International Journal of Performability Engineering, Vol.7, No. 6, November 2011, pp. 583-592.

Printed in India

Development of Information System for e-Maintenance Solutions within the Aerospace Industry

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(Received on December 15, 2010 and revised on July 27, 2011)

Abstract: Maintenance and support providers to modern aircraft need to manage an increasing amount of information generated by growing system complexity and stakeholder requirements. This introduces new risks in the information management process and makes traditional information services and systems inadequate. However, recent advancements in information and communication technology (ICT) have contributed to the emerging approach of e-Maintenance, which forms an important building block to achieve the desired information logistics. e-Maintenance enables remote and real time maintenance, and includes; collection, monitoring, analysis and distribution of data and information as decision-support to stakeholders of the maintenance and support processes, independent of organization or geographical location, 24 hours a day and 7 days a week (24/7). This paper describes a proposed development of information products by linking theories to practical methodologies and tools (*e.g.*, Quality Function Deployment, QFD) through the development of a demonstrator of a stakeholder-based information product in the context of a modern combat aircraft.

Keywords: *Information services, information logistics, information and communication technology (ICT), maintenance, maintenance support*

1. Introduction

Within the aerospace industry, customer demand for system dependability and Life Cycle Cost (LCC) has increased. This has led to reliability requirements other than the classic requirement of failure rate being imposed [1,2]. Examples of such requirements are "power-by-the-hour" on the commercial side and Maintenance Free Operating Period (MFOP) on the military side. These requirements are manifested by business solutions, such as Performance-Based Logistics (PBL), where the supplier takes an increased responsibility for the performance of the aircraft in its operational environment than traditionally. This change is also driven by an increased complexity of the aircraft and its support system, which makes it more difficult for the customer to keep the knowledge and resources necessary to support the aircraft.

Though increasingly more complex systems also provides more advanced capabilities. Fullington and Donaldson [3] argues that integration of health management to enhance product support supports knowledge-based maintenance and customer support system, and improves aircraft availability and cost efficiency through decreased delays and advanced reliability analysis. A technological approach to support the PBL trend is the

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integration of advanced prognostic health management system with the logistic solution, such as the US Airforce Joint Strike Fighter Autonomic Logistics system [4]. The application of PBL also drives the development of processes for Operational Performance Monitoring (OPM) and Life Cycle Management (LCM).This development is necessary to evaluate and manage system effectiveness and continuous improvement of the aircraft and its support system throughout their lifecycles in a global support environment with dynamic stakeholder requirements [5,6,7]. Hence, the OPM and LCM need to contribute to ultimate system effectiveness, see Figure 1.

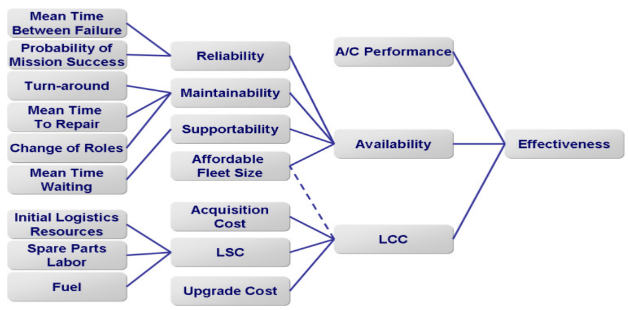

Figure 1: Important Stakeholder Requirements related to Aircraft Effectiveness

The increasingly complex design and computerization of aircraft systems also provides necessary continuous improvement and development of the system[8,9,6], as well as extended access to data and information. However, the ever increasing information flow that follows with the increased complexity is also a central and common problem for both suppliers and operators [10]. Today, there is still a problem for users to access and understand the information [11]. There are information deficiencies, the causes of which are data overload and information islands that cause problems in the decision-making process [12, 13, 14]. To achieve the necessary OPM and LCM in the context of PBL, the solutions need to support an improved utilization of operational data and maintenance information exchanged between system´s supplier and operators.

