Integrated Approach to Capability Enhancement and Maintenance: A Proposed Framework

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ABSTRACT

In the current climate, the defence sector is increasingly characterised by longer product life cycles and asset availability demands. There is likely to be a reduction in the number of defence acquisition projects in the future. This, combined with military organisational changes and the fact that governments are steering towards contracting for capability, has led to an internal shift in manufacturing centric companies. These traditional companies are now providing service support for their products, thereby offering reduced risk to the customer. The service support aspect includes the use of new technologies and methods for managing technical products over their life cycle and ensuring that the customers' required capability and availability demands are met. This imposes new challenges on subsequent maintenance, repair and capability enhancement procedures. This paper proposes a framework for the development of a Maintenance Dashboard. The underlying purpose being to establish an approach that supports the decision making process on whether to maintain, repair, upgrade or update a given platform system. The Maintenance Dashboard proposal is aimed at extending the 'useful phase' of a product's life.[†]

1 INTRODUCTION

The time between major platform procurements is increasing and thus there is a need to 'ramp up' the pace of technology insertion and capability enhancement. This can be achieved through taking into consideration advances in both the defence and civil sectors, thus allowing a response to both 'evolution and revolution in capability'. There is a requirement for open architectures which permit the incremental insertion of technology in a 'plug and play' manner. In order to enable this, platforms and systems need to be designed with upgrade and adaptability in mind. New roles for existing systems are also defined in response to changing threats. Targeting those systems that need to be modular in nature, requires specific identification of technologies which evolve rapidly. Alongside capability enhancement is the need to reliably predict system status. Prognostics is key to aiding both operational and support planning. Effective maintenance planning allows for improved fleet management and reduced support costs. This sets the scene for the development of an integrated approach to capability enhancement and maintenance

The reasoning behind the integrated approach stems from the fact that both topics are based on the same fundamental comparison of capabilities. At a basic level, in the case of preventive maintenance, the performance of a capability enabling system fluctuates between design operating and actual values. When considering capability enhancement, the current system capabilities are compared with future and/or desired capabilities. In this manner, it is possible to determine whether a system requires maintaining, repairing or upgrading. Intrinsic to the upgrade decision is the consideration of obsolescence management. Preventive maintenance and capability enhancement are thus two aspects within the lifecycle of a system which can be addressed in an integrated approach. These aspects are considered to embody the decision making process behind the proposed future framework.

The majority of defence customers face continuing budget pressure and as a consequence they are implementing service methods which are better value for money whilst maintaining equipment availability levels. There is likely to be a reduction in the number of defence acquisition projects in the future. This, combined with organisational changes in the military, has led to an internal shift within defence companies from a manufacturing centric organisation to a service centric organisation concerned with establishing a service based capability. Focus is required on Enabling Through Life Capability and a systems engineering approach. The organisational changes in the military have ultimately led to the platform manufacturer managing the risk. As such, emphasis has been refocused towards minimising the cost of ownership whilst maintaining high levels of operability and functionality.

The systems engineering approach highlighted in the Defence Industrial Strategy (MoD, 2005) can be adapted to illustrate the approach from a support services perspective (Figure 1). The top tier represents the customer, companies such as BAE Systems often perform the mid-tier integrator roles and, in conjunction with lower tier partners, produce a support service solution. Systems engineering provides an inter-disciplinary approach to problem solving. The end aim is to create a support service structure which satisfies the defined customer requirements whilst remaining within cost and schedule constraints.

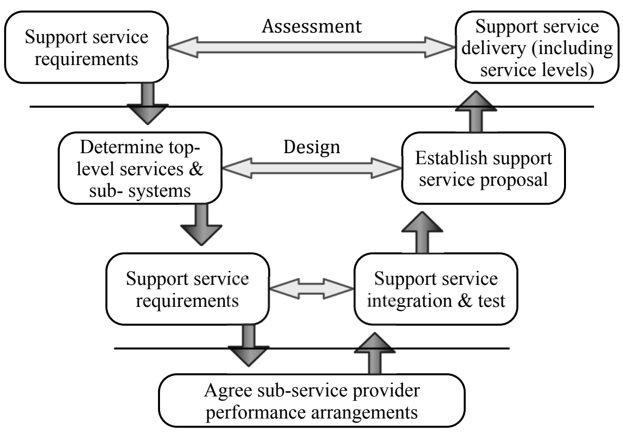

Figure 1. System Service 'V' Diagram

This paper proposes a framework for developing a Maintenance Dashboard that embodies an integrated approach towards capability enhancement and maintenance. The aim is to establish an approach which supports the decision making process on whether to maintain, repair, upgrade or update a system. A brief description of the facets considered in developing the integrated approach are detailed in Section 2. The concepts behind the Maintenance Dashboard and its relevance within the service engineering field are documented in Sections 3 and 4. Future Work and Conclusions are covered in Sections 5 and 6.

