Conceptual framework for e-Maintenance: Illustration by e-Maintenance technologies and platforms

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1. Introduction

The term e-Maintenance has emerged since early 2000 and it is now a very common term in maintenance related literature. e-Maintenance is sometimes considered by contributors as a maintenance strategy (Tsang, 2002), a maintenance plan (Ucar & Qiu, 2005), a maintenance type (Tsang, 2002) or a maintenance support (Crespo Marquez & Gupta, 2006). Some results of these contributions are already published at least within (a) a special issue on e-Maintenance (Iung & Crespo Marquez, 2006), (b) a review on e-Maintenance (Muller, Crespo Marquez, & Iung, 2008a) and (c) a proposal of a e-Maintenance framework (Levrat, Iung, & Crespo Marquez, 2008). The originality of this paper is, from the framework proposal, to illustrate the e-Maintenance technologies, e-Maintenance platforms and also the application of the framework for prognosis business process modelling. Indeed the reader can also appreciate that e-Maintenance emergence is linked with two main factors: The appearance of e-technologies optimising maintenance related workflow and the need to integrate business performance, which imposes to the maintenance area the following requirements: openness, integration and collaboration with the others services of the e-enterprise (new way of thinking maintenance). We consider that there is an academic challenge that consists in structuring the e-Maintenance knowledge in order to define a new scientific discipline devoted to e-Maintenance.

1.1. The scope of maintenance

Traditionally, the scope of maintenance activities has been limited to the production and operation phase. But as the paradigm of manufacturing shifts towards realising a sustainable society, the role of maintenance has to change to take into account a life cycle management oriented approach (Takata et al., 2004). From a global perspective of life cycle management, the role of e-Maintenance is now to enhance the eco-efficiency (DeSimone & Popoff, 1997) of the product life cycle while preserving the product “characteristics” in terms of not only its availability, reliability, safety, etc. but also maintainability (Cunha & Caldeira Duarte, 2004). Therefore, maintenance has to be considered not only in production or operation phase but also in product design, product disassembly, and product recycling (Erbe, Jung, & Morel, 2007; Van Houten, Tomiyama, & Salomons, 1998). The product can now play a major role in maintenance mainly when the product is “active” (i.e. Intelligent Product), i.e. able to support a part of its knowledge.

These two paradigms of “eco-efficiency” and “active product” confer the maintenance a major role, in the future, as a strategic
tool for controlling performances. In this sense, the concept of “life cycle maintenance” (Takata et al., 2004) emerged to stress this new role leading to develop a general maintenance value chain to keep the functional level of a product.

Thus e-Maintenance can be considered as a philosophy supporting the move from “fail and fix” maintenance practices to “predict and prevent” strategies – pro-activity concept (Iung, Morel, & Léger, 2003; Lee, Ni, Djurdjanovic, Qiu, & Liao, 2006) – while keeping maintenance as an enterprise process (holistic approach)—integration concept (i.e. IEC/ISO 62264) for optimising performances.

This philosophy allows the fulfilment of the maintenance global objective depending on a mandatory collaboration (inter and intra-company processes integration), mandatory synchronisation of knowledge between all the objects–actors–systems involved in the maintenance process all along the various phases of the product life cycle (i.e. human and/or automated actors).

Indeed the collaboration can be made inside a phase or outside a phase for supporting business process integration along the entire product life cycle (Macchi & Garetti, 2006). It implies to use new technologies such as Information and Communication Technology (ICT) for restoring the flows (e.g. informational) needed for integration. These new technologies support the implementation of e-Maintenance philosophy as an emergent support for collaboration and pro-activity. Through the “e” of e-Maintenance, the pertinent Data–Information–Knowledge–Intelligence (D/I/K/I acronym) becomes available and usable at the right place, at the right time for taking the best (anticipated) maintenance decision. In that way, e-Maintenance is integrating the principles already implemented by tele-maintenance (Lee, 1998) which are added to the web-services and collaboration vs. synchronisation principles (Iung, 2003) to support pro-activity.

