A Maintenance Management Framework Based on PAS 55

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Abstract This chapter shows the process of modelling a reference maintenance management framework (MMF) that represents the general requirements of the asset management specification PAS 55. The modelled MMF is expressed using the standardized and publicly available Business Process Modelling languages UML 2.1 (Unified Modelling Language) and BPMN 1.0 (Business Process Modelling Notation). The features of these notations allow to easily integrate the modelled processes into the general information system of an organization and to create a flexible structure that can be quickly and even automatically adapted to new necessities. This chapter presents a brief review about the use of UML in maintenance projects, general characteristics of PAS 55, modelling concepts and theirs applications in the project of modelling the MMF. The arguments underlying the methodology and the choice of UML and BPMN are exposed. The general architecture of the suggested MMF is described and modelled through diagrams elucidating the general operation of PAS 55. From this development is appreciated the operation structure of a software tool that can incorporate MIMOSA standards and that can be made suitable to e-maintenance functions, as an alternative from the commercial systems. Finally, some conclusions about the modelled framework are presented.

Keywords Maintenance · Framework · Standard · UML · PAS 55

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1 Introduction

Regarding to asset management, maintenance has been experiencing a slow but constant evolution across years, from the earlier concept of "necessary evil" [1] up to being considered an integral function to the company and a way of competitive advantage [2].

For approximately three decades, companies realized that if they wanted to manage maintenance adequately it would be necessary to include it in the general scheme of the organization and to manage it in interaction with other functions [3].

Implanting a high-quality model to drive maintenance activities, embedded in the general management system of the organization, has become a research topic and a fundamental matter to reach effectiveness and efficiency of maintenance management and to fulfil enterprise objectives [4].

On the other hand, it is known that for a significant number of organizations every activity or important action realized has its reflection on its information system. This means that the enterprise information system is a basic element to consider for the implementation of a maintenance management system. In fact, the most desirable situation is the complete integration of the maintenance management operations into the general information system [5].

To deal with the mentioned integration of maintenance management and enterprise information systems this research proposes the use of the BPM (Business Process Management) methodology, which aim is to improve efficiency through the management of business processes that are modelled, automatized, integrated, controlled and continuously optimized [6]. BPM involves managing change in a complete processes life cycle.

By adopting the BPM methodology it is possible to model a particular maintenance management process and afterwards "connect" this model with a general information system.

In this way, a flexible management process can be created. If it was necessary to modify the management process to adapt its activities to new necessities, it would be quickly and even automatically modified into the enterprise information system [7].

UML and BPMN are the internationally standardized languages used in BPM methodology. A review of the literature of the last 10 years revealed that some maintenance applications expressed using UML already exist, but the majority of those specific applications are designed only for monitoring and/or diagnosis. An integral maintenance management framework (MMF) expressed using an approach to business process modelling (UML and BPMN) is an innovative project. It is also, more innovatory because the approach of the model to the PAS 55 standard.

This chapter presents the process of modelling a MMF, aligned to the asset management specification PAS 55:2008 [8] and expressed using UML and BPMN. Several ICT (information and communication technologies) proposals for the implementation of this project are explained at the end of the paper.

2 The Use of UML and BPMN Languages in Maintenance

The use of UML and BPMN standards in maintenance is relatively new and it is an expanding area. During the past years, the most used modelling standards were IDEF (Integration DEFinition), RAD (Role-Activity Diagrams), EXPRESS-G or STEP (Standard for the Exchange of Product model data).

As a literature review of maintenance developments employing UML and/or BPMN revealed, it is just since 2000 when UML began to be mentioned in maintenance projects [9]. When the noticeable advantages of UML and BPMN as internationally standardized modelling languages got more recognition, the number of maintenance projects using them began to increase. This growth is referred particularly to the use of UML, and specially for developing e-maintenance applications.

This literature review was performed covering the maintenance projects published until September 2010 and it produced the following results:

- The first project found relating UML to a maintenance task appeared in 2000, and it was about a CBM system for e-monitoring applied to an electric system [9].
- The majority of the applications using UML are made in e-monitoring [10–13] and e-diagnosis [14–16].
- The electric and electronic industries, along with the transportation industry, lead the number of maintenance projects modelled using UML.
- Some other applications of UML have to do with several maintenance management areas, as the planning and control of repair operations [17–19], the design of specific information systems [20–22], the generation of optimal maintenance policies and decision-making processes [23], the use of knowledge management in the maintenance function [24, 25], or with the asset management [26].
- Ambitious e-maintenance projects like the fully integrated PROTEUS platform uses UML as well, to model its processes [27].
- The modelling of a MMF based on PAS 55 using UML and BPMN, is a not previously explored assignment in the reviewed literature.

3 General Characteristics of the MMF

In the historical development of maintenance, several authors have proposed what they consider the best practices, steps, sequences of activities or models to manage this function.

Different maintenance management models and frameworks have been developed by researchers as [4, 28–33] among many others, in an effort to create an structure with a set of characteristics that fulfils the maintenance and organizational objectives.

From an analysis made to those MMF proposals [34], some desirable characteristics were identified as necessary for a modern and efficient MMF oriented to operate with a quality system perspective: input–output processes approach, generation of documents and records, objectives entailment, possibility of incorporation of supporting technologies (CBM for example), orientation to operate integrated to computer maintenance management systems (CMMS), flexibility to adopt modern technologies (e-maintenance, expert systems, etc.), management of material, human and information resources, focus on the constant improvement, cyclical operation, generation of indicators (economics, efficiency, etc.), orientation to standards, among others.

Considering that a standard is by itself a norm or model widely recognized by its excellence, or a compendium of best practices, it is not a surprise that all the aforementioned factors among others have been identified as existing characteristics into the PAS 55 standard, basis and model of the MMF developed in this chapter.

PAS 55 is a Publicly Available Specification and it is the only standard available internationally for asset management. The management of assets deals with the whole life cycle of the asset, from its design until its final disposal; maintenance commonly only describes the activities during the operational life of the asset. Then it is possible to say that PAS 55 is a very complete reference to maintenance management.

PAS 55 can be applied to any business sector and is independent of asset type, but it is specially recommended to organizations strongly depending on the performance of the physical assets, as utility networks, power stations, roads, airports, railways, oil and gas installations, manufacturing and process plants, property and petrochemical complexes. The first version of PAS 55 was published in 2004 by the British Standards Institution (BSI). In 2008 a new version of PAS 55 was released, improving its content.

