2003). He also leads the SIM (Sistemas Inteligentes de Mantenimiento) research group related to maintenance and dependability management and has extensively participated in many engineering and consulting projects for different companies, for the Spanish Departments of Defense, Science and Education as well as for the European Commission (IPTS). He is the President of INGEMAN (a National Association for the Development of Maintenance Engineering in Spain) since 2002.

Vicente González-Prida Díaz holds a Ph.D. with Honours in Industrial Engineering by the University of Seville, and Executive MBA (First Class Honours) by the Seville Chamber of Commerce. He also has been awarded with the National Award for Ph.D. Thesis on Dependability by the Spanish Association for Quality; the National Award for Ph.D. Thesis on Maintenance by the Spanish Association for Maintenance; and the Best Nomination from Spain for the Excellence Master Thesis Award bestowed by the EFNSM (European Federation of National Maintenance Societies). Dr. González-Prida has authored a book with Springer Verlag about Warranty and After Sales Assets Management (2014) and many other publications in relevant journals, books and conferences, nationally and internationally. His main interest is related to industrial asset management, specifically the reliability, maintenance and life cycle organization. He currently works as Project Manager in the company General Dynamics-European Land Systems and shares his professional performance with the development of research projects within the SIM (Sistemas Inteligentes de Mantenimiento) research group in the Department of Industrial Organization and Management at the University of Seville and teaching activities in Spain and Latin-America.

Juan Francisco Gómez Fernández is Ph.D. in Industrial Management and Executive MBA. He is currently part of the SIM research group of the University of Seville and a member in knowledge sharing networks about Dependability and Service Quality. He has authored a book with Springer Verlag about Maintenance Management in Network Utilities (2012) and many other publications in relevant journals, books and conferences, nationally and internationally. In relation to the practical application and experience, he has managed network maintenance and deployment departments in various national distribution network companies, both from private and public sector. He has conducted and participated in engineering and consulting projects for different international companies, related to Information and Communications Technologies, Maintenance and Asset Management, Reliability Assessment, and Outsourcing services in Utilities companies. He has combined his professional activity, in telecommunications networks development and maintenance, with academic life as an associate professor (PSI) in Seville University, and has been awarded as Best Master Thesis on Dependability by National and International Associations such as EFNSM (European Federation of National Maintenance Societies) and Spanish Association for Quality.

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On the Family of Standards UNE-ISO 55000 and How to Effectively Manage Assets

Adolfo Crespo Márquez, Antonio Jesús Guillén López, Antonio Sola Rosique and Carlos Parra Márquez

Abstract The publication of the ISO 55000 family of standards on asset management is surely a very important event for many economic activity sectors, especially for those that are very intensive in capital investments devoted to physical assets. Although the standards set a framework for the requirements to fulfill in order to manage assets properly, companies, and organizations in general, need to know how to reach those requirements. What are the necessary steps to follow and the supporting structure that needs to be built in order to develop a proper, consistent and competitive assets management process and system? This chapter links ISO 55000 requirements to the assets management framework promoted by the authors, and at the same time, links the models presented in the different chapters of the book, with specific elements of the standards.

Keywords Assets management · Management framework · Management supporting structure · Maintenance engineering techniques

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1 Introduction

The ISO 55000 family of standards on asset management has just been published. These are three documents that present the minimum requirements on good practices to establish, implement, maintain and improve the management of any type of asset in organizations. They also offer a strategic approach to incorporate operations and maintenance applications, and thus improve asset availability and utilization. The benefits of asset management in organizations, with a focus on achieving value over the asset life cycle, are solidly proven in many industries and business environments. In addition, it demonstrates organizations' commitment to quality, performance or safety, helping to mitigate the legal, social and environmental risks associated with accidents in industrial facilities.

The recent publication of the family of ISO 55000 Standards on Asset Management (AM) aims to support a management oriented to obtain value of the assets. This is the ISO 55000 Asset Management. General aspects, principles and terminology, which provides a broad view of what AM represents; ISO 55001 Asset management. Management systems. Requirements, which specifies the requirements for establishing an AM system (see Fig. 1); and ISO 55002 Asset Management. Management systems. Guidelines for the implementation of ISO 55001, which provides guidance for the application of that standard. Thus, it presents in a generic way the minimum requirements on good practices to establish, implement, maintain and improve the management of any type of asset, establishing a strategic approach to incorporate operations and maintenance applications to improve the availability and use of assets. These requirements apply to all stakeholders, allowing to measure and show the organization's ability to meet legal, regulatory and contractual requirements, as well as those of the organization.