1.2. e-Technologies for e-Maintenance

From a technological point of view and for implementing all the collaborations vs. integrations, e-Maintenance support is globally made-up with Intra-Net, Extra-Net and Inter-Net parts. These parts are built from a lot of different e-technologies (see Section 3) such as web technology, new sensors, wireless communications, mobile components (e.g. Personal Digital Assistant, PDA) (Saint-Voirin, Lang, Zerhouni, & Guyennet, 2005).

In summary, e-technologies increase the possibilities: (1) to utilize data (or D/I/K/I) from multiple origins and of different kinds; (2) to process larger volumes of data (or D/I/K/I) and to make more advanced reasoning and decision-making, and; (3) to implement cooperative (or collaborative) activities. The implementation of these e-technologies to the benefit of the maintenance area is the second reason for the emergence of e-Maintenance.

But how we can implement an appropriate e-technologies-based e-Maintenance solution that meets e-Maintenance philosophy?

In this work, we use a conceptual framework helping us to connect e-Maintenance needs to the deployment of an effective e-Maintenance infrastructure. As this framework is already founded in Levrat et al. (2008), Section 2 of this paper aims at only summarising the first four abstraction levels of the framework. Then Section 3 details the last level entitled “infrastructure” by: (a) highlighting the type of new technologies required supporting an e-Maintenance service, and; (b) presenting an example of e-Maintenance platform based on e-technologies integration. This is the main scientific added value of this paper. A framework application to the maintenance proactive capacity modelling is developed in Section 4. It consists in prognosis process modelling. Finally, we present conclusions of the paper and prospective in Section 5.

2. An e-Maintenance framework

Our e-Maintenance framework modelling is based on the “Enterprise Architecture” (EA) principle which is promoted in the Zachman Framework (Sowa & Zachman, 1992) and was already investigated in maintenance activity integration by Léger and Morel (2001). To support this framework, we use the MEGA Process tool (http://www.mega.com) that provides a detailed mapping between Zachman cells and concepts as utilized in MEGA. Thus the e-Maintenance framework could be structured on five abstraction levels:

- E-maintenance strategic vision (business and goal) which supports the “scope” (sub-Section 2.1),
- E-maintenance business processes which support the Business view (sub-Section 2.2),
- E-maintenance organisation which supports the Architect’s view (sub-Section 2.3),
- E-maintenance service and data architecture which supports the designer’s view (sub-Section 2.4),
- E-maintenance IT infrastructure supporting the builder’s view (Section 3).

For each step, models have to be build according to the different areas of interest expressed in the Zachman framework columns: Data, Function, People, Network, Time, and Motivation.

The last two levels (service, infrastructure) materialise the emerging factor of e-Maintenance related to new ICT while the first two ones materialise the emerging factor of new maintenance needs. The “organisation” level is common for the two factors in order to support the interoperability and integration between needs and solutions (Fig. 1).

2.1. Strategic vision

E-maintenance strategic vision conforms a set of strategic decision rules of e-Maintenance in coherence to the strategic decision rules of the enterprise (strategic axis). They define not only the main trends of e-Maintenance but also its finality and objectives and consequently they determine the inherent objectives to all the other e-Maintenance processes integrated within the enterprise processes.

In summary, the models of e-Maintenance strategic vision (to be located in the framework) should be more textual than formal and define the main strategic e-Maintenance guidelines.

2.2. e-Maintenance business processes

The e-Maintenance strategic decision rules guide, at the operational stage, business processes considered as the key

![Fig. 1. From business to IT.](http://www.mega.com)
elements of the value chain related to the creation of the value for the customer. The processes are organised by means of business functions (cross-business processes).

As the global e-Maintenance value chain supports one phase of the product life cycle (e.g. design, production) or several phases, the business function can be described by a lot of activities potentially business “distributed”. A business process corresponds roughly to the whole of the activities of only one conventional maintenance process.

The activities can operate D/I/K/I and are formalised by traditional or more advanced techniques to be executed. Each business process (and activity) carries out e-Maintenance operational objectives which are controllable by performances indicators allowing modifying these objectives for e-Maintenance continuous improvement (Parida, 2006). All the business processes form the conceptual map of e-Maintenance business processes.