We can pronounce that the MMF modelled in this paper is a representation of PAS 55:2008. However, even if the presented MMF is strongly based on requirements of PAS 55, there are some remarks to make.

Firstly, the MMF does not exactly correspond to PAS 55:2008. Its elements have been arranged according to the experience of the authors in leading companies that actually operates with PAS 55 and inspired also, by the operation of the ISO 9001:2008 [35] model. The ISO standard was chosen since its spreading in industry [36], because it is the international reference for any quality management system, and hence it can be considered a generic guide for a process operation in which fulfilment with requirements should be demonstrated, such as the case of the maintenance function.

Secondly, the MMF suggests original flow processes for performing asset management (PAS 55 declares *what* have to be done, but not exactly *how* to do it). Part 2 of PAS 55 contains some recommendations and guidelines for the application of PAS 55 [37]. These recommendations jointly with the techniques referenced by other analysed models and previous works published by the authors [38, 39] gave rise to the internal algorithms and processes of the MMF.

Finally, the most noticeable originality of the MMF is that its structure is formalized in terms of processing models, flow models and data models using BPM techniques, UML and BPMN languages. This brings an important and distinctive feature of the MMF: flexibility to be adapted (for example as a software application) to new requirements.

At this point, it is important to mention that the purpose and requirements of PAS 55 are actually observed in the modelled MMF, regardless of the dissimilar organization of the elements into the proposed model and the use of UML and BPMN diagrams. The proposed MMF is not "an improvement" of PAS 55; it is just a representation of it.

In summary: the chapter proposes a MMF that represents the general requirements of the asset management specification PAS 55, and that it is expressed using the innovative approach to BPM (Business Process Modelling).

The general operation framework of the proposed MMF is presented in Fig. 1.

The model begins and finishes with the requirements and satisfaction of the stakeholders, using the concept proposed in maintenance management by Soderholm et al. [32] that is also in line with the ISO 9004:2000 standard [40]. Furthermore, the proposed model is designed to be efficiently used across the organization levels (reminding Pintelon and Gelders [3] who proposed a model to be executed in three organizational activity levels). This model is composed of four modules or macro-processes, each one containing several processes that are specified in sub-processes and tasks.

The four macro-processes are: System Planning, Resources Management, Implementation & Operation, and Assessment & Continual Improvement.

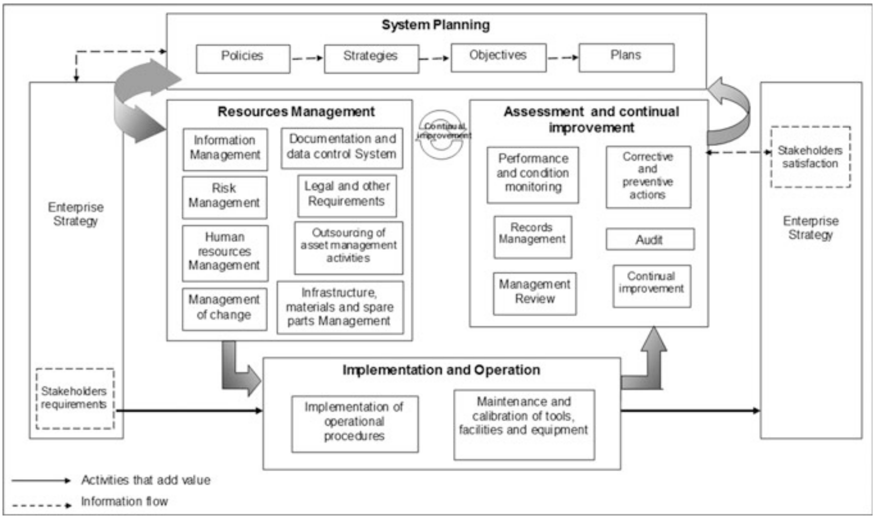

Fig. 1 The proposed maintenance management framework

The System Planning macro-process is constituted by four processes: Policies, Strategies, Objectives and Plans. The Resources Management processes are eight: Information Management, Risk Management, Human Resources Management, Management of Change, Documentation and Data Control System, Legal & Other Requirements, Outsourcing of asset management activities, and Infrastructure, Materials & Spare Parts Management. The Implementation & Operation macro-process is composed by the Implementation of Operational Procedures and by the Maintenance & Calibration of Tools, Facilities and Equipment processes. Finally, the Assessment & Continual Improvement macro-process is constituted by six processes: Performance & Condition Monitoring, Records Management, Management Review, Corrective & Preventive Actions, Audit, and Continual Improvement.

It is noticeable that the System Planning process entails the top Direction of Maintenance. In the presented MMF the medium levels perform the supporting processes (resources management) and control the maintenance execution. The level that executes maintenance also generates data to be used for the continuous improvement of the maintenance function.

The structure of this model enables a link among the maintenance function and the other organizational functions.

In the proposed model, each process (System Planning, Resources Management, Implementation & Operation and Assessment & Continual Improvement) is defined by UML diagrams using the "Eriksson-Penker Business Extensions" and BPMN diagrams that indicate the sequence of activities for the execution of every stage.

4 Business Process Modelling

According to Hammer and Champy [41], a (business process) is "a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer". Davenport [42] defines a (business) process as "a structured, measured set of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on how work is done within an organization, in contrast to a product focus's emphasis on what. A process is thus a specific ordering of work activities across time and space, with a beginning and an end, and clearly defined inputs and outputs: a structure for action".

The modelling of business process, understood as the use of methods, techniques and software to design, enact, control and analyse operational processes involving humans, organizations, applications, documents and other sources of information [43], has become an important subject specially since the 1990s, when companies were encouraged to think in "processes" instead of "functions" and "procedures". Process thinking looks horizontally through the company for inducing improvement and measurement [44].

From then on, business process modelling has been used in industry to obtain a global vision of processes by means of support, control and monitoring activities

[45], to facilitate the comprehension of the business key mechanisms, to be a base for the creation of appropriate information systems, to improve the business structure and operations, to show the structure of changes made in business, to identify outsourcing opportunities, to facilitate the alignment of the information and communication technologies with the business needs and strategies [46], and for several other activities such as the automatic processing of documents [47].

The increase in the last years of the quantity of research about business process modelling, and the application of recent technological advances have propitiated the use of business process modelling in other fields such as: planning of managerial resources (ERP), integration of managerial applications (EAI), management of the relations with customers (CRM), management of work flows (WFM) and communication among users to facilitate management requirements [45, 48].