Standard ISO 55001 does not define "how" to carry out such good practices. And this will depend on the context of the organization itself and the assets to be managed. In addition, it will in the future be a source of development for the different business areas and types of assets in the interpretation and application of the requirements established by the standard. The formal recognition through the standard of what needs to be done (elements and requirements), for the coordination and maintenance of good practices, is the basis for organizing the processes and achieving the goals set.

It helps organizations realize even more the value of their assets, enabling them to demonstrate their ability to control risks, reliability of their plants, loss mitigation and unplanned outages. In short, the purpose of this series of standards is to provide a model for the creation and operation of an Asset Management System (AMS). This system can be integrated (see Fig. 2) with other management systems, such as quality, environment or safety.

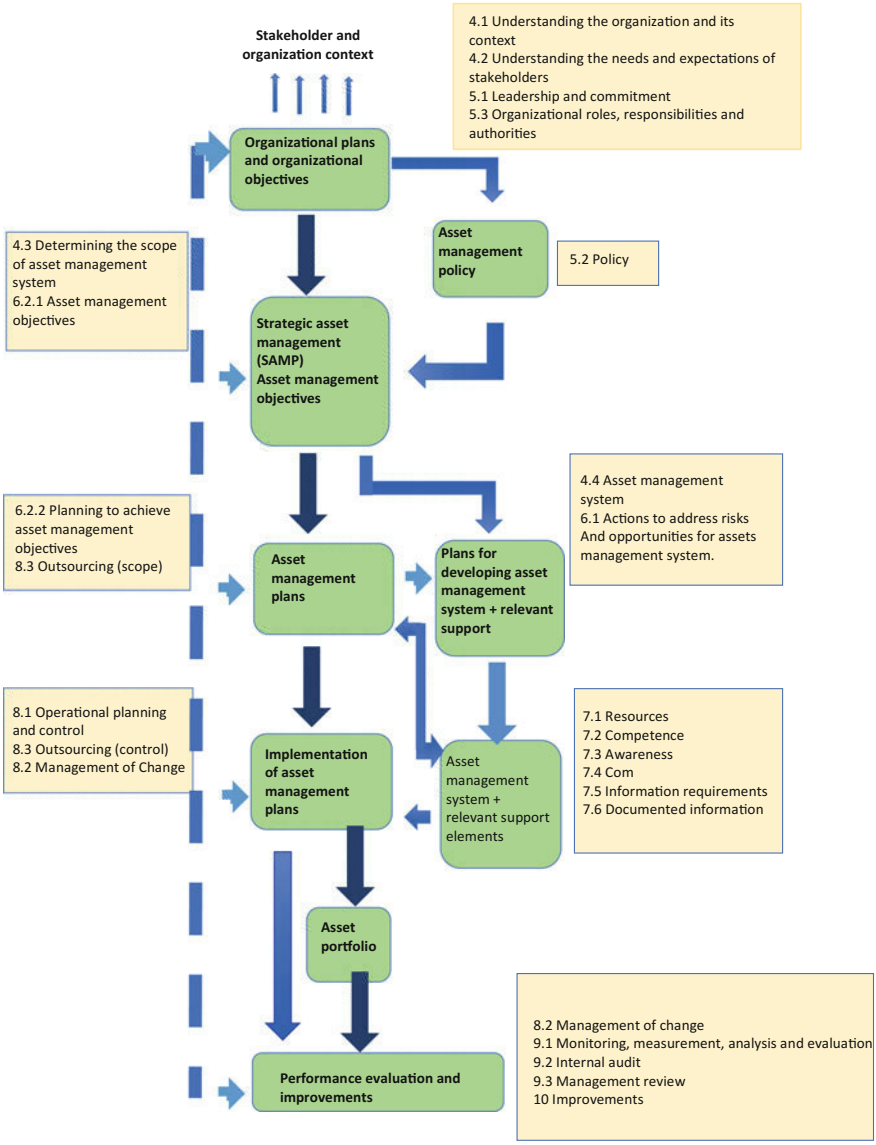

Fig. 1 Relationship between key elements of an asset management system

2 Principles Promoted by the Standards

Among the central themes of the ISO 55000 Standards family are the concepts of value creation and risk-based decision-making, considering four fundamental principles. That is, alignment of the objectives of the company, from the top leaders