In summary, the models to be formalised within the framework in relation to this level have to address: the identification of business processes, the identification of the external and internal environment on each business process, the way to assess business process (or function) and its activities in order to develop continuous improvement, the semantic interoperability between processes, etc.

2.3. e-Maintenance organisation

The e-Maintenance organisation must support the business process integration. It consists in projecting the business processes (but especially the associated activities) onto one or more organisations of e-Maintenance and then to assess the organisations according to the expected finalities related to the strategic and business levels. Defining an organisation consists in assigning activities (and their related procedures and operations) to the org-units that will perform these activities on a specific site (Fig. 2).

The organisation expected for e-Maintenance (based on collaborative–cooperative aspects) should be closed to the IMS (Intelligent Manufacturing System) paradigm (Yoshikawa, 1995) stating that the system behaviour emerges through the dynamics of the interactions of basic maintenance agents within the maintenance environment.

In summary, the models to be formalised within the framework in relation to this level have to address: the characterisation of the main e-Maintenance organisations, the definition of the org-units used in the selected organisation, the definition of each procedure, the assessment of the selected organisation, the organisational interoperability between procedures (operations), etc.

2.4. Service and data architecture

At this abstraction level, the objective is to define the generic (e-technologies) components able to physically support the various operations assigned to the org-unit at the organisational level. Indeed the operations have to be supported by applications, databases and other resources. This genericity, in IT domain, is associated to the concept of service-oriented architecture. These generic components or services should be software, hardware, etc. resources needed for supporting: the communication–processing–storage operations; the display of the D/I/K/I; and the search of some D/I/K/I (two technologies are omnipresent for the software development of these components XML (Extensible Mark-up Language) – and its link with BPEL, WSDL, HTML, etc., – and Java-platforms such as J2EE, JSP, JSF).

Items to be formalised in relation to this section are thus models offering answers to questions like: What are the most usable e-technologies for favouring the e-Maintenance deployment? What are the generic components materialising these e-technologies? What are the main technical features of these generic components? What are the standards of development needed for these components?

3. e-Maintenance IT infrastructure

The last framework abstraction level aims at modelling the detailed technical e-Maintenance IT infrastructure. This infrastructure consists of a set of specific components (hardware, software, hybrid) supporting each operation required to the right implementation of the procedures (and consequently of the e-Maintenance business processes and of the e-Maintenance strategic vision). It materialises the IT means required for running applications and for enabling communication between these applications according to their distribution on sites.

The specific components result from a dimensioning of the generic components adapted to the e-Maintenance organisation to be implemented. The IT infrastructure is thus defined by all the resources (e.g. applications, services) necessary to the execution of
all the operations identified at the organisational level. In that way, it is composed, for an e-Maintenance point of view, of one or several network(s) with the servers, workstations, applications, databases but also (smart) sensors, PDA, etc. It is also characterised by its operating principles (wireless infrastructure, highly fault-tolerant, secured, etc.) and the concrete implementation of a technological interoperability which consists in deploying the right ICT related to the standards to present, store, exchange, process, communicate D/I/J/K/I.

The operation of this infrastructure consists in ensuring the level of service quality expected for the process execution in terms of scalability and availability. It is a question of guaranteeing an acceptable response time to the e-Maintenance customer. In that way, the global performances (key indicators) of the infrastructure have to be assessed and compared to those expected for fulfilling the e-Maintenance business process performances.