Several benefits deriving from the adoption of business process modelling have been identified in the literature: improvement of the accomplishment speed of business processes, increase of the clients' satisfaction, optimization and elimination of unnecessary tasks, and incorporation of clients and partners in the business processes [49].

Process modelling is object of interest in many different fields, such as the managerial area and software engineering. This is due to the fact that it does not only describe processes, but in addition it represents a preparatory stage for the improvement of business processes, process reengineering, technological transference and processes standardization [50].

Software processes and business processes present certain similarities: they both try to capture the main features of a group of partially ordered activities carried out to achieve a specific goal. However, whereas the aim of a process software is to obtain a software product [51], the aim of a business process is to obtain beneficial results (generally a product or service) for clients or others affected by the process [52, 53].

Actually, the origins of the different business process modelling languages are inspired by software modelling languages. The informatics approach defines modelling as the "designing of software applications before coding" [54]; this focus has contributed to the development of several languages and applications for code generation and processes automation, which have increased in quantity and diversity especially during the last two decades [55].

5 Modelling Language and Software Tool Selection Process

Business processes are modelled using a modelling language, a standard that defines model elements and their meaning, allowing efficient, collaborative business process management across corporate boundaries and disciplines [56].

A large number of business process modelling languages exists and several taxonomies have been proposed [57]. In a general classification, a modelling language can be graphical or textual and in a more detailed taxonomy, Ko et al. [55] classify the BPM languages in relation to the BPM life cycle in: Graphical Standards (BPMN, UML), Execution Standards (BPEL, BPML, WSFL, XLANG), Interchange Standards (XPDL, BPDM) and Diagnosis Standards (BPRI, BPQL).

To select a suitable business modelling language to express the proposed MMF, the present investigation refers to the flowchart proposed by Ko et al. [55]. This flowchart presents a sequential decisional process that leads to define the type of language to be used.

Considering that the objective of this research is to model a new business process (not a web service or an automation application nor a diagnosis), that this model has a private application (for internal BPM, not for collaboration business to business) and that it is desired to work with a graphical representation in order to facilitate the modelling process, the result from Ko's et al. selection procedure indicates that the better choice is a Graphical Standard such as UML, BPMN, Event-driven Process Chains (EPC) [58], Role-Activity Diagrams (RADs) or simple flowcharts.

Among all the mentioned standards, UML 2.1 using the "Eriksson-Penker Business Extensions" and BPMN 1.0 were selected to model the proposed MMF. Both standards are maintained by the OMG (Object Management Group), an "international, open membership, not-for-profit computer industry consortium […] [that] develops enterprise integration standards for a wide range of technologies, and an even wider range of industries" [54].

A further decision element was the availability to freely access to the OMG website where it is possible to download the latest UML and BPMN specifications, and to consult a variety of resources about those standards.

UML was created in 1997 by Grady Booch, James Rumbaugh and Ivar Jacobson, who developed it from the union of their own methodologies. They proposed UML to consideration of the OMG, being accepted as a standard since the same year it was proposed [59].

For the modelling development of this research, UML will be accompanied by the "Eriksson-Penker Business Extensions" these extensions are a set of specifications about the use of semantics to express the elements of the model in terms of business modelling [6].

UML 2.1 specification is formed by thirteen kinds of diagrams that show a specific static or dynamic aspect of a system.

BPMN first specification was released to the public in May, 2004 with the objective of "provide a notation that is readily understandable by all business users, from the business analysts that create the initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally, to the business people who will manage and monitor those processes" [60].

BPMN defines a business process diagram (BPD) which is formed by a set of graphical elements to represent activities and their flow [60].

Regarding the software modelling tools there is a large number of applications, some of them non-proprietary and others of proprietary type. The selection of the most appropriate tool depends on the particular modelling requirements and the project scope.

Although a simple graphical tool for diagrams development could be used, a professional software modelling tool including a business process repository offers interesting advantages (storing of elements, simulation, code generation, etc.).

For this research the selected software was Enterprise Architect 7.1; an UML analysis, design, documentation and project management CASE tool, including basic UML models plus testing, metrics, change management, defect tracking and user interface design extensions. This software is developed by Sparx Systems. Enterprise Architect 7.1 was chosen because of its features and its availability to support this research.

6 Business Architecture and Modelling Strategy

The general description of a system that identifies its purpose, vital functions, elements, processes and defines their interaction is called "business architecture" [61]. The OMG [54] provides its definition: "Business architecture is a blueprint of the enterprise that provides a common understanding of the organization and is used to align strategic objectives and tactical demands […] business architecture defines the structure of the enterprise in terms of its governance structure, business processes, and business information".

The objective of modelling the proposed MMF is to express its business architecture using documents and diagrams known as "artefacts".

The general business architecture can be represented by three principal categories of data: the Business Context (models of the stakeholders relations, mission and vision statements, business goals and physical structure of the "as-is" business), the Business Objects (a domain model of all objects of interest and their respective data), and the Business Workflows (business process diagrams representing the structures and objects defined in the Business Context and in the Business Objects diagrams. These business process diagrams show how objects work together to provide fundamental business activities).

In this paper the Business Context is represented by a Goals Diagram (Fig. 2); the Business Objects by a Model of Classes and Objects (Fig. 9), and the Business Workflows by a set of process diagrams (Figs. 3, 4, 5, 6, 7 and 8).

Generally the business architecture is organized hierarchically so executives can observe how specific processes are aligned to support the organization's strategic aims [62].

The same hierarchical order is used to define the processes and sub-processes for the new MMF proposed in this investigation; the top-down approach will be initially preferred (starting modelling the top value chain process and later modelling the specific processes), not dismissing the possibility of using an inside-out approach in following stages (starting modelling a particular specific process and then extending its influence around the general organization) [63].

There is not a defined way of naming process levels although frequently the smallest process diagram is called an activity (according to UML and BPMN standards).