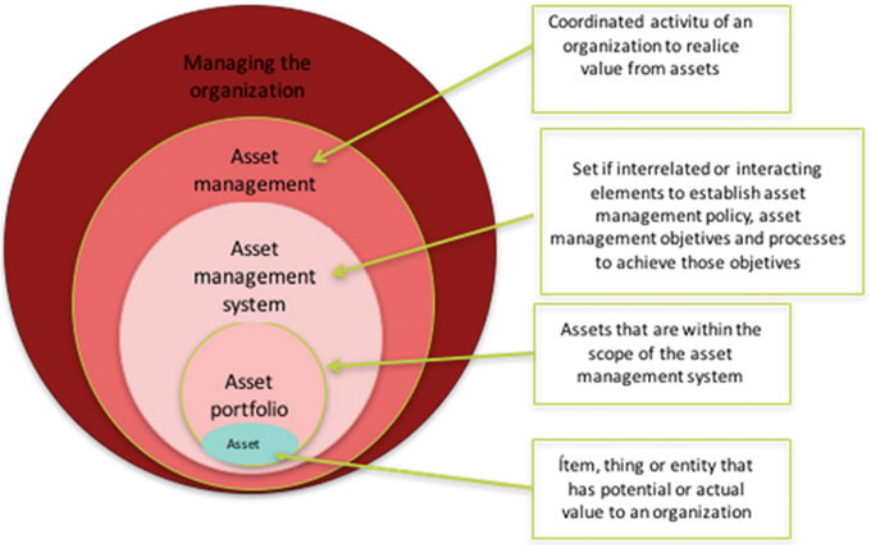

Fig. 2 Relationships between key terms: Integration the assets management with other systems of the organization

of the organization to the technicians responsible for the day-to-day operation of the assets; transparent and consistent decision-making, seeking a balance between potentially conflicting initiatives and limited resources; risk participation in the decision-making process; and balancing long-term asset requirements with short-term business planning cycles.

Emphasis is placed on value creation, but with a focus on the idea and long-term strategy since the duration of the assets can be much greater than the strategic plan of the corporation. Better knowledge of assets helps in making operational decisions and in understanding the performance of the organization in general. It also emphasizes stakeholder engagement as well as alignment with business finance and accounting. The standard ISO 55001: 2014 describes the requirements of the system emphasizing "what needs to be done" and not "how to do it", based on the following elements: organization, context, leadership, planning, resources and support, operation, evaluation, performance, and improvement.

It is important to consider that the application and use of this standard presents certain challenges for its implementation in the different organizations. To a great extent, these challenges are linked to the maturity of their systems and processes of the organization, since a high level of integration, harmonization, and coordination of functions between engineering, operations, maintenance, and the commercial part of the business is required for good management. In this sense, it is necessary to emphasize the "culture" in the use of Management Systems. This will be the main challenge in organizations with no prior experience in these systems. Also, if the organization has competent personnel, since even mature organizations will

have to acquire competencies to evaluate the processes and the Asset Management System. In addition, it is necessary to interpret the standard to adapt its generalist approaches to the particularities of the business to which it applies. Finally, leadership commitment is essential, requiring the involvement of top management from the beginning of the implementation process of an Asset Management System.

As a result, the ISO 55000 family of standards offers important opportunities for asset owners to re-examine and refine their management model. It also helps to improve relationships with service providers and customers, governance of the management model, regulatory frameworks, and stakeholder trust. The benefits that the improved of asset management contribute, with an integrated approach to value across the asset life cycle, are solidly proven in many industries and business environments, improving the quality of life through contributing to safety, human health and environmental protection while demonstrating the organization's commitment to quality, performance or safety and helping to mitigate the legal, social, and environmental risks associated with accidents in industrial facilities.