2 BACKGROUND

2.1 Capability

'We have now reached a crossroads. We are seeing a shift away from platform oriented programmes towards a capability-based approach, with corresponding implications for the demand required of the traditional defence base', A1.4 (MoD, 2005).

The term capability is commonly used in a variety of contexts, and thus it is necessary to define the term in relation to the context in which it is referenced. The UK Ministry of Defence (MoD) Acquisition Operating Framework (MoD, 2009) describes Capability as the 'enduring ability to generate a desired outcome or effect, and is relative to the threat, physical environment and contributions of coalition partners'. Capability, in this sense, is delivered by a Force Element for a particular operation or mission and is assumed to comprise a number of components. Capability can be defined on a number of levels ranging from high level military operational capabilities to low level capabilities of providing cool airflow, for example.

Capability is not a particular system or equipment and is formed from various components. These components can be split according to whether capability is assumed from either a military or industrial perspective for example. In delivering a capability however, there are interactions between the individual components; e.g. an industrial product is likely to feed into military equipment. For the purposes of future discussion, capability is considered from a platform/system perspective, 'the ability of a platform or system to deliver a specific requirement in support of an overall goal'.

2.2 Capability Management

Capability enhancement through the insertion of technology, either for the purposes of upgrade or update (discussed in Section 3.1), falls within capability management. This involves developing a clear definition of the capability requirements (MoD, 2009).

Capability enhancement occurs in response to an influencer. An influencer may be either an internal or external factor which must be taken into account if a given platform or system is to deliver the effect required. Influencers are generally considered at a strategic level and may comprise threats, opportunities, environmental factors and/or internal policy changes. A further notable relationship occurs between capability management and technology management. Technology management (Shanks, 2008) is key to the successful implementation of capability management since it involves developing an awareness of available and upcoming technologies, and can thus inform the decision making process of the critical technologies available to meet a noted capability requirement.

Specific areas which should be addressed in order to implement an effective capability-based planning approach cover:

- Requirements management.
- Integration on two levels; technologies into systems and systems into platforms.
- Robust decision processes for determining potential solutions to the capability requirements identified.

Capability management employs a top-down approach to its delivery. Key to the integrated approach towards capability enhancement and maintenance is a rigorous planning and requirements specification phase. The underlying integrated decision process is discussed in Section 3 under the proposal of a Maintenance Dashboard framework.

2.3 Maintenance

Maintenance involves maintaining and securing systems in, or restoring them to, a state in which they can perform their required function(s). One of the challenges for maintenance planning is to identify the actions for preventive maintenance and ensure that necessary resources are available (Rosqvist *et al*., 2009). The role of maintenance has changed from simply being a repair solution to having an intrinsic role in through life management. To this end, models for predicting the remaining useful life of components or systems and prognostic methods for determining future system defects can be utilized (Jardine *et al*., 2006; Wang, 2008).

From the viewpoint of examining maintenance within through life management there are a number issues which require consideration (Takata *et al*., 2004):

- Adaptation to changes in platform capability requirements during the life cycle.
- Adaptation to platform changes due to technology insertion and capability enhancement techniques.
- Integration of past and future maintenance information.

2.4 Requirements Engineering

One of the fundamental measures of success for a system is the degree with which it meets its intended purpose. Requirements Engineering (RE) is described as the process of discovering that purpose by identifying stakeholders and their requirements and documenting them in a suitable manner that will aid analysis (Nuseibeh and Easterbrook, 2000). The eliciting of capability requirements is vital to the successful implementation of a maintenance and capability enhancement decision process. RE has developed into a key stage in the overall systems engineering process (Stevens *et al*., 1998). It is concerned with interpreting and understanding user requirements and their successful transformation and implementation. Parallels may be drawn between Section 2.2 and research conducted under the KARE project (Ratchev *et al.,* 2003) where a new knowledge ‘enriched’ RE approach is presented.

3 INTEGRATED APPROACH TO CAPABILITY ENHANCEMENT AND MAINTENANCE: MAINTENANCE DASHBOARD

‘Industry needs workable, VFM-based solutions to predictive maintenance and capability insertion problems, resulting from a confidently exhaustive and rigorous examination of all best practise available everywhere derived from preventive maintenance and capability enhancement.’

Extract from a presentation (unpublished, 2008) given by Work Package Four in the S4T Research Programme (S4T, 2008)

Industry examples (Pagotto and Walker, 2004; R&W, 2005; AeI, 2003), indicate that maintenance management and capability enhancement programmes have been managed in isolation. Both the UK government and governments across the world are now declaring that they are more likely to contract for capability rather than purchase specific products (MoD, 2005). The priorities within defence acquisition are shifting towards procuring the capability to carry out operations. From a customer perspective this offers reduced risk and helps stabilise maintenance and support costs. This research aims to develop a framework which will allow preventive maintenance and capability enhancement to be viewed in an integrated manner. These two aspects are embodied within the move towards servitization, especially where the capability being delivered is underpinned by data collection and information processing/analysis techniques. The framework will form the high-level architecture for a Maintenance Dashboard.