3.1. Types of new technologies–components needed to support e-Maintenance capacities

A lot of innovative products/components (e.g. wired, wireless, mobiles, embedded) are already available to be integrated in an e-Maintenance infrastructure with satisfying interoperability issues. A brief presentation of the main categories of the innovative technologies (hardware and/or software) needed to support e-Maintenance capacities are given below:

- New sensors such as smart sensors—MEMS (micro-sensor technology equipped with autonomous power, memory cells, analogue amplification, converter, etc. well adapted for vibration analysis, oil analysis) (Zhang, Gu, Vlatkovic, & Wang, 2004), wireless sensors, sensor networks. The sensors are the key factor for performing the basic business processes of e-Maintenance which materialise the “Condition-Based Maintenance” concept (CBM). Thus these sensors support more than conventional capacities (such as CM, diagnosis, prognosis).
- RFID tag (passive and active; Radio Frequency Identification Device) which supports operator and component identification, storage of conventional data on the machine, the provider but also traceability of the past maintenance actions. These tags (Ramarurthy, Prabhu, & Gadh, 2005) can offer an aid for the geolocalisation of the maintenance tools, of the maintenance operators.
- Global Positioning System (GPS) in complementary way with the RFID tag for calculating the location of an operator or of maintenance tools.
- Wireless technologies have to provide considerable savings in networking cost and degree of flexibility not met in wired systems. It should probably become a new paradigm in industrial networks (Egea-Lopez, Martinez-Sala, Vales-Alonso, Garcia-Haro, & Malgosa-Sanahuja, 2005). The main wireless technologies include Wireless Personal Area Networks such as IEEE 802.11, 802.15.4 ZigBee, 802.15.1. Bluetooth; Wireless Local Area Network such as WiFi, WiMax; GSM-UMTS (for long distance).
- Innovative communication equipment (virtual reality) for supporting man/machine or man/man exchanges (to speak, hear, see, touch, and feel). For example, head mounted displays allow receiving directly information in the form of text, of fixed or animated image.
- Tools for diagnostics and prognostics (Jardine, Lin, & Banjevic, 2006; Muller, Sühner, & Jung, 2008b; Venkatasubramanian, 2005) allowing to develop “intelligent” support to maintenance decision-making.
- PDA, SmartPhones, Graphic tablets, harden laptops, etc. (equipped with WiFi, Bluetooth, RFID Reader, Windows Mobile), for developing a lot of functions to aid the operator on site.
- Specific standards for ensuring Integration and Interoperation issues between all the IT components to develop e-Maintenance solutions (Chen & Doumeingts, 2003). In that way, current initiatives such as OpenQAE initiative (e.g. MIMOSA for Machinery Information Management Open Systems Alliance, IEC62264, OPC foundation for Open Connectivity) and ISO18435-1 are very promising. A complementary set of standards are the W3C managed XML and Semantic web standards.
- Web services (for monitoring, diagnosis, prognosis, scheduling) are based on a set of protocols and technical standards (Internet-based technologies) used for exchanging data between applications within heterogeneous environments: SOAP (Simple Object Access Protocol) for message exchanging; WSDL (Web Service Description Language); UDDI for referencing the web services, etc.
- Full Web-CMMS (e-CMMS) is a CMMS (Computerised Maintenance Management System) able to monitor and manage the preventive maintenance activities of the enterprise but by offering new functionalities such as ASP (Application Service Provider/Providing); link with mobile technologies for retrieving data, loading maintenance action; workflow module, etc.

The integration of the previous technologies in a unique infrastructure can bring a real added value for developing the maintenance actions. The integration leads to e-Maintenance system solution, most of time called e-Maintenance infrastructure or e-Maintenance platform.

3.2. Examples of e-Maintenance infrastructure or platforms

An e-Maintenance platform is sometimes considered by people as a software platform, a hardware/software platform or a full platform integrating also physical process and integration with enterprise tools. A common definition is not known today. Considering all the cases, the most well known e-Maintenance platforms are ICAS-AME, CASIP and its up-graded version KASEM, WSDF, PROTEUS, TELMA, MRPOS, IMS/D2B4DM, REMOTE DATA SENTINEL, DIAMOND, IPDSS, INTERMOR, QUESTRA, ENIGMA, DEXTER, DYNAWeb and SEMATECH (Campos, 2009) and agent-based platforms (Yu, Iung, & Panetto, 2003). The majority of these platforms are still operational today. These platforms result either of the industrial world or of the academic one. Some of them are related to European projects such as DYNAMITE (Dynamic Decision for Maintenance), PROTEUS, PROMISE, I’PROMS, TATEM, SMMART, etc. They are most of time made up of software, e-technologies allowing supporting new business processes for maintenance. Most of them support an evolution of the CBM to which is added access to remote experts using web interface for decision-making aid. Only few recent platforms (TELMA, DYNA-Web or KASEM) are fully consistent with the global e-Maintenance philosophy (e.g. knowledge co-operation and new services concepts).