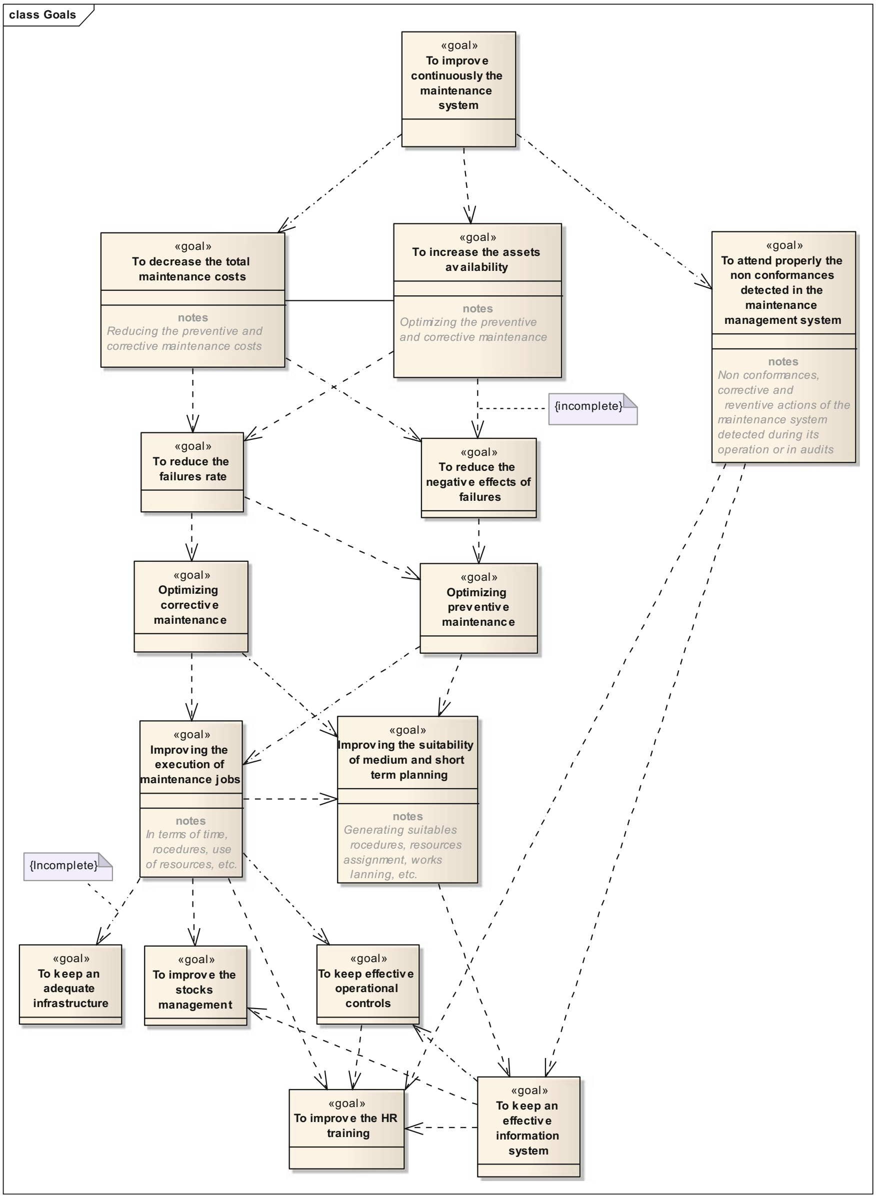

Fig. 2 Goals tree diagram for the proposed MMF

Neither a technical limit exists for a maximum number of processes subdivisions. The most important concept is to keep in mind that processes can be hierarchically arranged [62].

Therefore the proposed MMF has its own nomenclature to refer to its hierarchical levels.

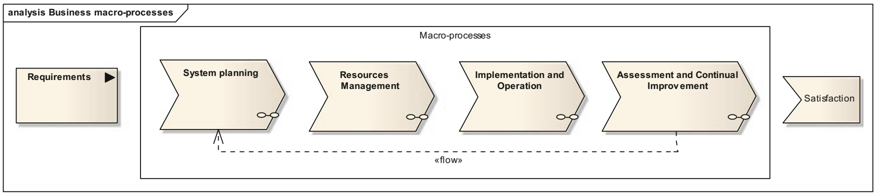

Fig. 3 Macro-processes (top value chain process) of the proposed MMF

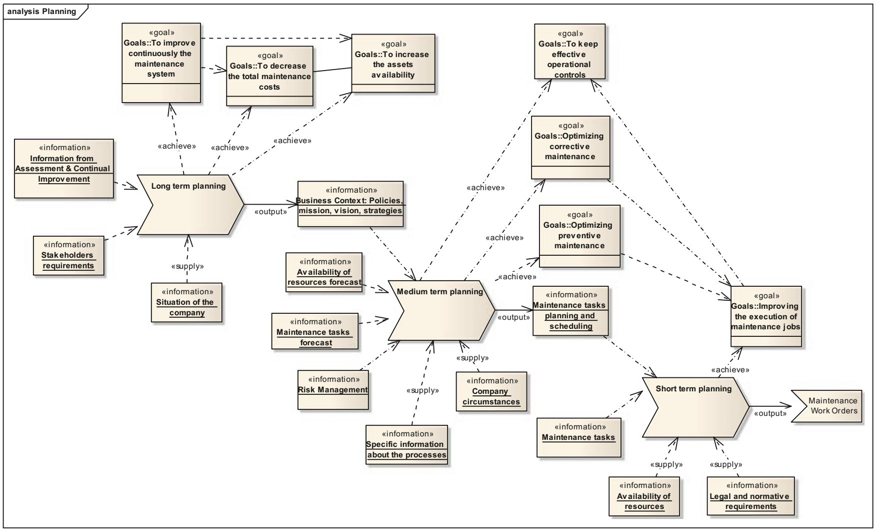

Fig. 4 UML diagram of the system planning macro-process

Once have been defined the operations to be modelled, the boundary of the system and after identifying its mission and vision, is necessary to describe the business strategy to fulfil the goals set. These goals must be achieved through the operation of one or more business processes [64].

In Fig. 2 is represented an example of the goals tree that can be designed for the proposed MMF using a specific type of UML diagram: a class diagram. In this kind of diagrams a goal is described as a class object with the stereotype ≪goal≫. Due in this project a new system is being designed; all the goals presented in the tree diagram are illustrative and of qualitative type.

