eMaintenance - Information Driven Maintenance and Support

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ABSTRACT

Today's providers of maintenance and in-service support related to modern aircraft are facing major challenges. A central problem with maintenance and support of aircraft and other complex technical systems is to manage the ever-increasing information flow and system complexity. Both military and commercial operators need to reduce downtime and one way to do this is to speed up the turnaround time for scheduled and unscheduled maintenance, or even better, to reduce the need thereof by implementing condition based maintenance. In order to implement these improved support solutions in a global support environment, eMaintenance is seen as one important building block. eMaintenance includes monitoring, collection, recording and distribution of real-time system health data, maintenance generated data as well as other decision and performance support to all stakeholders independent of organization or geographical location, 24 hours a day, 7 days a week (24/7). eMaintenance has the potential to improve the management and performance of activities related to the maintenance process, and thereby improve the dependability, safety and life cycle cost of critical systems. This is realized through the application of Information & Communication Technology (ICT) throughout the maintenance and support processes, thus integrating built-in tests, external tests at different maintenance echelons, technical information, diagnostics, prognostics and other sources of support information. The purpose of this paper is to present some results from a joint academic and aerospace industry research project, describing requirements and expectations that are important in a global support environment, and also to propose some central components in an eMaintenance framework that integrates maintenance and ICT perspectives.

1. INTRODUCTION

Aircraft manufacturers, as well as maintenance and in-service support providers, are experiencing ever-increasing customer requirements to increase dependability and decrease life support cost. A central problem for the industry is to manage the rapidly increasing information flow that follows the development of more complex and technologically advanced aircraft systems. Customers are also demanding improved system availability, cost effectiveness, operational flexibility and tailored worldwide support 24 hours a day, 7 days a week (24/7). This changing business environment requires new and innovative improvements of support products and services to satisfy the needs of customer and end user.

Maintenance and support concepts for modern complex technical systems, such as civil airliners and military combat aircraft, can be described as focussing on optimizing two fundamental and interdependent elements. The first element is the way in which the design of the aircraft (i.e. the system-of-interest) is influenced to maximize its inherent availability within available Life Cycle Cost (LCC) requirements. This ensures that the aircraft will have high reliability and maintainability in relevant operational profiles and support environments. The second element concerns the design of the maintenance and support system, which provides necessary support during the operation and maintenance phases of the system-of-interest. The maintenance and support system is an enabling system, i.e. a system that complements a system-of-interest during its life cycle stages, but does not necessarily contribute directly to its function during operation [11]. An enabling system provides functions and services to users and other stakeholders to ensure the proper and efficient function of the system-of-interest. [6]

On an operational level, end-users and managers utilizing the support and maintenance system of a modern aircraft are confronted with a multitude of computerized functions and information technology solutions. However, today there is little or no integration of functions and services related to the maintenance and support system, such

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as technical information (publications), maintenance programmes, maintenance plans, job cards, fault localization support, amendment services, health monitoring, and operational feedback. [4][7]

At the same time, producers and suppliers of maintenance products and customer support services are facing escalating challenges trying to sustain high quality and increase service levels for increasingly complex technical systems in an environment characterized by multiple products, suppliers and customers with increasingly stringent requirements. Hence, both customers and suppliers are facing increased complexity levels regarding information related to configuration control and change management for both the aircraft and its enabling system. This high complexity level of information management will hamper the operational effectiveness and drive LCC.

Therefore, suppliers need to change methodologies and processes for information management to be both more customer-focused and more efficient for internal development and sustainability. New concepts for the application of Information & Communication Technology (ICT) need to address information quality, lead time, accessibility 24/7, usability and an overall reduction of cost for information management related to maintenance and support. Capability also needs to be developed to enable more agile and efficient use of new maintenance and support functions integrated in the aircraft, exploitation of operational feedback, as well as rapid supplier adaptation to continuously changing customer specific requirements on both hardware and software products as well as services.

2. SCOPE

This paper focuses on a concept for ICT-based products and services for maintenance and support to modern aircraft operation. However, it is believed to be extensively applicable to similar challenges regarding maintenance and support of other complex technical systems, e.g. within the transport, process and power industries, as well as telecom and health care. The paper presents requirements and needs regarding the mentioned products and services that are important for both suppliers and customers (operators) of modern aircraft systems in a global support environment and proposes some central components of an information management concept, called eMaintenance Management Framework (eMMF), that integrates maintenance and ICT perspectives to address the challenges presented above.