An industrial consultation conducted by the Engineering and Physical Sciences Research Council (EPSRC, 2009) noted product life-cycle as one of the key manufacturing research challenges, with emphasis placed on providing a whole systems approach towards servitization. The proposal of a Maintenance Dashboard is directly aimed at extending product life cycles. Extensions to product life cycles are achievable through lengthening the ‘useful phase’ of the product, where the ‘useful phase’ is defined as the period during which the product has a functional value. It is proposed that this be realised through a balanced integrated strategy towards preventive maintenance and product modifications. In this sense, modifications may cover system adaptations due to changing capability requirements, thereby conducted via capability enhancement. In order to increase product life, the application of new technologies is imperative as a means to ensure the possibility of permanent upgrading.

The concepts behind the Maintenance Dashboard are discussed in the following sections. The main principle behind the Maintenance Dashboard proposal is a decision process. The decision process involves assessing the platform capability requirements alongside information retrieved from both preventive maintenance and capability enhancement trade-off programmes; the aim being to provide an indication of platform status. In this manner it is possible to specify, for example, whether a particular sub-system requires maintenance due to a predicted defect or, if due to capability trade-off information, upgrade should take place at the next maintenance opportunity. The decision process thus acts to integrate preventive maintenance and capability enhancement. Through utilising (i) condition based data for preventive maintenance, (ii) capability trade-off decisions and (iii) platform capability requirements, the decision process may be viewed as a maintenance management assistance tool. Maintenance planning, with regards the ordering of parts and organisation of resources, can be managed in conjunction with optimising maintenance activities associated with scheduled maintenance and repair tasks or system upgrade.

3.1 Decision Process

The principal aim of the decision process is to provide a means for comparing current and future required capabilities in order to determine if the platform (or constituent systems) requires maintaining, repairing, upgrading or updating. The decision process thus presents a solution that indicates whether the maintenance and/or capability enhancement route should be followed. This gives rise to one of four solutions; maintain, repair, upgrade or update. The definitions assumed for each of these terms are detailed in Table 1.

Decision	Function
Maintain	Conduct scheduled maintenance according to a maintenance plan.
Repair	Conduct unscheduled maintenance & indirect capability enhancement through the replacement of faulty system components if spares comprising upgraded technology are used.
Upgrade	Conduct capability enhancement through the replacement of systems or components containing newer technologies capable of increased functionality (i.e. technology refresh).
Update	Conduct scheduled maintenance to maintain system capability through the replacement of obsolete components.

Table 1. Maintenance Dashboard Solution Definitions

Taking into account the factors raised in RE, the decision process adopts a three-phase evolutionary approach (Figure 2):

1. dentification: Identification of specific capabilities (either individually or collectively) to be taken into account. This phase also involves defining the system/platform capability requirements (i.e. requirements elicitation).
2. nalysis: The majority of the analysis phase involves developing, refining and evaluating all possible solutions to the given capability requirements from (1) above. The decisions which govern whether a system should be maintained or upgraded depend on, in brief; (i) the obsolescence attributes of the technology in question that provide the capability, (ii) the ‘utility’ (e.g. performance) realised to the system or platform by changing the technology and (iii) associated capability priorities.
3. olution: Determination of the best solution for meeting the required capability(s) identified in (1).

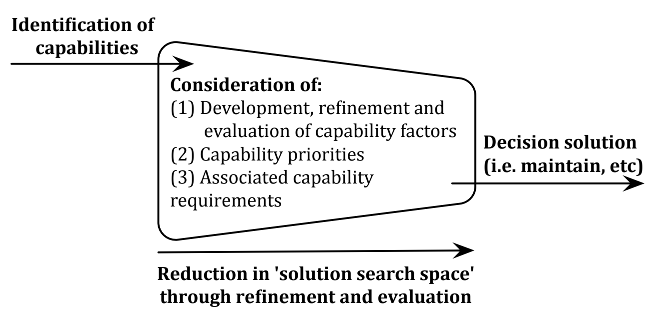

Figure 2. ‘Evolutionary’ Decision Approach

3.2 Methodology: Development of the Maintenance Dashboard Framework.

The central framework, which the Maintenance Dashboard is based upon, is adapted from the precedent set by the reference architecture for the CommonKADS system (Schreiber *et al.,* 2000; Schreiber *et al.,* 1994; Kingston, 1998). The CommonKADS methodology is a collection of structured methods for building knowledge-based systems (KBS); permitting a structured, detailed analysis of knowledge-intensive tasks and processes.