For this particular MMF the main goal is “to continuously improve the maintenance system”. This main goal depends on the fulfilment of other three goals (identified by a dependency line): to decrease the total maintenance cost, to increase the assets availability, and to attend properly the non-conformances detected in the maintenance management system. It is necessary to notice that the first two aims (to decrease the total maintenance cost and to increase the assets availability) are

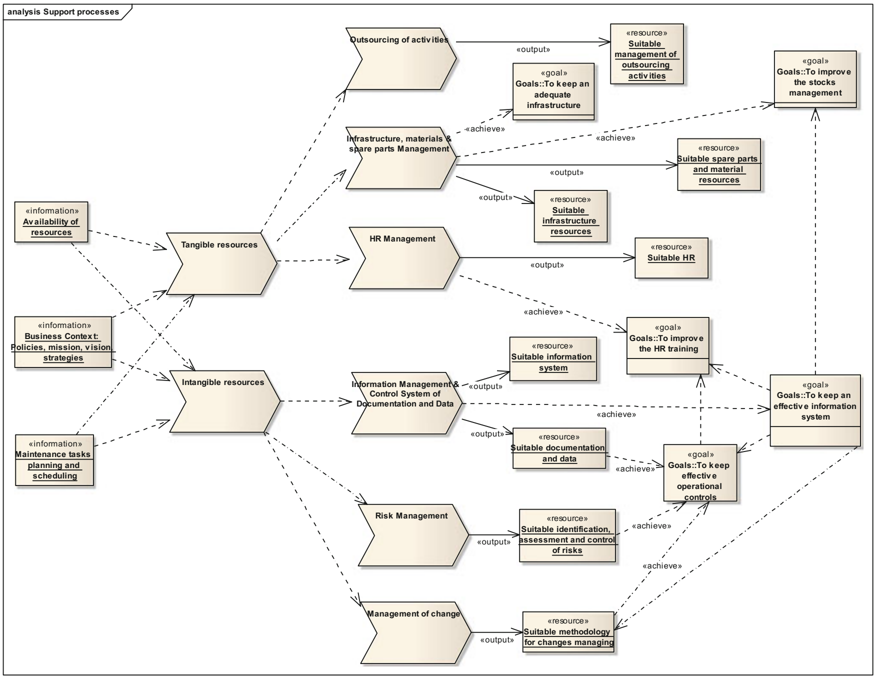

Fig. 5 UML diagram of the resources management macro-process

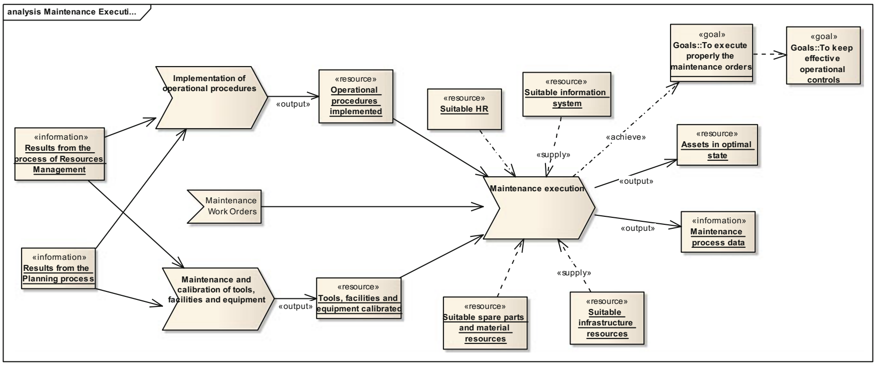

Fig. 6 UML diagram of the implementation and operation macro-process

contradictory goals. This contradictory feature is identified using an association line between the goal objects.

Moreover, the fulfilment of each one of the already mentioned goals depends on another series of hierarchical goals (or sub-goals), which have to be totally or partially achieved. In the diagram, a tag with the legend "incomplete" indicates this condition.