3 Integration of a Maintenance Management Model (MMM) with the Asset Management Standard ISO 55000

Although there are no simple formulas for the implementation of an integral model of management of asset, nor fixed or immutable rules with validity and applicability for all the assets of production, the requirements needed by the proposal of standard ISO 55000 can be covered by the integral maintenance management model (Fig. 3) proposed at the beginning of this report. In the MMM, composed of eight phases, specific actions are described to follow in different steps of the process of management of maintenance that are integrated in a direct form within a process of management of assets [4]. The MMM offers a dynamic, sequential process and in a closed loop that tries to accurately characterize the course of actions to be carried out to ensure the efficiency, effectiveness and continuous improvement of the management of assets from the use and integration of techniques of engineering and maintenance management and reliability.

In particular, in Table 1, a relationship is made between the 8 phases of the model proposed and the general points of the standard ISO 55000, so that the gradual implementation of the generic model progressively covering the requirements of the standard ISO 55000 may be looked at. According to 1, the activities to be developed within the eight stages of the MMM can help organizations, to meet with the 24 requirements demanded by the standard ISO 55000. The following describes in more detail the relationship between the phases of the MMM and the requirements of ISO 55000.

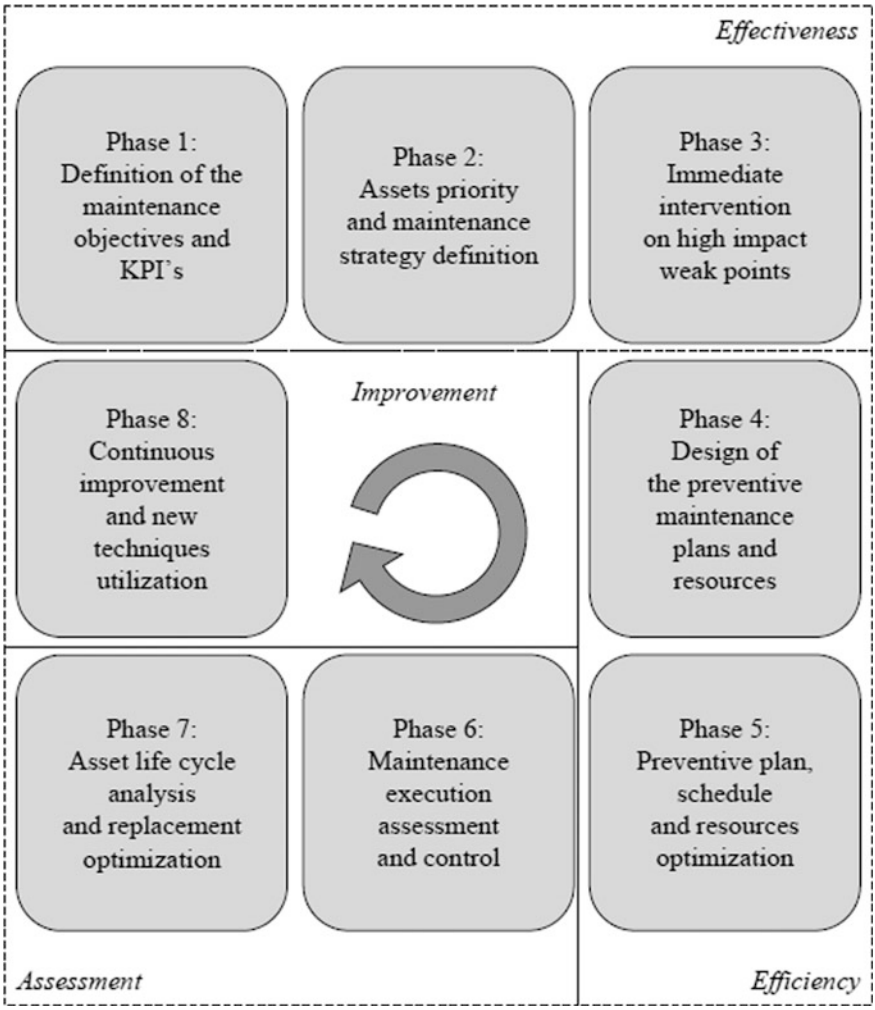

Fig. 3 Model of the process of maintenance management (MMM) integrated into ISO 55000 Crespo Márquez [4]

According to Table 2, out of the 24 requirements defined by the standard ISO 55000, the maintenance management model (MMM) can help us totally or partially meet the demands of the requirements expected by this standard (the proposal of standard PAS 55 represents the most important background of standard ISO 55000).