In brief, CommonKADS is a methodology for KBS development which proposes the creation of different models between which implicit links are identified. The models are thus both related to each other and depend on each other. The CommonKADS methodology comprises six key models; organisation, task, agent, communication, expertise and design. The design model is the main element of regard in relation to the development of a framework for the Maintenance Dashboard. The design model is principally used for structuring the actual implementation of a KBS. The model developed as part of this research comprises the technical design process of the Dashboard.

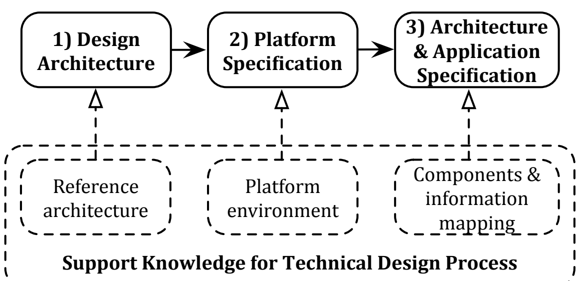

Figure 3. Three-Stage Design Process

The technical design process followed consists of three main stages. Generic descriptions of the stages are summarised below for reference. More detailed information is provided in Sections 3.3-3.5.

1. ystem Architecture Design: The general architecture of the Maintenance Dashboard is specified.
2. dentification of Implementation Platform: The constraints with respect to the implementation platform are identified i.e. environment in which the Maintenance Dashboard is set.
3. pecification of Architecture Components and Application: The individual architectural components of the dashboard are defined in greater detail, in particular the interfaces between components. All knowledge based information is then mapped onto the system architecture. This includes tasks to be performed (i.e. aim of dashboard), knowledge bases, associated inferences and decision process mechanisms. The application specific sections within the architecture are specified.

The three-stage technical design process is graphically summarised in Figure 3. The following sections describe the stages in relation to the Maintenance Dashboard in greater detail

3.3 System Architecture Design

The first stage in the design process involves defining the structural framework (architecture) of the Maintenance Dashboard. The reference architecture identifies three main components. If the framework for the Maintenance Dashboard were to be viewed as a system, then these components would comprise the principal sub-systems. The three sub-systems are termed Controller, Views and Application Model. The framework also structures the information flow from requirements elicitation through the three major components, thereby delivering a solution.

The purpose of the three components is described later. Detailed component functional information in relation to the Maintenance Dashboard framework is expanded in Section 3.5, where the architecture components are specified under Stage 3 of the design process. Figure 4 illustrates the formation of the structural framework for the Maintenance Dashboard based on the reference architecture (Schreiber *et al.,* 2000).

The ***Controller*** represents an integral "command and control" centre which handles external information (i.e. User Input) in order to activate application functions. The input requirements model is composed from two data streams obtained through requirements elicitation: (i) current system capability levels, and (ii) required system capability levels. The integration of preventive maintenance techniques and capability ranking data provide the system status with regards (i) maintenance schedule, (ii) urgent actions to be addressed e.g. component failure, (iii) failure profiles and (iv) technology insertion programmes.

The ***Application Model*** specifies the functions and data that together deliver the functionality of the dashboard application. Additionally it contains the reasoning functions, including information and knowledge structures, which give rise to the decision approach. It primarily contains the elements that realise a solution from the functions and data specified during analysis.

Within the dashboard application, the ***View*** allows static and dynamic information from the application to be available. Utilising information from the decision process, the View delivers the output. This comprises one of four possibilities; (i) Maintain system (according to maintenance plan), (ii) Initiate repair strategy, (iii) Update system or (iv) Upgrade system.

3.4 Identification of Implementation Platform

Platform specification in the development of the Maintenance Dashboard is two-fold; (i) specification of the application platform (e.g. aircraft fuel system) and (ii) specification of the computational infrastructure which will support the Maintenance Dashboard. From a theoretical and concept generating perspective, the design process behind the development of the framework for the Maintenance Dashboard can be conducted independently of the implementation platform. Whilst the Implementation Stage constraints may be identified prior to specifying the maintenance dashboard framework components (Section 3.5), it is complete upon the realisation of an automated Maintenance Dashboard. This phase of work is expanded in Section 5. It is noted that an automated Maintenance Dashboard will be proposed in future research using an exemplar platform for representative purposes. Within the automated environment, the knowledge bases and requirements will be represented using leading industry requirements management tools such as Telelogic DOORS™. A top level Graphical User Interface (GUI) will be generated for the Maintenance Dashboard, behind which, the