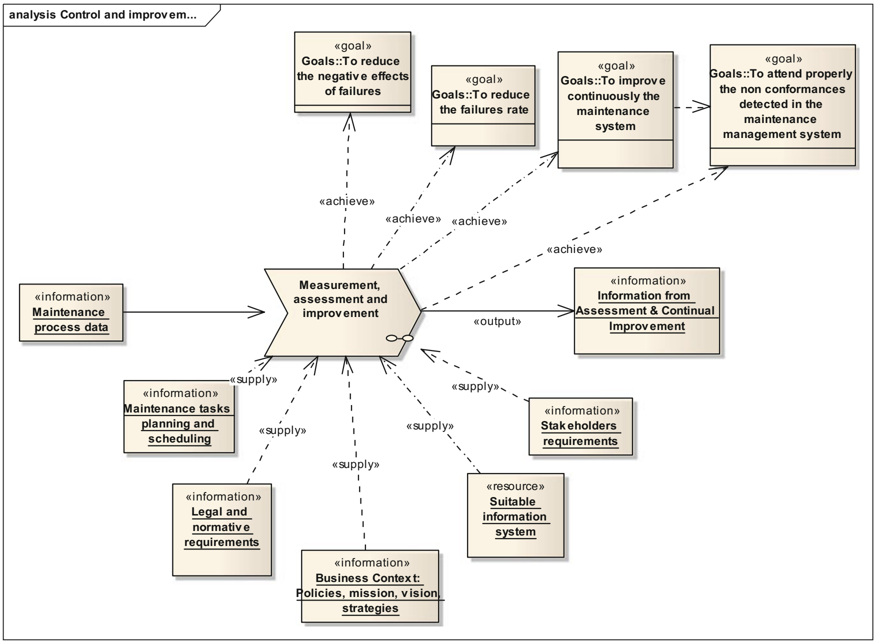

Fig. 7 UML diagram of the macro-process of assessment and continual improvement

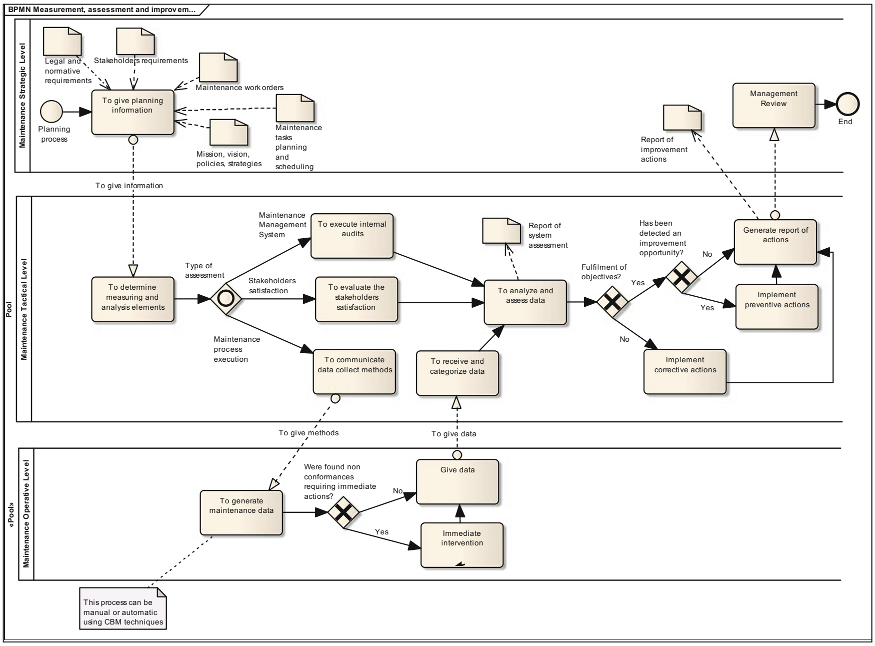

Fig. 8 BPMN diagram of the assessment and continual improvement

Every macro-processes, process and activity described in the model is focused to the satisfaction of the objectives drafted in the goals tree diagram.

7 Modelling the Proposed Maintenance Management System

Following the mentioned top-down approach, the top value chain process of the proposed MMF (or level 0 process) is constituted by the already mentioned four macro-processes: System Planning, Resources Management, Implementation & Operation, and Assessment & Continual Improvement.

Subsequently each macro-process is conformed by processes (level 1 processes) and each process can be subdivided in sub-process (level 2 processes), finally each sub-process can be subdivided in activities (level 3 processes).

In Fig. 3 appears an UML diagram made using the Eriksson-Penker Business Extensions. This diagram represents the top value chain process (or level 0). In a software platform, this diagram can also operates as a main menu to access to the rest of processes.

Every macro-process and process modelled has some invariable related elements: one or several goals associated using a dependence relation with the stereotype ≪achieve≫ (these goals are derived from the goals tree); input resources, output resources, both linked using dependence relations, supply resources with a dependence relation and the stereotype ≪supply≫ and control resources having the stereotype ≪control≫.

The first macro-process to model is System Planning module. Figure 4 shows the level 1 planning diagram, which it was modelled using UML with the Eriksson-Penker Business Extensions. In this diagram it is possible to identify the mentioned elements related to every process (goals, input, output, supply).

Besides, in Fig. 4 it can be observed the three processes composing the total System Planning module: long-term planning, medium-term planning and short-term planning. The information and supplies required are identified in the diagram, as well as the goals to be achieved by each of the three processes.

It is interesting to notice that the output of each process is an input element for the next.

In a general way, this macro-process has defined as start inputs: the maintenance information for improvement (generated by the Assessment & Continual Improvement macro-process), the stakeholder's requirements and information about the situation of the company. Other input elements are going to be needed for the entire planning development, but it is observed that the three mentioned as "start inputs" are the earlier required initiating the process flow.

As a final output of this entire macro-process appears the maintenance work order, which has to be executed by operative personnel. Besides the maintenance work order, there are other essential outputs generated during the planning as: the business context document (policies, mission, vision, agreements, strategies) and the planning and scheduling of maintenance tasks.

The procedures to carry out every planning process belong to level 2 and for this project are named sub-processes. On the whole, a procedure contains a description more detailed of the flow of activities to perform, the required, related and generated documents and the responsibles for the performance.

If it is necessary due the sub-process size or complexity, a level 3 diagram describing activities can be made as well.

Both level 2 diagram and level 3 diagram could be produced using UML (if there is an important quantity of information inside it) or using BPMN (if the procedure is not too long). It is also possible going beyond level 3 if more specific information is required.

The next macro-process to be modelled has to do with Resources Management processes, as Fig. 5 shows using an UML diagram with the Eriksson-Penker Business Extensions.

The Resources Management module classifies the processes into the management of tangible resources, composed by three not sequenced processes (Management of Outsourcing Activities Process; Infrastructure, materials & spare parts Management Process; and Human Resources Management Process) and into the management of intangible resources composed by three not sequenced processes (Information Management & Control System of Documentation and Data Process; Risk Management Process; and Management of Change Process).

These processes are independent in their operation, although they are linked by their goals and by being part of the same general system.

These six supporting processes share the same start input elements as well: information about the availability of resources, about the business context (policies, mission, vision, etc.) and about the planning and scheduling of maintenance tasks.

An appropriate execution of these supporting processes results in having suitable resources to the maintenance development (output elements).

Required procedures for every supporting process can be managed in level 3 diagrams, as previously explained in the System Planning macro-process.

At first glance the macro-process for the maintenance execution, the Implementation & Operation macro-process (Fig. 6) seems to be very simple, since its diagram does not have so many elements as the previous macro-processes. But in fact, this is the core process of the whole system [65].

Beginning from the work order, maintenance tasks are developed according to the particular procedures defined by the organization, using the resources managed in the previous macro-process, and via the outputs supplied by the corresponding level 2 processes: the Implementation of Operational Procedures; and the Maintenance & Calibration of Tools, Facilities and Equipment Process.

From this development, the desirable outputs are: to have and/or to keep the assets in optimal state and, to compile outstanding data about maintenance process.

To have and/or to keep the assets in optimal state is an output that goes directly to satisfy a tangible necessity, generally outside the maintenance function. To compile outstanding data about maintenance process is a required input element in the Assessment & Continual Improvement macro-process.

The particular technical procedures inside the Maintenance execution process, generally involve very specific aspects which can be expressed using UML and BPMN likewise.

These specific technical procedures depend on the kind of organization applying the system and as a core process, its performance is highly supported by the others macro-processes.

The remaining macro-process, Assessment & Continual Improvement is presented in Fig. 7. In its UML diagram it is possible to identify the process start input: data about the maintenance process execution.

Further information is required as well (in diagram expressed as supplies). The desired output of this macro-process is the information for the improvement, which will be used by the following System Planning macro-process.

In this way, the system operates cyclically favouring the continuous improvement approach.

As an example of how the system operation can be detailed in deeper levels, Fig. 8 shows a level 2 BPMN diagram, representing the process inside the Assessment & Continual Improvement module, where the working flows and activities necessary to achieve the corresponding goals are identified.

In this BPMN diagram can also be identified the activities corresponding to the six elements constituting this macro-process (see Fig. 1).

Figure 8 shows the basic elements of a BPMN diagram: flow objects, connection objects, swimlanes and artefacts [66]. Also the six processes inside can be identified as activities.