The discussion of the central characteristics of system-of-interest (e.g. aircraft) and enabling systems (e.g. a maintenance and support system external to the aircraft) uses nomenclature based on established and agreed international standards [5] [6]. ‘Availability’ is used as a general term referring to availability performance and its influencing factors: reliability performance (the way the aircraft is designed to eliminate the need of maintenance, i.e. reducing or eliminating the probability of loss of required functions); maintainability performance (the way the aircraft is designed to facilitate maintenance, i.e. to retain or restore the aircraft’s required functions); as well as maintenance support performance (effectiveness and efficiency of the maintenance and support organization).

3. MAINTENANCE WITHIN AVIATION

Experience from maintenance and support system development and real life operations [14], combined with expectations for future scenarios, stress the importance of supporting the operational capability and competitiveness through high availability of aircraft (but also other complex technical systems, such as, maritime and ground systems). Increasing civil requirements on mobility and availability, and military operations from provisional bases combined with rapidly shifting conditions, increase the importance of information and decision support to personnel that service and maintain systems in operation.

The aircraft design, as well as the maintenance and support system, needs to be very structured and controlled, meeting requirements with the overall objective of maximizing the total system capability at the lowest LCC, see Figure 1. The design of the maintenance and support system itself also needs to take into account other requirements, such as operators’ requests to consider re-use of existing resources and capabilities (e.g. facilities, manpower, competencies, ICT infrastructure and standards) and future requirements, operational or product development requirements, as well as desired levels of self-support.

Figure 1: Important requirements related to aircraft effectiveness

New technology and innovation also drive development and create new needs. A military example is the so-called fourth generation combat aircraft, e.g. Dassault Rafale, Eurofighter Typhoon and Saab Gripen. These are system aircraft with a digital infrastructure and fully integrated computer systems that utilize a common database through standardized interfaces [1] [10]. The building principle of a system-of-systems supplies an immense potential for functional development, but also an extremely complex aircraft system [14]. The civilian equivalents, such as the Boeing 787 Dreamliner and Airbus A350, have focused on ICT as a central component for more efficient maintenance and support solutions. A central part of this aircraft technology development is advanced Built-in Test (BIT) systems. The aircraft BIT is constantly being developed to improve safety, maintainability, testability and supportability of the aircraft as well as to provide health information. This extended access to qualified data from operation and maintenance provides the technical foundation for condition monitoring, extensive data recording, test, diagnostics, prognostics and decision support for condition-based operation and maintenance [14]. These technology trends, together with the pervasiveness of ICT in the maintenance system and support processes, are also key enabling factors for implementation of remote support services accessible world wide and 24/7. Nevertheless, the BIT is itself a development that adds further requirements and puts strain on supporting ICT frameworks and information management processes.

Thus information management and new ICT solutions has become a central aspect and common denominator for many of the new challenges regarding system complexity, configuration control, change management and applicability of product information, both for the systems-of-interests and their related support system products. To meet the increasing demand on availability and to cut costs, maintenance and support actors are becoming more and more dependant on ICT to provide timely and accurate information. Efficient ICT solutions have rapidly risen as a key driver for good decision-making and effective operations. One example of an area with great improvement potential is technical publications. A large proportion of the information support used by maintainers in the aerospace industry is still paper documents, or 'paper-on-screen' solutions (e.g. paper publication suits published as PDF). All this, despite the fact that new aircraft complexity, integrated digital systems and air-to-ground real-time communication tools make paper-based approaches increasingly inadequate. This generates unnecessary cost for the simple reason that maintainers often lack products and services for information support that are adapted to specific roles and situations, and therefore cannot work as efficiently as possible. [3] [4].