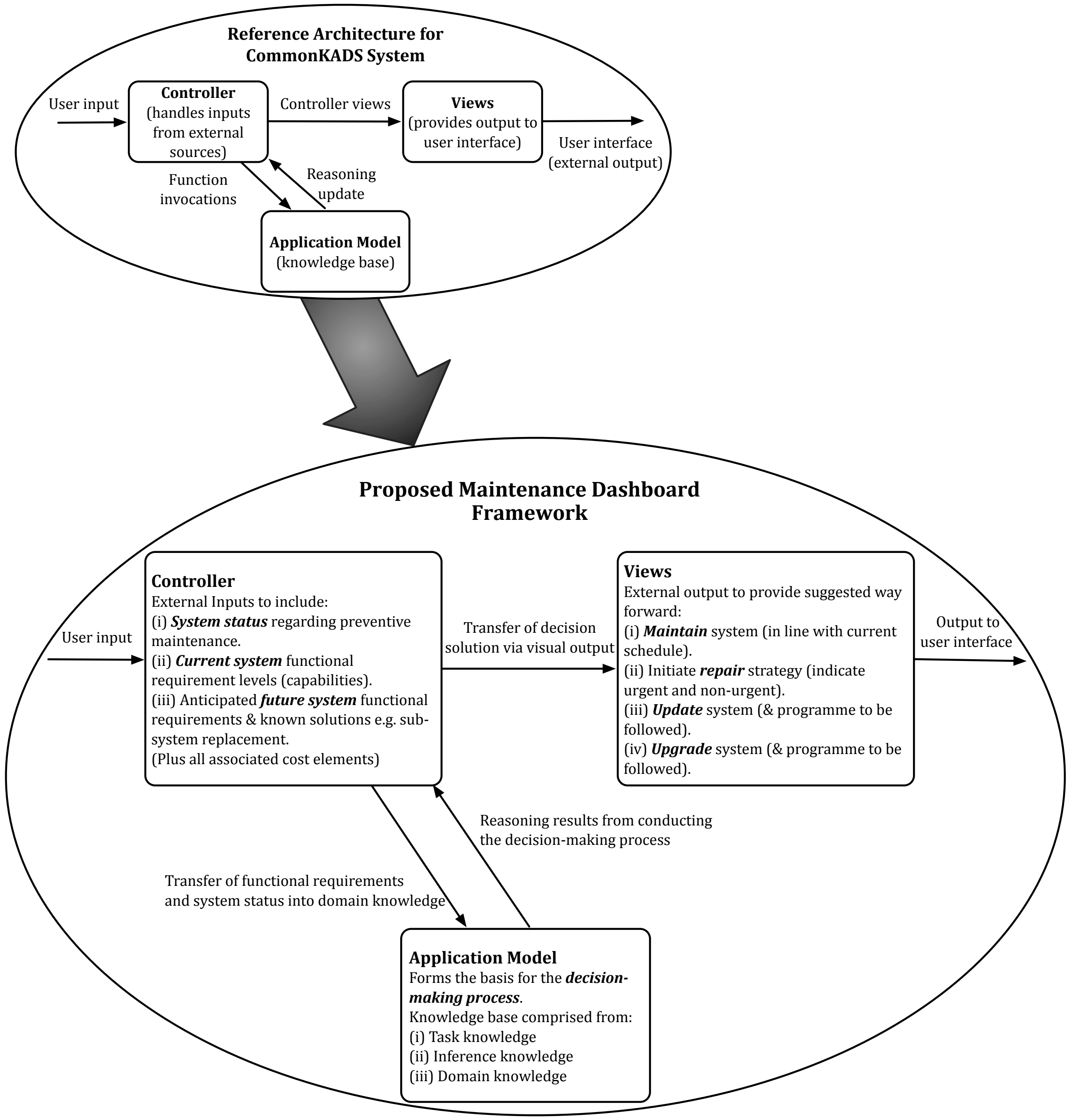

Figure 4. Proposed Maintenance Dashboard Framework

components will conduct the necessary decision analysis.

3.5 Specification of Architecture Components & Application

The final stage in the design process involves defining the three major components (Controller, Application Model, Views) in the proposed Maintenance Dashboard framework. In addition, the interfaces between the components and application specific facets of the framework are also identified. The main purpose of this stage is to decompose the knowledge base into 'chunks of information' which may be then used by the Application Model to determine a solution. In the case of the Maintenance Dashboard functional decomposition is employed; inferences between knowledge elements are preserved according to their functionality. A graphical representation of the proposed Maintenance Dashboard framework developed during the design phase is illustrated in Figure 5. The precise nature of the three components within the framework are described in further detail. The component of most importance, with regards the functionality of the Maintenance Dashboard, is the Application Model. The Application Model embodies the decision process which ultimately determines the solution with reference to maintain, repair, upgrade or update.

Under the third stage of the design process the application specific sections of the architecture are also defined. The Maintenance Dashboard framework is not platform dependent and thus fully adaptable. The processes contained within the framework are however scenario dependent. Therefore, the Maintenance Dashboard is only applicable within remit of determining platform status (maintain, repair, upgrade or update) based on the current and required platform (and/or system) capability levels. The processes, and scenario related information with regards the decision approach, are changeable and thus the Maintenance Dashboard can be 're-set' for other scenarios. This would require re-defining the framework components.