Table 1 Relationship between the phases of the maintenance management model (MMM) proposed and the requirements of ISO 55000 [18]

ISO 55000 requirements	Integration of the phases of the MMM proposed with standard ISO 55000
4. Context of the organization 4.1. Understanding the Organization and its context 4.2. Understanding the needs and expectations of interested parties 4.3. Determining the extent of the asset management system 4.4. system of management of assets 5. Leadership 5.1. Leadership and commitment 5.2. Policies 5.3. Roles, organizational responsibilities and authorities	Phase 1. Proposes the use of the scorecard (balanced Scorecard—BSC), proposed by Kaplan and Norton, model that translates the mission of a business unit into its strategy in a set of objectives and quantifiable measures. By implementing the BSC, organizations get to: 1. Formulate policies and strategies for the operation and performance of the maintenance of assets throughout their lifecycle 2. Put into practice the strategies of maintenance and operation, which is translated into objectives at short, medium and long term 3. Develop the plans of action. These are the means to get to the purposes stipulated in the objectives set out in step (2) 4. Establish leadership in the different processes to improve in all areas of the Organization 5. Review and periodically audit the performance of implemented strategies. Monitoring will be made and the casual relations between the measures will be investigated what will be validated at intervals previously established and plans of contingency will be defined Additionally in phase 1, the MMMC model proposes that an cohesive organization is designed which supports the process of asset management and is able to implement a holistic process optimization based on the application of techniques of reliability and maintenance, with the assignment of roles, responsibilities, and definition of the leadership of all the activities to be developed during the lifecycle of the asset Phase 2. Proposes the use of models of prioritization, which must comply and align with the expectations of stakeholders (interested parties) and at the same time, cover the legal requirements demanded by the environment of the asset

(continued)

Table 1 (continued)

ISO 55000 requirements	Integration of the phases of the MMM proposed with standard ISO 55000
6. Planning 6.1. Actions to address the risks and the opportunities in the system of management of assets 6.2. Objectives for the management of assets and planning to achieve them 7 Support 7.1. Resources 7.2. Competencies 7.3. Awareness 7.4. Communication 7.5. Requirements of information 7.6. Documented information	Phase 2. Proposes at the beginning of a process of improvement, the development and the application of basic models of prioritization of assets based on the analysis of the risk factor (example: qualitative and technical matrix of risks AHP: Analytics Hierarchy, Process, etc.) Phase 3. Proposes the use of the methodology of root cause analysis (RCA) to assess the failures of major impact events, taking as a basis for the definition of solutions, the level of risk caused by failure events to be analyzed Phase 4. Proposes the use of methodology of reliability-centered maintenance (RCM) to optimize maintenance and operation depending on the level of risk plans that generate failures within the context of the operational modes Phase 5. Proposes the use of methods of optimization to be used in the programming and allocation of resources for maintenance and operations. Within the selected methods are the techniques related to processes such as risk analysis: theory of queues, Monte Carlo simulation and probabilistic techniques of point of order from inventory Additionally, at this stage, using continuous improvement methods is proposed in the programming, planning and allocation of resources for maintenance and operations, risk management-based Phase 8. Proposes the use of the systems of information support (ERP, EAM, software of reliability, etc.), to manage and disclose all the documentation and information to be generated by the different assets in their processes of operation and maintenance. The information systems for the management of assets are key tools for their ability to support and facilitate their management, thanks to the transmission and processing of information at high speeds and quantities exceeding the organizations´ own borders and strengthening the convergence among sectors. The need for a correct implementation of the support for the management of information systems is the basis for the development of programs to improve reliability, maintenance and operations

(continued)

Table 1 (continued)