Today, new and innovative Information & Communication Technology (ICT) are included in the aircraft and its support system provides technological and methodological possibilities to implement solutions for the required information logistics [15] to provide just-in-time information to the targeted users and to optimize the information supply process. One application of information logistics within the support area is the emerging approach of e-Maintenance for decision-support to stakeholders. However, the development of appropriate information logistics is a challenge, when dealing with maintenance of aircraft system.

The context presented above combines the need of improving user information products, consisting of both services and systems, as a vital part of effective and efficient e-Maintenance solutions. However, design of information for users is primarily an issue about content and meaning and should according to Jacobson [16]. To manage the growing system complexity, design of information flow and usability requirements, both methodologies and tools for the development of information products need to be improved. Therefore, the purpose of the study presented in this paper was to explore and describe the development of information products for e-Maintenance solutions related to aerospace industry.

2. Information Product Development

As all other products, information products might consist of goods, services or any combination thereof (see, *e.g.*, [17, 18]. User information can be seen as a spectrum of information types that support the users in operational activities during different types of tasks, as well as knowledge focused information for education, training and other non-operative tasks [13]. Today, this implies a very wide domain of information types, such as descriptions, instructions, user manuals, on line-help, check lists, illustrated spare parts catalogues, and functional and wiring diagrams [13].

Technical user information can be approached as an interface between man and technology [19, 20] , and it can thereby be seen as a part of the joint system of man and machine. As such, user information exists to a great extent for communicating intention or instruction about a technical system to humans. This implies that the author or designer develops a user information product which envisions about the connections between the purpose and properties of the information, the system-of-interest, as well as about the abilities of the human recipient. These envision are based on a mix of experience and theoretical knowledge from different domains.

A consequence of choosing a system and cognitive perspective is that, the choice of channels and media for the transfer of information will be a secondary issue. Design of information for users is primarily an issue about content and meaning, and should according to [16], not primarily takeoff in discussions about media or technology for the transfer of the message. However, studies by Sonesson [21] and Jernbäcker [22] discuss the advantages of utilizing small computers compared to traditional print, to supply user information for operative technical military personal. Similar experiences are presented by Drury [23], whose study showed that a computer-based system of work cards for aircraft inspection was a significant improvement compared to traditional paper-based solutions.

In the end, aspects of both content and technology need to be taken care of as the process of supplying user information can be described as a chain of functions, starting at the design of the actual technical system and ending at that time and place, where the users need support [13]. Hence, information products should deal with the four aspects of; time management, content management, communication management, and context management [24, 25].

There are many different approaches to the development of information products, *e.g.,* software engineering and quality technology. One proven methodology that has been used in the development of a multitude of different products is Quality Function Deployment (QFD); see *e.g.*, Karlsson [26] and Herzwurm and Schockert [27]. Akao [28] describes QFD as a methodology for developing a design quality aimed at satisfying the consumer and then translating the consumer's demands into design targets and major quality assurance points to be used throughout the production phase.

3 Approach Employed

The study was performed as a single case study in combination with actions research within the context of the Swedish Saab JAS39 Gripen aircraft, a fourth generation combat aircraft which is a highly complex technical system with stringent requirements on dependability, safety and costs. The study approached the aircraft (*i.e.,* system-of-interest) and its support system from a user information perspective. Hence, other parts of the support system, such as material support, training, facilities or maintenance engineering were not explicitly studied. The major information stakeholders that were included in the study were technicians that support and maintain the aircraft, as well as pilots that fly the aircraft.

The empirical data from the JAS39 Gripen system were collected for the purpose of studying the application of the suggested development process, that were adapted to support the development of information support services and products for complex technical systems in general, and JAS39 Gripen in particular. These data were mainly collected in the forms of requirements, notes and other statements not only from workshops and interviews, but also from documents. [29]

To develop and validate a proposed way of working of user information products, the research included the development of a demonstrator. This work was performed in a cross-functional team consisting of researchers, informatics specialists and software developers. The work was conducted in small PDSA-cycles (Plan-Do-Study-Act) towards established and clear goals. As supporting methodology for the work, both the theoretical part of the study and initial empirical work resulted in the choice of QFD as an appropriate way of working. Details of the study approach are described in Candell [13].