The Maintenance Dashboard framework components are summarised:

The ***Controller*** represents an integral "command and control" centre which handles both external and internal information (e.g. user input) in order to activate application functions. Within the Maintenance Dashboard framework the controller represents the central information hub and its function is three-fold:

1. he principal purpose of the Maintenance Dashboard is to provide the platform status with regards maintain, repair, upgrade or update. Relevant information is input into the Controller component to aid this task. The inputs are formed from databases, of which the data within is transferred to the Application Model for analysis purposes. The databases are system specific (e.g. propulsion). The databases comprise data streams on (i) current system capability level, (ii) required system capability level, (iii) preventive maintenance results (prognostics, remaining useful life calculations, failure profiles), (iv) urgent actions to be addressed (e.g. failure/imminent failure) and (v) capability trade-off ranking results taking technology insertion into consideration (capability enhancement route).
2. he Controller component informs the Application Model when to conduct analysis. The Controller thus initiates the first task that is necessary in order to determine the status of the platform systems with regards the four decisions highlighted in Section 3.1.
3. he results from the Application Model (discussed later in this section) are relayed to the Controller. The Controller 'handles' this information and transfers the solution of the analysis conducted by the Application Model to the View Component. The Controller also retrieves all data from the Application Model with regards the analysis reasoning process. The added handling of this data provides traceability of information and permits report printing, if applicable.

Within the dashboard application, the ***View*** allows static and dynamic information from the application function to be available. In brief, the View realises the presentation of the Maintenance Dashboard purpose to the users. All data presented by the View is transferred from the central information hub (Controller). The View does not perform any computational analysis, it simply illustrates the output determined by the Application Model and acts as an interface between the decision process and the end user. The solution output comprises one of four possibilities; (i) Maintain system, (ii) Initiate repair strategy, (iii) Update system and (iv) Upgrade system.

The ***Application Model*** specifies the functions and data that together deliver the functionality of the Maintenance Dashboard. The Application Model knowledge base is formed from the data streams input into the Controller component as well as the reasoning functions behind the decision approach. The Application Model therefore contains the elements necessary for realising a solution. Within the Maintenance Dashboard framework the Application

Model performs the decision process. As noted in the preliminary background section on the decision process (Section 3.1) an evolutionary approach is adopted through the use of a decision algorithm. The task initiated by the Controller component results in the commencement of the decision process. This task defines a single operation; conduct a comparison of current capability levels with required capability levels. The execution of the task invokes the decision algorithm (simplified in Figure 5), which in turn results in the initiation of decision tasks (represented by ♢).

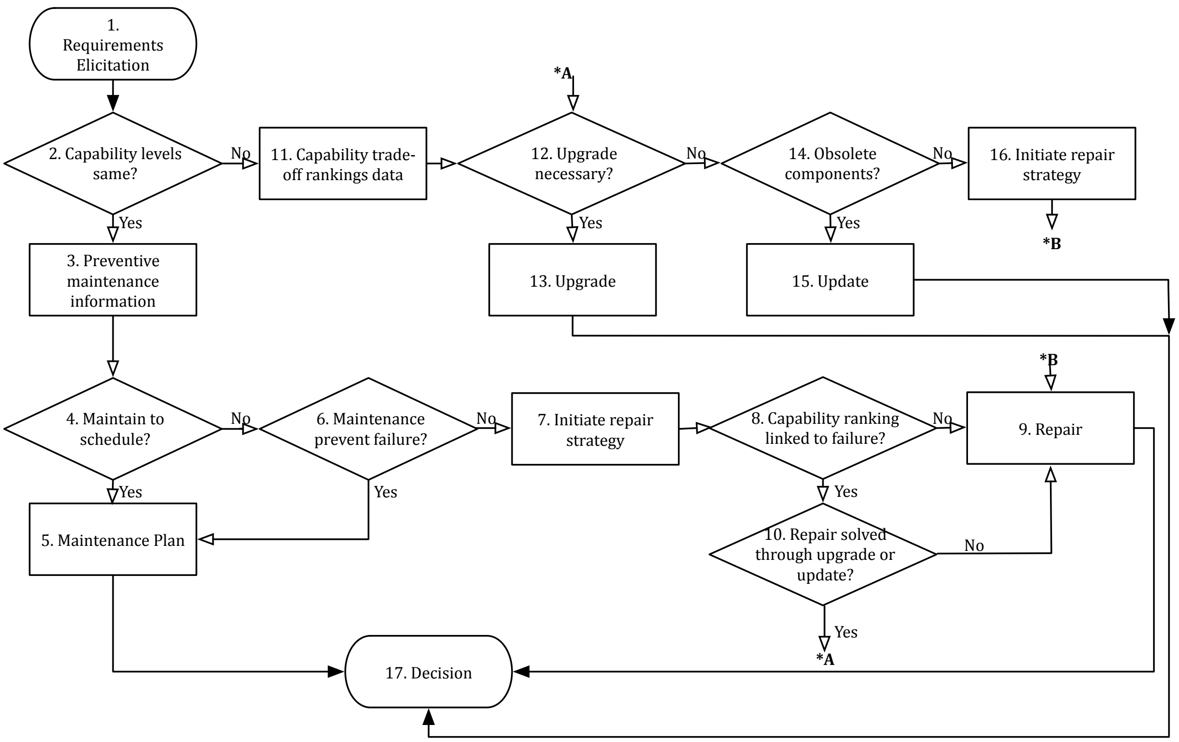

Figure 5. Representative Application Model Decision Algorithm (Decisions based on definitions from Table 2)