In relation to the 5 levels of the conceptual e-Maintenance framework, a classification of the platforms can be proposed (it is no formally approved) by assessing mainly the ability of the platform: (a) to support the engineering and the implementation of new maintenance services; (b) to integrate new e-technologies needed to support collaboration vs. synchronisation principles for fulfilling maintenance services; (c) to support semantic and technical interoperability required for the right interconnection of all the previous technologies to make operating the platform as a whole; (d) to integrate the e-Maintenance services with the other enterprise processes (integration with tools such as Enterprise Resource Planning—ERP, Manufacturing Execution System—MES). To experiment most of the previous criterion not only on the research items but also industrial ones (in relation to our education
and transfer activities), it was decided at CRAN to design and deploy a new full e-Maintenance platform: the TELMA platform (Levrat & Iung, 2007). TELMA is based on a physical process connected both to automation architecture and to maintenance architecture. It is developed from market components to be as closed as possible of industrial context.

The TELMA platform (Fig. 3) is located at the Nancy University and has been developed mainly for supporting e-Maintenance purpose (deployment of CBM and pro-active maintenance strategies in consistent with OSA/CBM, Integration of these strategies within enterprise context, Assessment of the strategy impacts on the performances of a global manufacturing system).

The platform is designed for (a) a local use in the frame of conventional training activities; (b) a remote use via Internet for operation on industrial e-services and for accessing via VPN to data and indicators; (c) a use for e-teaching and e-learning as application support of lectures in the e-Maintenance domains.

Moreover, TELMA is used to validate our maintenance research contributions (prognostic, decision-making) and for showing demonstrations on e-Maintenance components, software and web-services in the DYNAMITE project.

TELMA is a platform materialising a physical process dedicated to unwinding metal strip. This process is similar to concrete industrial applications such as sheet metal cutting and paper bobbin cutting. The physical process is divided into four parts: bobbin changing, strip accumulation, punching–cutting and advance system. Each part consists of several components such as pneumatic cylinder, chuck, marking system, motor, etc.

A lot of sensors and actuators are in link both with the physical process and with the automation system which is composed of control screens, control boards, PLCs (i.e. TSX premium with web interface), Altivar for engine control with web interface, Web-Cam and remote I/O.

Another PLC is fully dedicated to generate failures and potential degradation using software algorithms or by modifying I/O signals. Some mechanical parts (actuators) have been also added to simulate other physical failures and degradations. The degradations and failures (and their evolutions) are programmed (i.e. following a Weibull law, random events; Markov Chains) and checked by the teacher/researcher (in a local or remote way). In the same way, the failed components are repaired according to a maintainability law, exponential law or by a certain action
proposal made by a student and validated by the teacher. Moreover to simulate the component ageing, it is considered that the maintenance action done is not always perfect (i.e., As Good As New; As Bad as Old). It is a very innovative view for the platform and offers means for validating and assessing the e-Maintenance capacities by emulating technical and functional degradation/failure.

The “maintenance part” of the platform is built on the CASIP® product (Computer Aided Safety and Industrial Productivity) from PREDICT company (used for the engineering and implementation of the e-Maintenance services; http://www.predict.fr) supporting a local real-time maintenance system, a centralized maintenance system (with Oracle) and some remote stations. These systems are integrated through Data Bases such as SQL-server by using OPC server, a Technical Data Base System called Advitium. The maintenance part is also integrated with the ERP system (ADONIX product), CMMS system (EMPACix product), MES system (FLEXNET product) and in link with enterprise modelling tools such as MEGA product. Thus this TELMA platform has the following functionalities:

- Technical intelligent agents directly implemented at the shop-floor level into the PLCs or the remote I/O of the components (Pétin, Iung, & Morel, 1998) to support the first layers of OSA/CBM.
- Infotronic platform supporting the D/I/K/I processing, storing and communication on the different levels (e.g., business, shop floor).
- Services (off-line) among users for aided decision-making in front of the degraded situation (assessment of the (current degraded) process performance; prognostic of the future situation; decision to be taken to control the process in its optimal performance state).