ISO 55000 requirements	Integration of the phases of the MMM proposed with standard ISO 55000
8. Operation 8.1. Operational planning and control 8.2. Change management 8.3. Outsourcing 9. Evaluation of performance 9.1. Monitoring, measurement, analysis and evaluation 9.2. Internal audit 9.3. Revision of the management	Phase 1. Proposes the use of the Balanced Scorecard-BSC table to measure and review the indicators of economic performance of the Organization and subsequently, integrate them with the technical indicators of operation and maintenance (technical indicators that are developed in phase 6). Additionally, in this phase 1, the use of audits of control and continuous improvement was proposed among which is found: MES (Maintenance Effectiveness Survey), QMEM (Qualitative Matrix of Excellent in Maintenance), etc. Phases 3 and 4. Propose the application of reliability as the RCA and the RCM methods that allow evaluating modes of failure and determine their causes. These methods help to determine the incidents and non-conformities, allow to evaluate the consequences that the failures can cause on safety, the environment and operations and additionally, these techniques propose procedures that help to define actions of improvement and control: corrective, preventive, of redesign and by condition Phases 5. Proposes the application of methods of optimization of maintenance and reliability engineering, which would help to define the processes of planning, programming, outsourcing and the level of training necessary to improve the management of assets in their lifecycle Phase 6. Offers a comprehensive process of measurement, analysis and evaluation of indicators of performance and improvement (indicators of probabilistic assessment: reliability, maintainability, availability, cost and risk) Phase 8. Proposes to establish a process of continuous improvement which should be able to register and to adjust to the constant changes related to techniques and emerging technologies in areas that are considered of high impact as a result of the studies carried out in the previous 8 phases of the proposed maintenance management model

(continued)

Table 1 (continued)

ISO 55000 requirements	Integration of the phases of the MMM proposed with standard ISO 55000
10 Improvement 10.1. Non-conformity and corrective action 10.2. Preventive action 10.3. Continuous improvement	Phase 2. Proposes at the beginning of a process of improvement, the development and application of basic models of prioritization of assets based on the analysis of the risk factor (example: technical and qualitative risk matrix AHP: Analytics, Hierarchy, Process, etc.) Phase 3. Proposes the use of the methodology of analysis cause root (RCA: Root Cause Analysis) to evaluate them events of failures of greater impact, taking as base for the definition of solutions, the level of risk caused by them events of failures to be analyzed (processes of not conformity and actions corrective) Phase 4. Proposes the use of the reliability-centered (RCM) maintenance methodology, to optimize maintenance and operation depending on the level of risk plans that generate the modes of failures within the operational context (preventive action) Phase 5. Proposes the use of methods of optimization to be used in the programming and allocation of resources for maintenance and operations. Selected methods techniques include related processes such as risk analysis: theory of queues, Monte Carlo simulation and probabilistic techniques of point of order from inventory Phase 6. Proposes a holistic process of probabilistic evaluation of the indicators of: reliability, maintainability, availability, cost and risk Additionally, in this phase a procedure is explained that allows to relate the indicators of reliability and maintainability, with decisions of optimization in the areas of maintenance and operation based on techniques of cost risk benefit analysis (continuous improvement) Phase 7. Proposes a process of cost analysis of life cycle that allows optimizing decision-making associated with the processes of design, selection, development and replacement of assets that make up a production system. The process of life cycle begins with the definition of the different tasks of production for the preliminary design. Then activities are developed such as: plan of production, layout of plant, selection of equipment, definition of processes of manufacturing and other similar activities. Subsequently, prior to the design phase logistics is considered. This phase involves the development of the necessary support for the design and the different stages of production, the possible user support, maintenance plan intended for the use of the asset and the process of divestiture of assets (continuous improvement) Phase 8. Proposes establishing a process of continuous improvement which must be capable of reviewing and evaluating the technical and economic performance of the Organization in a continuous way