4 The Gripen Case Study

The Gripen case study showed that the development of information services and systems as support to operation and maintenance of complex systems should consider a number of central requirements that needed to be addressed, 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 support 24/7;
- Facilitation of configuration control, change management and directive information applicability for the system-of-interest, products and services, as included in the enabling system;
- Integration of role and situation adapted for information and performance support for 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; and
- Adherence to international (information) standards.

In this context, the human receiving the message is not thought of only as a receiver but as an active part in the communication process, influenced by environment and culture. This can be described as cognition "in the wild", *i.e.,* cognitive activity as an activity in a context often distributed across multiple agents rather than isolated in a single individual [30] .

By striving towards better composed and more integrated information solutions and state-of-the-art tools gives end-users a smooth information flow between different tasks and applications, troubleshooting resulting in reduced maintenance time and reduced documentation costs. More specifically, in the studied Gripen case, the information need is tailored to fit the role and situation of a so called general aircraft technician, who replaces the concept for older aircraft types with different types of technicians specialized in disciplines like engine, avionics and weapon.

The Gripen aircraft technician, as a representative end-user, is a central actor within an overarching maintenance process that may be described by the six phases: Maintenance

Management, Maintenance Support Planning, Maintenance Preparation, Maintenance Execution, Maintenance Assessment and Maintenance Improvement, see Figure 2.

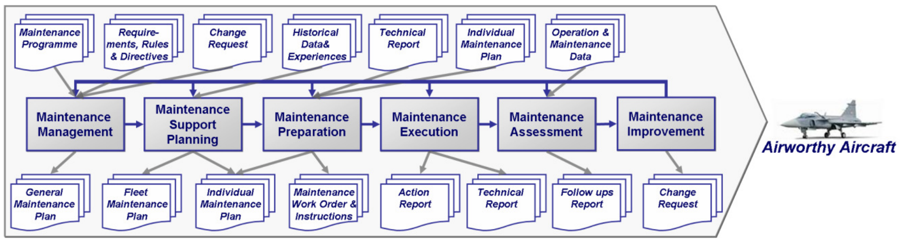

Figure 2: Example of Aircraft Maintenance Process

Actors who act within each such phase needs to be supported with adapted and timely information, which in turn may be of dual-use, *i.e.,* in other phases. The generic maintenance process does also need information feed-back, *i.e.,* user experiences as well as operation and maintenance data (sub-sets from *e.g.,* the operators Maintenance Management System, MMS), for processing as well as for operational and maintenance performance monitoring (OPM), Life Cycle Management (LCM), as for continuous improvement of the primary product and the maintenance Compared to traditional processes, the presented approach focuses on provisioning of process oriented, situation and role adapted information support, as well as better attention to the improvement value of operational experiences and data feed back.

Though the information provided for a complex technical system such as an aircraft, need to be both process oriented (compare Figure 2) as well as accessible for support in a hierarchical, or vertical, system dimension of a and very intricate configuration and item structure. See Figure 3.

On a practical 'micro-level', the end-user needs information for their work in the maintenance process is today accessing it in a multi-application environment with little, or no, integration of information products and services, fault localization support, amendment services, health monitoring or functions for feedback of operational data or maintenance records.

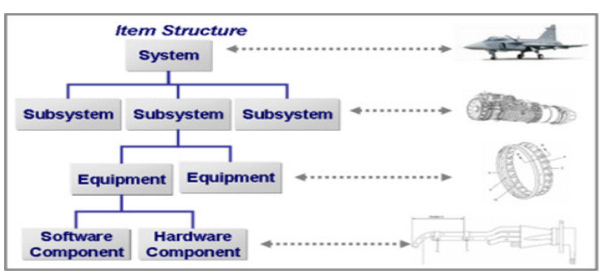

Figure 3: As a vivid example of a complex technical system, a modern combat aircraft has a hierarchical and very intricate configuration and item structure. [29]

By observing the information needs in the maintenance process' inherent phases, some characteristics get crystallized, which help to identify some common generic problems. Central to this study in a maintenance actor perspective, *e.g.,* the maintenance technicians, is the need to interact with various types and formats of information through different information sources when conducting a maintenance action as illustrated in Figure 4.