Inside every activity modelled in the BPMN diagram it is also possible to add more specific procedures, being identified by consecutive levels numeration. Different macro-processes can be conformed by different number of levels, depending on the complexity of the procedures to model.

Besides the diagrams used to symbolize process workflows, there are other kinds of diagrams (called also artefacts) that are useful for having a complete view of the whole system and are indispensables if there is the idea of developing an informatics application.

Those diagrams are categorized by the UML 2.1 standard into structural diagrams (defining the static architecture of a model) and behavioural diagrams (representing the interaction and instantaneous states within a model as it 'executes' over time).

A structural diagram (a class diagram) was used before to symbolize the goals tree (Fig. 2). There are other different kinds of structural diagrams. In order to exemplify, Fig. 9 shows another important structural diagram. This class diagram represents a conceptual model, defining the business concepts about a maintenance management system and how they are related among them.

A conceptual diagram identifies the important concepts related to a specific context and it can be useful to model the business resources, rules and goals [67].

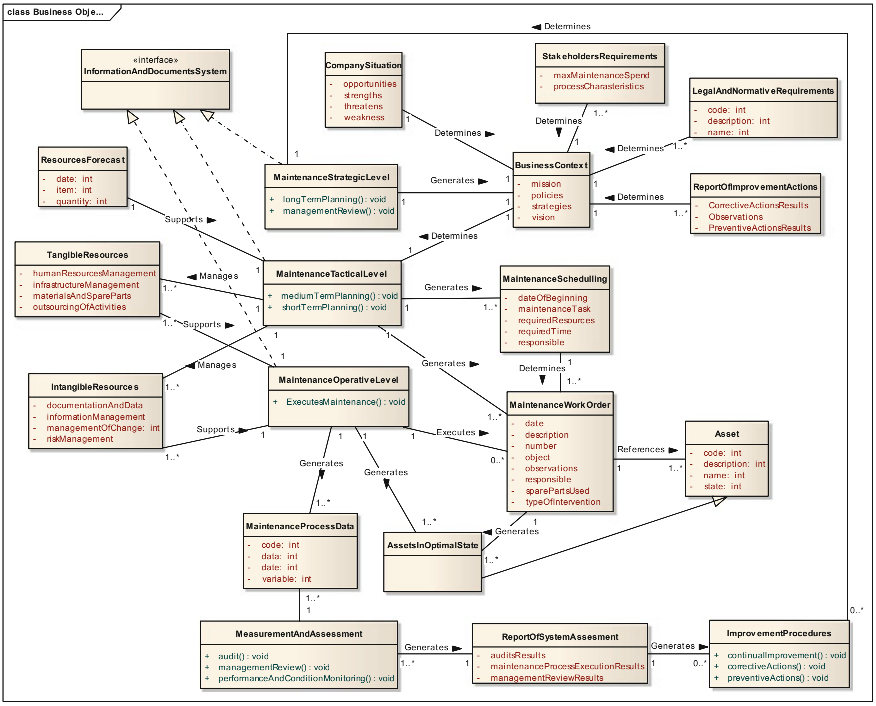

Fig. 9 Conceptual model of classes and objects

Regarding behavioural diagrams, there are also several kinds: use case diagrams, sequence diagrams, state diagrams, etc. Figure 10 shows a state diagram detailing the transitions or changes of state that an object (in this case a maintenance work order) can go through in the system.

State Diagrams show how an object moves from one state to another and the rules that govern that change. State charts typically have a start and an end condition [67].

All diagrams appearing in this chapter were made using Enterprise Architect 7.1. This software was perceived as agile and easy to use, with a variety of online resources.

8 ICT Issues Related to the MMF Implementation

An important distinctive attribute of the proposed MMF is that it has been modelled using the BPM methodology, UML and BPMN languages.

This attribute provides the MMF with integration capacities and flexibility to take advantage of the information and communications technologies (ICT).

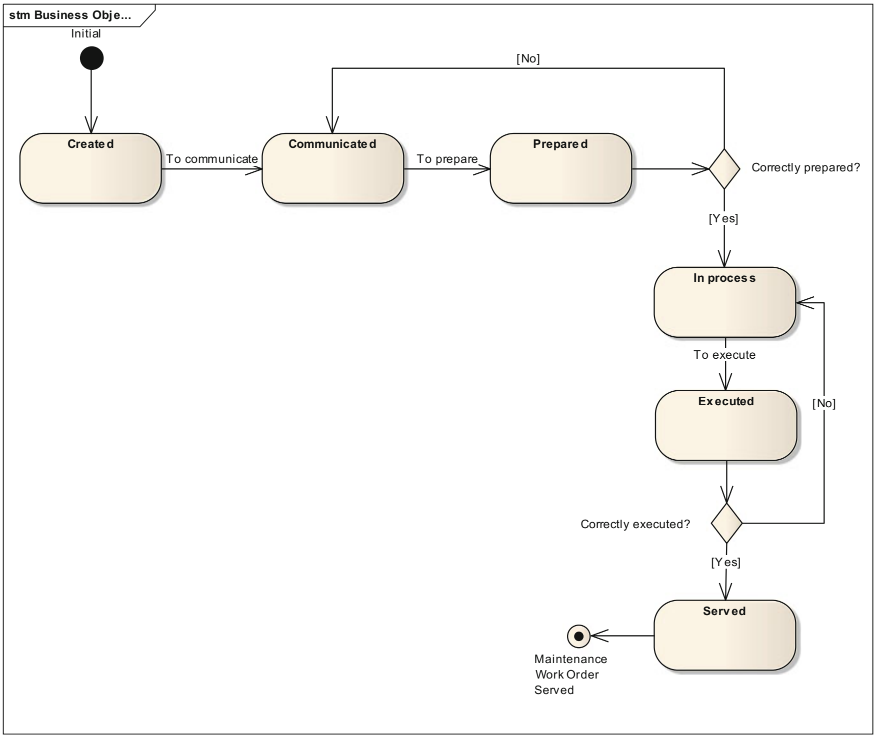

Fig. 10 UML state diagram for a maintenance work order

For instance, from a complete description of the MMF operation algorithms using UML and BPMN diagrams, it is relatively not difficult to generate code for the development of a software application that executes the MMF modules [68, 69].

Some of the ERP systems that currently exist in the market have maintenance management modules, and there are likewise, some software applications specific for asset management [70] (EAM systems); nevertheless the practical experience reveals that there are still several novel functions that can be added in a new system to improve maintenance management. Most of these functions are related to e-maintenance and can be incorporated to the proposed MMF through UML and BPMN models as well, specifically looking for coordination in real time among CMMS, RCM and CBM systems.