Table 2 Link between parts and published references

Part	References
Part I: Introduction	Sola Rosique, Antonio, Crespo Marquez, Adolfo, Guillen Lopez, Antonio Jesus [19]. Bases para la mejora de la gestión de activos en las organizaciones. Industria Química
Part II: A changing asset management framework	López Campos, Mónica Alejandra, Crespo Marquez, Adolfo [13]. Modelling a maintenance management framework based on PAS 55 standard. Quality and Reliability Engineering International
	López-Campos, Mónica Alejandra; Crespo-Marquez, Adolfo; Gómez-Fernández, Juan Francisco [14]. Modelling using UML and BPMN the integration of open reliability, maintenance and condition monitoring management systems: An application in an electric transformer system. Computers in industry
	Guillén A.J., Crespo A., Macchi M., Gómez J [10]. On the role of Prognostics and Health Management in advanced maintenance systems, Production Planning and Control (In printed)
	Antonio J. Guillén, Juan Francisco. Gómez, Adolfo Crespo [11]. Framework for effective management of CBM programs. Computers in Industry
Part III: Pursuing high management effectiveness in a dynamic environment	Adolfo Crespo Márquez, Pedro Moreu de León, Antonio Sola Rosique, Juan F. Gómez Fernández [5]. Criticality Analysis for Maintenance Purposes: A Study for Complex In-service Engineering Assets. Quality and reliability engineering international
	González-Prida, Vicente; Viveros, Pablo; Barberá-Martínez, Luis; Crespo-Marquez, Adolfo [9]. Dynamic Analytic Hierarchy Process: Ahp Method Adapted To A Changing Environment. Journal of Manufacturing Technology Management
	P. Viveros, A. Crespo, R. Tapia, F. Kristjanpoller, V. González-Prida [20]. Reliability Stochastic Modeling for Repairable Physical Assets. Case study applied to the Chilean Mining. DYNA, 91(4). 423–431. doi:http://dx.doi.org/10.6036/7863
	Carlos Parra, Adolfo Crespo, Fredy Kristjanpoller, Pablo Viveros [17]. Reliability stochastic model applied to evaluate the economic impact of the failure in the life cycle cost analysis (LCCA). Case Study for the Rail Freight and Oil Industries. Proc IMechE Part O: Journal of Risk and Reliability. 226(4) 392–405, DOI:10.1177/1748006X12441880

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Table 2 (continued)

Part	References
Part IV: Advanced methods and techniques to improve management efficiency	Crespo-Marquez, Adolfo; Gómez-Fernández, Juan Francisco; Moreu-De Leon, Pedro; Sola-rosique, Antonio [6]. Modelling on-line reliability and risk to schedule the preventive maintenance of repairable assets in network utilities. IMA journal of management mathematics
	Juan F. Gómez Fernández, Adolfo Crespo Márquez, Mónica A. López-Campos [8]. Customer-oriented risk assessment in network utilities Reliability Engineering and System Safety 147 (2016) 72–83
	J.F. Gómez Fernández, F. Olivencia, J. Ferrero, A. Crespo Márquez, G. Cerruela García [7] Analysis of Dynamic Reliability Surveillance: a Case Study. IMA Journal of management Mathematics
Part V: The need for innovation in assessment and control	Barberá Martínez, Luis; Crespo Marquez, Adolfo; Viveros Gunckel, Pablo; Arata Andreani, Adolfo [2]. The Graphical Analysis for Maintenance Management Method: A Quantitative Graphical Analysis to Support Maintenance Management Decision Making. Quality and Reliability Engineering International
	Barberá-Martínez, Luis; Crespo-Marquez, Adolfo; Viveros, Pablo; Stegmaier, Raúl [3]. Case Study of GAMM (Graphical Analysis For Maintenance Management) in the Mining Industry. Reliability Engineering and System Safety
	Viveros, Pablo, Crespo Marquez, Adolfo, Barberá Martínez, Luis, Gonzalez, Juan Pablo [21]. Graphical Analysis for Operation Management: A Graphical Method to Support Operation Decision Making. Quality and Reliability Engineering International
Part VI: Continuous improvement through emergent process and technologies	Macchi, Marco; Crespo-Marquez, Adolfo; Holgado-Granados, María; Fumagalli, Luca; Barberá-Martínez, Luis [15]. Value-Driven Engineering of E-Maintenance Platforms. Journal Of Manufacturing Technology Management
	Olivencia, Fernando, Ferrero, Jesus, Gómez Fernández, Juan Francisco, Crespo Marquez, Adolfo [16]. Failure mode prediction and Energy forecasting of PV plants to assist dynamic Maintenance tasks by ANN based models. Renewable Energy
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	Barberá Martínez, Luis, Viveros, Pablo, Mena, Rodrigo, Gonzalez-Prida Diaz, Vicente [1]. Influence of the Input Load on the Reliability of the Grinding Line. Dyna