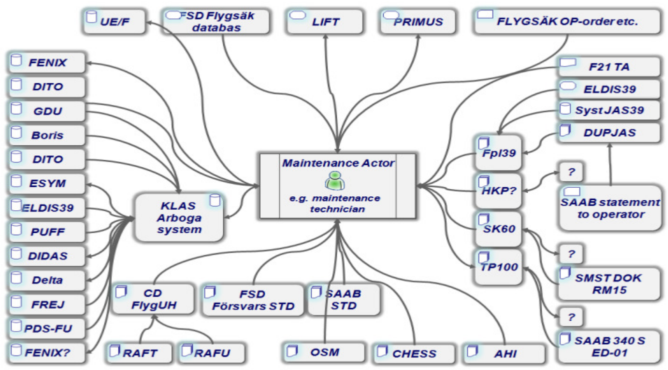

Figure 4: Illustrating the Example of Information System Needs of a Saab JAS 39 Gripen Maintenance Technicians or Planners

This interaction can be reading, writing or both. Behind the great number of abridgements figuratively depicted in Figure 4, lie a variety of artefacts ranging from separate binders or books (*e.g.,* Swedish Airforce OSM (Processes and safety regulations for Ground Service), to a major IS resource such as FREJ, the Swedish Defence Forces common supply database system. The different information sources and types does in turn emanate from different stakeholders or providers, such as the aircraft manufacturer (*e.g.,* DUPJAS, the Gripen aircraft tech pubs suite) and the operator *e.g.,* Swedish Airforce OSM, witch even further complicates a more sophisticated coordination and harmonization of information content, structures and usability.

The technical personnel that work with aircraft (civil or military) and are central information stakeholders could roughly be classified in two categories:

- Aircraft mechanics (can be military conscripts) and technicians (technical officers) at operator of civil or military aircraft (flight line operation and operational maintenance level, O-level);
- Technicians (civilian or military personnel) at intermediate and depot level maintenance workshops.

This classification comes from the division of technical work into different maintenance levels. The daily operation of the aircraft is supported by so-called operational level maintenance, which is performed on the flight line or in local workshops, on site at the air wing. For the operational level maintenance, the primary users of technical publications are aircraft technicians and conscript aircraft mechanics. They are mainly doing on-aircraft service and maintenance, *i.e.,* working with the complete aircraft. At intermediate and depot level maintenance workshops the users are civilian technicians and engineers, and the maintenance is both made on-aircraft (*e.g.*, remove and replace of Line Replace Units, LRUs) and off-aircraft (*i.e.,* on LRUs removed from the aircraft). This gives a natural separation between operational and intermediate or depot level maintenance and finally between a complete aircraft versus removed equipment and components.

Though on an higher 'macro-level', the information support solution also need to support the six phases in the overall maintenance process as sub-processes for management, support planning, preparation, execution, assessment, and improvement. 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 that both 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.

5. Results

The outcome of the Gripen case study may be described in two parts. The first part is the identification of methodologies and tools for elicitation of requirements and user-information development, from the area of cognitive science and joint systems of man-machine, quality technology and formal requirements management. The second part of the study is the validation of the suggested way of working, tested through the development of the demonstrator. Summing up, the study presents results that central e-Maintenance stakeholders need correctly designed information products integrated in information support solutions. Different perspectives considered are: supplier perspective; data and information exchange; extraction of on-board maintenance data; and scalable software solutions.

The development work showed that the QFD-methodology, matrix and affinity diagrams, combined with the system view, could support actual development work of stakeholder-based information products for complex technical systems. The suggested way of working that emanated is illustrated in Figure 5, and some particularly important tasks are marked with the letters A-E and shortly described below.