Although the e-maintenance term has been used since 2000 as a component of e-manufacturing, at present time there is not yet a standardized definition of e-maintenance given by an official institution [71].

From a pragmatic point of view, we may say that e-maintenance is “the set of maintenance processes that uses the e-technologies to enable proactive decisions in a particular organization” (definition partially derived from Levrat et al. [72]).

Such e-maintenance processes are supported by means of a variety of hardware and software technologies as the wireless and mobile devices, embedded systems, web-based applications, P2P networks, multi-agent applications, specific software architectures, among others.

That variety of technologies implies the existence of multiple communication protocols, data connections, configurations, etc. At this respect, several standards have been developed in order to obtain interconnection and interoperability among the different systems.

The Machinery Information Management Open Systems Alliance or MIMOSA is an important not-for-profit trade association dedicated to developing and encouraging the adoption of open information standards in operations and maintenance (O&M) just to support interoperability [73].

MIMOSA standards are interesting references for the proposed MMF because of two main reasons: the former is that MIMOSA standards are expressed using UML language; the latter is that MIMOSA has developed two types of information-exchanging open standards that are also related to the processes to develop in the proposed MMF: a standard for management applications (OSA-EAI™) and a standard for condition based maintenance (OSA-CBM™). Both standards provide metadata reference libraries and a series of information exchange standards using XML and SQL.

Therefore, it is necessary to consider the adoption of MIMOSA standards to continue modelling deeper levels of the MMF and particularly for the operation of the e-maintenance processes.

Concerning these e-maintenance processes, although e-maintenance can be characterized as a technique, the general idea of this project (based on Iung et al. [74]) is considering e-maintenance as a philosophy supporting the operation of the entire MMF and making possible the information exchange among remote elements. This philosophy allows the decision-making and the fulfilment of the maintenance global objectives depending on collaboration, which implies the use of the ICT.

The majority of the e-maintenance processes to be included in the proposed MMF involve the realization of the classical maintenance management activities but using e-technologies, in a distance environment. The proposed MMF becomes a CMMS system with remote capabilities.

However, the use of e-technologies and large volumes of different data necessarily increases the possibilities to create new emerging e-maintenance processes.

During the development of this MMF, several novel e-maintenance processes have been identified as required, particularly processes related to an integration and exchange of information among CMMS, RCM and CBM systems [75]. This e-maintenance integration is able to optimize the decision-making processes related to the feasibility of the maintenance strategies and programs.

In general terms, this integration works as follows [76]: using the information managed by the CMMS (saved inside each module of the proposed MMF), the RCM methodology is applied to the pre-defined system(s), defining the operational context and the processes involved, doing the FMECA analysis and selecting the appropriate maintenance policies. From the RCM analysis it is possible to detect the necessity of applying CBM in some particular elements in order to generate important economical savings. The real-time CBM signals feed the CMMS and subsequently the RCM, generating an automatic suggestion if a maintenance strategy has to be updated according its behaviour. Then, the RCM is applied again and the improving cycle begins one more time. Moreover, the integration of this information can maximize the effectiveness of the diagnosis: the CBM signals are related to the most critical and frequent failures modes of the RCM analysis, allowing time savings in corrective and preventive actions.

The specific operational characteristics of those e-maintenance processes, the ICT related to them and the additional interoperability standards required to their implementation (i.e. ISO 18435, ISO 62264, OPC standards, etc.) have to be defined according to the special requirements of the specific industrial sector that applies the proposed MMF, and they are material for another paper.

9 Conclusions

In the historical development of maintenance, several models and frameworks looking for the optimal maintenance management structure have been developed [34].

Among all those proposals, PAS 55 standard emerges in 2004, as a complete framework, not only for maintenance but also for management of the entire life cycle of assets.

Besides, PAS 55 involves a set of desirable characteristics and best practices identified as necessaries for the operation of a modern and efficient maintenance management framework (MMF), as the input–output processes approach, the objectives entailment, the orientation to new technologies and the continuous improvement approach.

Then, this chapter shows the process of modelling a MMF that represents the general requirements of PAS 55.

The flow diagrams and processes proposed inside the MMF are a representation of how PAS 55 structure can be implemented in an organization. We have to remember that PAS 55 declares *what* have to be done, but not exactly *how* to do it. For this reason, each company is able to develop its own specific techniques and methodologies to fulfil the PAS 55 requirements.

For the realization of this project, the modelling work involved researching about the basic concepts in the area (business process, modelling, modelling language, business architecture, etc.) to select the most suitable language and software tool to the case.

UML 2.1 and BPMN 1.0 were the modelling languages selected to express the proposed MMF, due to their recognition as international standards, their increasing use in successful maintenance projects (e.g. PROTEUS project [77], among others) and their interesting capabilities.

Later, a modelling methodology was chosen to represent the system architecture, and to develop the structural and behavioural diagrams exposed in this chapter.

Summarizing, the general steps to model the proposed MMF and that have been shown in this chapter are: (i) PAS 55 analysis, (ii) design of the conceptual MMF according to standards, (iii) selection of modelling language and modelling software tool, (iv) definition of the business architecture, (v) modelling of goals tree, (vi) identification of top value chain process, (vii) modelling of involved processes and activities, (viii) tracing several UML and BPMN diagrams to represent specific features of the system, (ix) analysis of the ICT issues related to the implementation of the MMF and conclusions.

The use of processes modelling languages (UML 2.1 and BPMN 1.0) gives to the MMF the interesting possibility of generating code and the subsequent creation of software as an alternative from the ERP, CMMS and EAM commercial systems.

Code generation and the development of a software application involve a hard work detailing the data and operation models for the MMF, a profound working out of algorithms and artefacts describing the use of the tools and techniques required for the operation of the MMF. Also, the identification and interpretation of the interoperability standards required according to the ICT executing of the MMF modules is necessary.

At this respect, the operation of the system through e-maintenance processes [78] is a recommended approach.

Finally, it is important to mention that the activities flow and processes modelled in this paper correspond mainly to the real operation of PAS 55 in a leading Spanish enterprise of the energy sector, and that the project of the e-maintenance integration among CMMS, RCM and CBM for decision-making is actually, being implemented in a transformer and in a water pump [76], equipments of the same energy production and distribution enterprise.

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