With reference to the problem and solution domains presented above, the concept of eMaintenance presented in this paper can be defined as a structured and coherent application of ICT in the design of the maintenance and support system,, coordinated with technical solutions in the aircraft system. The main goal is to create a more efficient maintenance and support process by optimization of an eMaintenance framework as a part of the enabling systems, and thereby improve overall system effectiveness,

To secure the performance of an aircraft at a reasonable cost, it is vital that the design of maintenance and product support concepts is done correctly right from the design phase [2] [11]. The character, scope and allocation of the support needed, must also be influenced by the customers' competencies, as well as the environment for the operation, but also organizational and cultural issues [11] [13]. The overall maintenance process needs to be taken into consideration, including its sub-processes for management, support planning, preparation, execution, assessment and improvement (see Figure 2). Hence, the requirements analysis must consider a multitude of aspects, facts, needs and properties of the technical system, customer requirements and the context for operation and maintenance for the given system, supplier requirements and other stakeholders, as well as environment and legislation.

Yet another aspect is the fact that traditionally the civil and defence aerospace industries have built and sold systems to operators. Today, this approach is changing and the industry also has to provide services that traditionally have been carried out by the operators or other third party suppliers. The highest degree of commitment is needed when delivering total care, or functional products, where the customers are offered availability performance at a fixed price. One example of this is the requirement of 'Maintenance Free Operating Period' (MFOP). These are market driven requirements on an eMaintenance solution, which introduce additional stakeholder perspectives. [3]

4. EMAINTENANCE REQUIREMENTS

With reference to the material presented above, the development of products and services integrated with ICT in an eMaintenance solution for support to operation and maintenance of complex systems, needs to address a number of central requirements such as:

- integration of the system-of-interest and its enabling system, to exploit technological development of modern aircraft and ICT in efficient solutions for global maintenance and support 24/7,
- Facilitation of configuration control, change management and directive information applicability for both the system-of-interest and products and services included in the enabling system,
- Integration of role and situation adapted products and services for information and performance support with high accessibility and usability,
- coordination and integration of consumption and production of information at different phases of the maintenance process
- coordination and integration of tests, diagnostics and prognostics for condition-based operation and support at different maintenance echelons
- support to performance-based contracts and functional sales (e.g. power-by-the-hour)
- adherence to international (information) standards.

eMaintenance needs to facilitate support to operators' and other stakeholders' work through information and performance support to the overall maintenance process related to modern aircraft, including ground support equipment and training devices. eMaintenance also needs to provide a framework and processes for managing product data and information, maintenance and support information as well as feedback of data and information from operational and maintenance activities. This spectrum of requirements built on industrial and operator experience, drives the approach that the improvement of the operative performance and effectiveness of maintenance and support through the introduction of eMaintenance, need to target all phases of the maintenance process (see Figure 2).

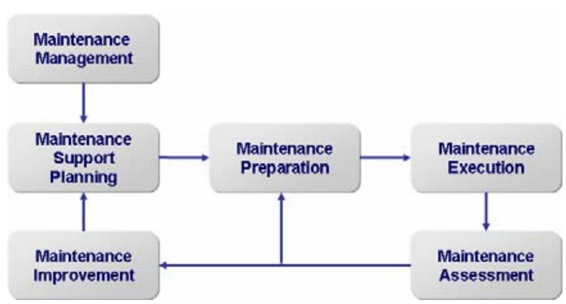

Figure 2: Sub-processes of an overall maintenance process, adapted from [5]

In order for the aerospace industry to manage the risks associated with these new, diversified and enhanced solutions in a global support environment, a wide collection of heterogeneous information sources need to be funnelled and made available for the right user, in the right format, in the right place, at the right time. In the past, the information flow has been quite rigid and inflexible between a rather small number of stakeholders. However, in the future the exchange of information is required to reflect closer working relationships and a more dynamic, global support environment and deliver efficient and tailored support for decision-making to stakeholders spanning from Original Equipment Manufacturers (OEMs), sub-system suppliers, through system integrators on to operators, maintainers and support providers.

Another important requirement that follows on from the character of the challenges presented above is that information management concepts and application of new ICT solutions within the aerospace industry, to a growing extent need to be both based on, and capitalize on international standards for structured product data sharing. Central among these standards are Product Life Cycle Support (PLCS) [12], Sharable Content Object Reference Model (SCORM) [15] and the ASD (AeroSpace and Defense Industries Association of Europe) specifications suite of standards for Integrated Logistic Support (ILS); S1000D, S2000M and the emerging S3000L and S4000M.