From the “wired” situation of TELMA previously explained, improvements have been done since 2007 and additional ones are in progress actually in order to move to “wireless functionalities” by using e-technologies. This up-grading is required also for DYNAMITE project.

The improvements while keeping the integration facilities are related to (Fig. 4):

- The change of the wired communications by wireless communications. Collectors (e.g., MicaZ) at field level with ZigBee protocols are introduced, gateway for transferring data from ZigBee area to WiFi area (e.g., StarGate SPB400), WiFi access point.
- The use of wireless sensors more adapted to provide plant information for decision-making in maintenance. These wireless sensors will be MEMS to measure vibration on accumulation system.
- The use of PDA for aiding the maintenance crew on site. It is a HP iPAQ hx4700 (Pocket PC) in which is implemented maintenance functionalities developed in DYNAMITE.
- The implementation of a MIMOSA Date Base (SQL-server) to be able to integrate all the data produced and consumed by the different components. It allows solving interoperability issues. However, some maintenance actors are not able to address directly MIMOSA and need the use of a MIMOSA translator.
- The implementation of web-services (WS) and the way to the access to them (e.g., prognosis WS detailed in Section 4).

From this new version, a lot of tests and experimentation is in progress for assessing the feasibility and the added value of e-Maintenance services and technologies. It is done by using scenarios (uses cases) closed to industrial situations and by simulating degradations/failures (use case 1: support in case of failure—stoppage; use case 2: support of incoming failure—degradation step).

The assessment is planned in relation to tests dedicated to internal capacities of the H/S (Hardware/Software) components, to interconnection of the H/S components and to global performances (results of tests are available in Deliverable D10.1. and D10.2. of DYNAMITE project).
4. Framework application to maintenance pro-active capacity modelling through the prognosis process

In order to illustrate the models that the framework has to support, it is proposed to apply the frame to the example of pro-activity capacity modelling for e-Maintenance and more precisely to the prognosis process. The illustration is based on the work done by Voisin, Levrat, Cocheteux, and Iung (2008).

4.1. Strategic vision

In the way to support the move from “fail and fix” maintenance practices to “predict and prevent” strategies, the e-Maintenance strategic decision has to promote pro-activity allowing anticipation. It means to avoid failed situations with negative impact on product or system or enterprise performances (zero breakdown maintenance).

4.2. Business process

The most important business processes to develop anticipative action are monitoring, diagnosis, prognosis and decision-making business processes. These four business processes belong to the business function called “To assess performance of future condition of the equipment” which is one of the MES functionality. Among these modules, the prognosis process is often considered as the Achilles heel (Wang & Vachtsevanos, 1999) while its goal is fundamental for implementing anticipation capabilities. Thus prognosis could be considered as a new maintenance business process because emerging with degradation and anticipation concepts (Muller, Suhner, et al., 2008).

Since 2004, the standard ISO 13381-1 gives a “textual” frame of the prognosis by defining it as “estimation of time to failure and risk for one or more existing and future failure modes”. In relation to other definitions as those of Byington, Roemer, and Galie (2002), Lebold and Thurston (2001), this definition specifies that the output of the prognosis process is composed of several remaining useful life’s (RUL). These definitions were completed by Voisin et al. (2008) to consider finally the prognosis business process which has to: (a) predict the future health state of the system; (b) generate the different RULs (of the system, component, etc.) for each detected or potential degradation/failure mode; (c) by taking into account the knowledge of the system (functional and dysfunctional), past information (background), current information (current state) and future information.