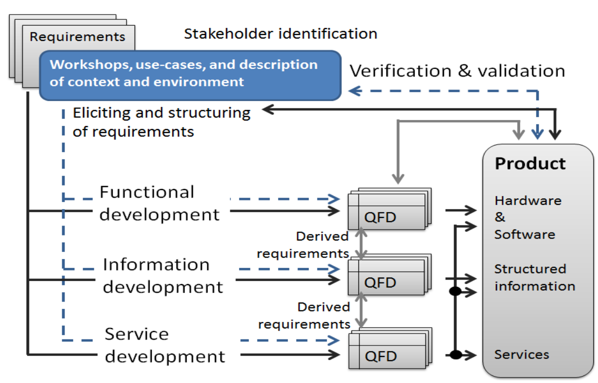

Figure 5: The Suggested Way of Working for Development of User Information Products and Services [13].

6. Discussion and Conclusions

The results of the study indicate that positive impact of improved methodologies for development of e-Maintenance and Product Support Information that facilitates aircraft operation and maintenance is to be expected on two levels. The suggested way of working emphasises on: increased stakeholder focus; more efficient communication between developers, stakeholders, and development team; facilitating and improving the requirements management; to reduce business risks connected to misinterpretations and disagreements over specifications; a holistic view of the system-of-interest; and continuous knowledge transfer. This makes it possible to identify in early stages of the development problems and needs for adaptation, or change, in the way of working and the demonstrator design.

The development of the demonstrator, both software and hardware, provides a validation of the way of working and a user information product prototype for future user information products. It uses existing structured information from the JAS39 Gripen system to achieve a high level of realism and thereby also creates realistic conditions for a validation of the demonstrator.

On the ‘maintenance micro-level’, e-Maintenance solution will serve as a performance support facilitating hands-on execution of maintenance tasks by technicians, mechanics and support engineers. On the higher ‘maintenance macro-level’, it will support managerial maintenance planning, preparation and assessment, enabling information driven maintenance and support processes, and fleet-efficiency.

In order to develop and implement the improvements of information support solutions in a global support environment discussed above, e-Maintenance is seen as one the important building blocks. e-Maintenance solutions also facilitate the information exchange and integration between different stakeholders within the maintenance process, throughout the life cycle of the system-of-systems, see Figure 6. e-Maintenance solutions also support the implementation of principles of Integrated Logistic Support (ILS) [15], which is a disciplined, unified, and iterative approach to the management and technical activities which can be expressed as follows: I) define support; II) design support; III) acquire support; and IV) provide support. [31]

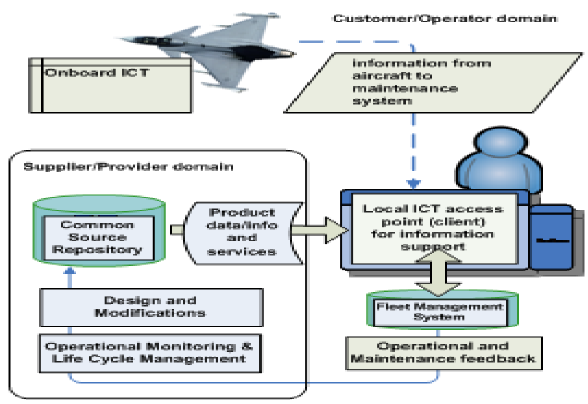

Figure 6: Illustration of an e-Maintenance concept for Information Integration

The results of the development of the demonstrator showed that the use of the matrix diagrams could be adapted to transfer of requirements to the design process, and thereby support the development of stakeholder based user information products. This comprised, for example, documentation of correlation between quality elements and functions numerically as attributes, instead of graphically in the so-called House of Quality (HoQ) roof, and the concept of requirements deployment in matrices in three different tracks for development of functions, structured information and services. In summary, the results of the research project may be viewed from two perspectives. The first is the development of a way of working to support the development of user information products for aerospace industry. The second perspective is the dual use of the development of a demonstrator, both as a means for validating the suggested way of working and as methodology for product development.

It can be concluded that development of information products for aerospace industry can be facilitated through e-Maintenance solutions that can provide effective information logistics for internal and external stakeholders involved in the maintenance process.

Acknowledgement: The authors acknowledge the financial support of the National Aeronautics Research Programme (NFFP) and Saab Aerotech. The Aircraft Services Division at Saab Aerotech has together with Sörman Information & Media participated in the NFFP-project and assisted with information to the study.

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