As discussed above, the overall maintenance process involves sub-processes for management, support planning, preparation, execution, assessment, and improvement, see Figure 2. These sub-processes consist of different sets of activities, which are interrelated and adapted to fulfil requirements from different stakeholders. Stakeholders within the maintenance process consume and produce information when performing different activities. For example, during maintenance execution, a maintenance technician receives a work order that requires a maintenance action, and after the performed action the technician reports the outcome. The information from the execution process can further be aggregated to a context in the assessment process. As illustrated in Figure 3, the maintenance technician needs to access various types and formats of information through different information sources when conducting a maintenance action.

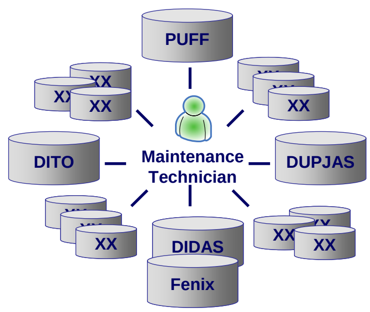

Figure 3: Illustrating the information system needs of a maintenance technician

Hence, one of the main objectives of establishing a platform for eMaintenance is to provide a supporting ICT environment that improves the performance of the maintenance process by providing seamless and integrated services for sharing content. It is commonly accepted that data collection and distribution is a major issue in the maintenance process and a cornerstone in the area of eMaintenance [7]. It is also accepted that there is a need to be able to convert data to information, and based on this information to generate knowledge valuable for decision-making. In order to make the right decisions, there is a need to be able to access and manage the right knowledge. Since knowledge, a term which basically refers to what is known, is not only a summarization of known raw data through information interpretation, but also implies other artefacts, such as documentation and experiences, the authors believe that the focus should be on the content and the content sharing in the maintenance process rather than on data and data processing. [8]

ICT is one of the main prerequisites, not only to improve the maintenance process for complex systems with long lifecycles, but also to reduce risks, and contribute to a more efficient business process. The utilization of ICT facilitates content sharing and knowledge management within the processes of the maintenance process, coordinates the maintenance process with other processes (e.g. operation and modification processes) and links it to strategic business objectives and external stakeholder requirements In order to offer an effective and efficient eMaintenance solution, some essential requirements need to be fulfilled by means of an eMaintenance Management Framework

As shown in Figures 5 and 6 the eMaintenance Management Framework (eMMF) is the institution of a framework, a meta-level model through which a range of concepts, models, techniques and methodologies can be clarified and/or integrated. The main aim of an eMMF is to facilitate maintenance. The framework consists of two parts: the eMaintenance Management Model (eMMM) and the eMaintenance Platform (eMP). The eMMM is a package of roles, processes and repositories required for managing the eMP. The eMP is a Service-Oriented Architecture (SOA) application, created to provide its stakeholders with tailored information for making decisions on the choice of appropriate maintenance activities.

The eMP is divided into three levels: Specification, Design, and Implementation (see Figure 6). The Specification level contains all the information necessary for conducting industrial maintenance. It describes the identified requirements, which are realized in various ways using notations such as text and models. The Design level identifies design components that are needed to fulfil the requirements specified in the Specification level. This level is realized as service components. Finally, the Implementation level materializes the service components specified in the Design level into the web services and business processes orchestrated for the needs. Each level consists of one or several groups of components. All components in the specification level provide a platform for creating other components in the Specification level or they get directly realized on the Design and/or Implementation levels. [9]

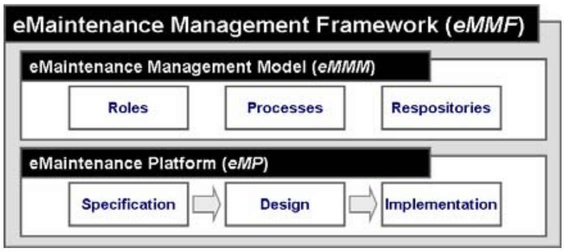

Figure 5: Illustrating the substances in eMMF [9]

eMP provides artefacts for supporting the maintenance process, e.g. situation adapted information and services for performance support [4][7]. Further, we have explored how SOA can be exploited in eMP. Hence, our conclusion is that the eMP can be utilized to implement an eMaintenance platform in organizations that provide maintenance of complex technical systems. We believe that eMP also is applicable in any organization providing maintenance, since it has been based on a generic overall maintenance process.