These three last items constitute the “textual identification of the prognosis business process objectives”. The external environment of prognosis (Fig. 5) consists of the following business processes: “To acquire and to process signal”, “To manage operations”, “To manage maintenance”, “To manage company”. The interactions between the external business processes and the prognosis process are done through a lot of flows. From the flows to be consumed and produced in order to achieve the RUL objective, the internal environment of prognosis is composed of four generic sub-processes: “To pilot prognosis” which coordinates the others, “To initialize state and performances”, “To project” and “To compute RUL” (Fig. 6). The semantic interoperability between sub-processes of prognosis is based on MIMOSA–OSA/CBM standards for which it was proposed some extensions to represent all the data contains by the flows produced and consumed (Fig. 7 represents only a part of the MIMOSA DB required to support data modelling for prognosis).

4.3. Organisation

Defining a maintenance organisation consists of assigning business processes (and their decompositions into activities) to the org-unit or actor that will perform these activities on a specific site (external or internal with the company). In general, the actors the most used in maintenance field are: the maintenance expert (local or remote), the CMMS actor, the Computerised Maintenance Operational System (CMoPS), the MES actor, the SCADA actor (Supervisory Control and Data Acquisition), the PDA actor (materialising the operator on site), the web-service actor, the PLC actor, the sensor actor. From this list, the maintenance actors addressing the prognosis process deployment are mainly: web
actor—outside the company; the CMMS actor, located off site in the business area; the CMOpS actor, located on site but not closed the machine; the MES/SCADA actor, located on site for developing the right production actions (in synchronisation with maintenance); the PDA actor, located on site and very closed the machines. The identification of the activities supported by each one of the previous actors and consequently the sequence required to develop the prognosis are directly generated from the generic view. A sequence diagram of the prognosis service is then developed. This diagram is defining the flows and communication operations between all the actors for supporting interoperation issue. The procedures (sequence of actions) were developed to support, at least, two type of RUL computing for the asset/segment (Voisin et al., 2008). Indeed the same prognosis web-service (WS) is addressing reliability-based prognosis (taking into account influences variable through the use of PHM) and condition-based prognosis (use of parameter to make the choice).

4.4. Infrastructure

The prognosis sequence has to be now implemented on TELMA. The principle of operation is to deliver a client-actor (PDA, CMOpS, CMMS, ...) the result of prognosis. In that way, a software agent is used in order to collect data and send them to the prognosis web service. Hence, the prognosis web service performs only the prognosis whatever the data could be. The following points have to be noticed:

- The client is the end user HMI. A template client is provided, i.e. the client is designed for working with the prognosis web service.
- The provided agent is designed for working with the prognosis web service hosted at a specific URL.
- The prognosis specific database containing model and Limit Level data is hosted on a SQL-server 2005 on a specific remote computer.

The WS uses MIMOSA database as an interface with the client. That is, the agent reads data in MIMOSA database and after that invokes the web service. The WS read the data transmitted (via XML file) by the agent, process it and send back the results to the agent. Finally the agent inserts prognosis result in the database and sends it to the client.

5. Conclusion

This paper uses a framework, built on five abstraction levels, to serve as reference for inventory most of the work related to e-Maintenance. First, e-Maintenance is justified in relation to new expected services and not only to e-technologies integration. Thus the first four levels are summarised to focus more on the infrastructure level. It allows to highlight the type of new technologies well adapted to up-grade the maintenance capacities and the existing e-Maintenance platforms. TELMA is then introduced and described as a full e-Maintenance platform. A more concrete application of the frame is illustrated to the case of

Fig. 6. Model of the prognosis sub-processes (internal environment).

Fig. 7. Item Prognosis represented with MIMOSA tables.
pro-activity capacity modelling for e-Maintenance on the basis of prognosis process modelling. All these contributions are expected to structure a new scientific and technological discipline called e-Maintenance. To complete this contribution, three main ways have to be both driven among the future common industrial/academic working/research directions:

- A way for improving the framework: It has to be reconsidered, assessed, and modified to be approved.
- A way for developing all the generic models needed for founding well the first three levels (only few models are available today); a way for developing (a) another e-technologies (level four and five) more adapted to support maintenance services and (b) e-Maintenance platform really based on collaboration and cooperation capacities to well support new services. We also should assess other platforms than TELMA in relation to the classification proposed.

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References

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