In order for the algorithm to 'run', data is sought from the knowledge base. This includes the current system status obtained from preventive maintenance techniques, system specific technology insertion programme data retrieved from capability ranking procedures and associated inferences between the variables contained in the data bases and the decision tasks. A 'snap-shot' of the knowledge base structure is illustrated in Figure 6.

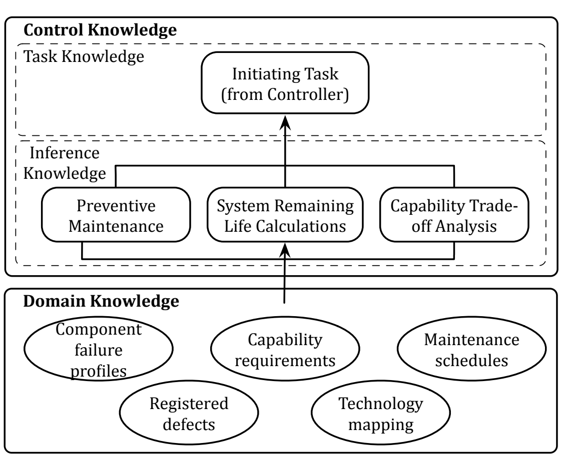

Figure 6. Application Model Knowledge Base 'Snap-shot' (requirements mapping illustration)

Control Knowledge defines both the content and structure of the task and inference specific data: (i) *Task Knowledge* is defined by a key goal and describes the decomposition process involved in the decision algorithm (decision tasks referenced in Application Model). (ii) *Inference Knowledge* describes the inference steps that are to be followed in completing the key goal (task) through utilising information obtained from capability ranking procedures for example.

Domain Knowledge contains the concepts, relationships and facts that are required in order to reason a given application domain. For example, in cases where preventive maintenance techniques are used to describe inference steps, system failure profiles are contained within domain knowledge.

4 DISCUSSION: RELEVANCE TO SERVITIZATION PUSH

The majority of defence customers face continuing budget pressure and are consequently looking for new service methods that provide better value for money whilst maintaining equipment availability levels. There is likely to be a reduction in the number of defence acquisition projects in the future. This, combined with organisational changes in the military, has led to an internal shift within defence companies from manufacturing centric to service centric organisations concerned with establishing a service based capability. Popular advice to manufacturing based companies has been that 'in order to remain competitive they should move up the value chain and focus on delivering knowledge intensive products and services' (Baines *et al*., 2007; Hewitt, 2002). Occurring in conjunction is that fact that governments are now declaring that they will contract for capability (Neely, 2009) and, as such, the support service aspect is outsourced to the supplier. From a supplier perspective, servitization may be viewed as a way in which sales revenue can be increased, whilst from a customer perspective, servitization offers reduced risk and improves the way in which costs and budgets may be set.

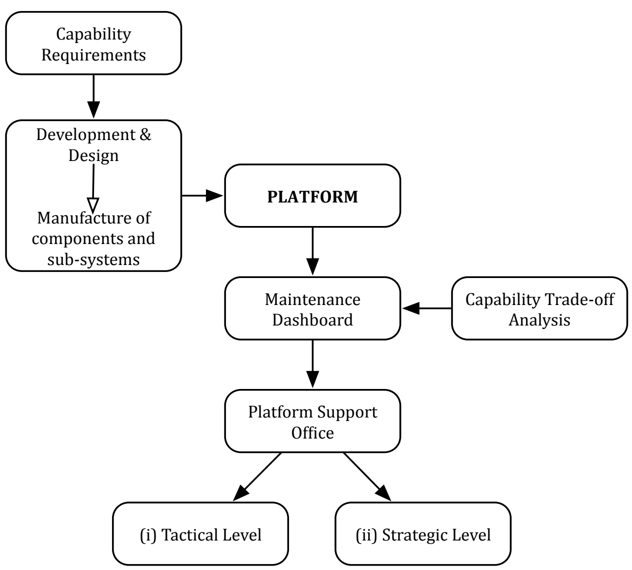

Figure 7. Information Flow during the 'Useful Phase'

Servitization involves the use of the new technologies as well as methods for managing technical products (i.e. platforms) over their life cycle. Within the support service environment, product life needs to be evaluated. The Maintenance Dashboard proposal is aimed at extending the 'useful phase' of a product's life. The 'useful phase' is defined as the period during which a product performs a particular function (meets a given capability). This extension is achievable through conducting preventive maintenance and modifications, where modifications involve capability enhancement. To enable product longevity, the option for permanent upgrading and updating must remain viable. The Maintenance Dashboard provides an option for initiating a balanced strategy with regards maintenance and capability enhancement and thus serves to increase the 'added value' of the product during its 'useful phase' in the life cycle.