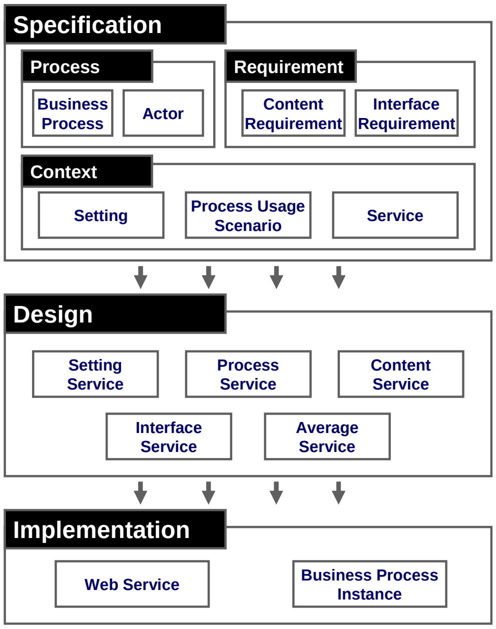

Figure 6: Illustrating the substances in eMP [9]

The Specification level contains all the information necessary for conducting industrial maintenance. It consists of three components: Process, Requirements and Context. The Process component lists and describes the business processes and actors involved in them. It consists of two parts: Business Process and Actor. The Context component lists and describes various backgrounds and their interrelated conditions in which maintenance activities take place. It consists of three components: Setting, Process Usage Scenario, and Service. The Requirement component lists and describes all the functional and non-functional requirements on the information needed for a specific maintenance task and the interface through which this information should be presented. It consists of two components: Content Requirement and Interface Requirement.

The Design level transforms most of the specification components into SOA components. The role of the Setting Service component is to design choreography for a certain set of services. The role of the Process Service component is to design a composition of miscellaneous services orchestrated for serving a particular process. The role of the Content Service component is to design services that implement logic for interaction with different data sources, such as existing systems or legacy systems. The role of the Interface Service component is to design services that handle/manage/wrap/adapt interface to other devices such as a portable handheld computer. The Implementation level materializes the SOA components into the web services and business processes orchestrated for the needs at hand. The Web Service component implements the SOA components in the design level as Web Services. We use Web Services, since they provide a generic interface for encapsulating logics and can be utilized as an intermediate layer to access legacy systems. The Business Process component corresponds to business processes as orchestrated for the needs at hand and delivered to the service consumer. In the context of eMaintenance, there is a need for both predetermined business processes and reactive business processes.

5. CONCLUSIONS

The positive impact of eMaintenance is to be expected on two levels. On one, the 'maintenance micro-level', it will serve as a performance support facilitating hands-on execution of maintenance tasks by technicians, mechanics and support engineers, by providing a reduced number of interfaces to information sources, improved fault diagnosis, knowledge sharing and automated or facilitated procedures for technical administration. On the higher 'maintenance macro-level', eMaintenance will support managerial maintenance planning, preparation and assessment, enabling information driven maintenance and support processes, and fleet-efficiency, e.g. aircraft maintenance programme evaluation, elimination of redundant information and operational monitoring.

There is also the challenge of going from a product-oriented to a service-oriented business strategy. Product-oriented strategy relies on a transaction/exchange marketing, while service-oriented emphasizes the relation between provider and customer. A service-oriented business strategy also demands the harmonization of support processes, such as the maintenance process, to the business's core process. The business's core process ought to be adaptable to the changes in the customers' value-generating process, and the business's supporting processes need to be adaptable to the core process.

Since an eMaintenance platform's major purpose is to support the maintenance process, the components of the platform need to be considered from a service-oriented perspective in order to increase its adaptability to the different parts of the maintenance and support process in different organizations. Hence, eMaintenance can be considered as a platform for smart content sharing between information provider and information consumer. We use the term-pair provider/consumer to emphasize that the ICT support to the maintenance process should adopt a process-centric approach, supporting efficient maintenance and support solutions. In a supplier/customer approach, the definition of the organizational boundary is important, which is not necessarily an issue of importance for delivery maintenance ICT services.

The maintenance process has to interact with a number of correlated processes in an enterprise, e.g. business, operation, information, support, and logistics. Hence, a service-oriented eMaintenance platform should provide services that can be incorporated and orchestrated to flow of these processes. While the requirements on the maintenance process vary over time, the architecture of eMaintenance should be constructed to provide applicability and effectiveness.

With applicability and effectiveness as the two major requirements, it is clear that a Service-Oriented Architecture (SOA) approach is a prerequisite for being able to design an ICT architecture which will provide applicable and effective eMaintenance services. Furthermore it should be noted that a Service-Oriented Infrastructure (SOI) is a prerequisite for implementing SOA. , It is important to be aware that Web Services (WS), and their related technologies, e.g. WS-BPEL, WS-Transaction and WS-Coordination, are not synonymous with SOA: SOA is a way of thinking that approaches the architectural issues and WS is technology that is designed to facilitate the implementation of SOA.

We believe, based on our study of the effects of eMaintenance, that the eMaintenance platform, mainly through its improvement of the different parts of the maintenance process, impacts on the dependability, safety, and life support costs of critical systems. Hence, our conclusion is that an eMaintenance platform (eMP) structured, designed, and implemented from a service-oriented perspective with focus on the business process, increases the ability to fulfil the requirements such as context-awareness, situation-awareness, seamless information integration between processes (e.g. operation and maintenance), improved knowledge-sharing, flexibility, extensibility and cost-reduction. Further, we can conclude that SOA as an approach and Web Service as a technology can be utilized to implement service-oriented maintenance services. Loosely connected maintenance services can easily be re-composed and orchestrated to the new process, situation and context to better fulfil different stakeholders' requirements.

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REFERENCES

[1] Ahlgren, J., Christofferson, L., Jansson, L. & Linnér, A., Faktaboken om Gripen. (4th ed.), Industrigruppen JAS, 1998.(In Swedish).

[2] Blanchard, B. S. , Logistics engineering and management. (4th ed.), Englewood Cliffs, NJ: Prentice Hall, 1992.

[3] Candell , O. and Söderholm, P., A customer and product support perspective of eMaintenance. 19th International Congress on Condition Monitoring and Diagnostics Engineering Management (COMADEM), pp. 243-252, Luleå, Sweden, 2006.

[4] Candell, O., Development of User Information Products for Complex Technical Systems, licentiate thesis, Luleå University of Technology, Luleå, Sweden, 2004.

[5] IEC 60300-3-14: Dependability management, Part 3-14: Application guide; Maintenance and maintenance support. International Electrotechnical Commission (IEC), Geneva, Switzerland.

[6] ISO/IEC-15288, "Systems engineering – System life cycle processes", (International Organization for Standardization, Geneva. International Electrotechnical Commission, Geneva., 2003), 2003.

[7] Saab, internal document. Candell, O., Maintenance WorkStation – MWS, Final Report, 2007.

[8] Karim, R and Söderholm, P., "Application of Information and Communication Technology for Remote Support Services: Transferring experiences from an e-Health Solution in Sweden", Submitted for publication, 2007.

[9] Karim, R., Kajko-Mattsson, M. and Söderholm, "Exploitation of SOA within eMaintenance", 2008.

[10] Lorell, M., Raymer, D. P., Kennedy, M. & Levaux, H., Grey threat : assessing the next-generation European fighters. Santa Monica, Ca.: Rand Corporation, 1995.

[11] Markeset, T. and Kumar, U., Design and development of product support and maintenance concepts for industrial systems. Journal of Quality in Maintenance Engineering, 9, (4), 376-392, 2003.

[12] OASIS, "OASIS Product Life Cycle Support (PLCS) TC". Available <http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=plcs>, 2006.

[13] Pinet, J., Human factors: A humanist and ethical approach to aeronautics. Part I/III. Air & Space Europe, 2, (1), 2000.

[14] Sandberg, A. and Strömberg, U.. Gripen: with focus on availability performance and life support cost over the product life cycle. Journal of Quality in Maintenance, 5, 325-334., 1999.

[15] SCORM, "Sharable Content Object Reference Model", Available http://www.w3.org/2004/04/webapps-cdf-ws/papers/SCORM.htm , 2004.