Figure 7 illustrates the information flow cycle. The solution retrieved from the Maintenance Dashboard is of relevance at two specific levels:

1. actical with regards the Maintenance Manager and logistic planning (resources, spares, work-space).
2. trategic with regards budgetary control and assessing the 'most sensible time' to conduct maintenance, repair, upgrade or update.

5 FUTURE WORK

A transparent decision process, such as that proposed by the Maintenance Dashboard framework, would advise the most suitable route with regards maintenance and capability enhancement. The next phase of research involves delivering an automated Maintenance Dashboard. A GUI will be generated to represent the 'front end' of the Maintenance Dashboard, behind which all aspects of the framework (i.e. components) will be programmed. The University of Nottingham will liaise with industrial partners to develop a suitable scenario, and associated constraints, to prove the functionality and applicability of the Maintenance Dashboard. The purpose of the demonstrator scenario will be to substantiate the reasoning behind the Maintenance Dashboard for a range of platforms.

A further factor which is intrinsic to the successful implementation of any decision process within the Maintenance Dashboard is the consideration of technology assurance. This is particularly relevant to the 'upgrade' decision. From an assurance perspective, the implementation and integration of new technologies causes questions related to technology readiness, reliability and integration risks to arise. Robust mapping processes linking relevant technologies under consideration (technology roadmapping) are consequently advised in order to minimise the likelihood of embedded risks and potential system failures (Phaal *et al*., 2008).

6 CONCLUSION

'The quality and shelf life of current technical products is no longer determined by wear and attrition but by being technically out of date' (Niemann *et al.*, 2009). Current, and future, strategies for achieving maximum product utilisation are required to consider longer term planning for product life-cycles. The concept behind life-cycle management aims to optimise product performance. This covers the three main phases within a product life-cycle; (i) manufacture, including design and development, (ii) usage and (iii) disposal/recycling. The Maintenance Dashboard framework proposal is directly aimed at extending product life cycles and aiding the planning process associated with this. Extensions to product life cycles are achievable through lengthening the 'useful phase' of the product. Within the Maintenance Dashboard this is realised through a balanced integrated strategy towards preventive maintenance and capability enhancement.

During the development of the Maintenance Dashboard framework, costing factors were excluded from the assessment. Cost modelling falls outside the remit of current research, however, issues that will require future consideration with regards the analysis of cost influencers include:

- Assessment of benefits Vs risks.
- Examination of solution optimisation.
- Management of decision sensitivity.

The Maintenance Dashboard framework has been developed to support the analysis involved in integrating preventive maintenance and capability enhancement. The framework architecture illustrated in Figure 4 provides a concise representation of the processes involved in determining the status of platform systems with regards maintain, repair, upgrade or update. The three-stage technical design process described in Section 3.2 provides useful documentation covering the development of the framework. The knowledge base for the decision process (Application Model component) is customisable dependent on the platform and related systems under consideration. The task, inference and domain levels of knowledge representation permit clear traceable reporting by the Maintenance Dashboard and thus increase its functionality.

It has been reported (Neely, 2009) that new business models for manufacturers have implications for operations management frameworks and philosophies. This is of particular relevance to situations where the delivery of an operational capability is underpinned by the data collection and information analysis techniques. The proposed Maintenance Dashboard decision approach is initiated by a single task; comparison of current and required capabilities (assumed from a platform/system perspective). The Dashboard is dependent on the results obtained from platform prognostics and capability trade-off analyses. These, in turn, are dependent on the data that can be retrieved from the platform and planners. For cases where the operational capability may vary the Dashboard would be able to provide an updated platform status with respect to the individual systems, which could then be used to aid planning at both tactical and strategic levels. The Maintenance Dashboard is aimed at aiding decisions at the platform level through indicating the status of the main systems. The framework detailed in this paper discusses an approach for providing platform support by taking into account data from system prognostics and capability ranking procedures to increase the 'useful phase' of a platform life-cycle.

It is postulated that the Maintenance Dashboard may form part of a higher level Integrated Support Dashboard. The creation of a dashboard hierarchy would enable increased planning of maintenance activities alongside other functions (e.g. supply chain). This would enable, for example, clear representation of fitment opportunities for capability upgrade and maintenance activities. The control checks for the proposed high level dashboard would be sought from associated platform key performance indicators.

ACKNOWLEDGMENT

The authors wish to acknowledge the support provided by BAE Systems and the Engineering and Physical Sciences Research Council (EPSRC).

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