CHEMICAL ENGINEERING TRANSACTIONS
VOL. 33, 2013
Guest Editors: Enrico Zio, Piero Baraldi

ISBN 978-88-95608-24-2; ISSN 1974-9791

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at: www.aidic.it/cet

DOI: 10.3303/CET1333069

Research on Framework of Product Health Management Center Based on DoDAF

Xing Pan*, Baoshi Yin, Lin Ma, Tianjian Wen, Zilin Xin

School of Reliability & Systems Engineering, Beihang University, Beijing, 100191, China
panxing@buaa.edu.cn

The healthy status of product reflects its ability to perform a specified task at a reliable and maintainable level in a certain period of time. It is significant for long-term storage and disposable products to estimate storage reliability, determine maintenance intervals, optimize storage cost and accomplish product tasks by means of establishing product health management center (PHMC) aiming at monitoring and managing product's healthy state synthetically. This paper, regarding PHMC as a system of systems (SoS), builds a framework of PHMC based on the U.S. Department of Defense Architecture Framework (DoDAF), on the basis of comprehensive analysis of the characteristics of usage and maintenance for long-term storage and disposable product in maritime industry. The framework involves personnel, organization, and a variety of maintenance and support activities in relation to product health management. This framework describes the top-level design of the system with the help of high-level conceptual diagram. This paper also makes a specific design of the system in detail based on activity-based modelling (ABM) method. It shows that the framework is a useful practice in terms of adopting systems of system engineering (SOSE) ideas and DoDAF architecture to build PHMC system. Outcomes of the system implementation indicate that, for long-term storage and disposable product, PHMC can improve the efficiency of maintenance and support, at the same time it can reduce maintenance and support cost.

1. Introduction

With constant increase of complexity and integration of modern equipment, in order to satisfy demands of different missions on efficiency, cost-effective and continuous support capabilities, Prognostics and Health Management (PHM) technologies and systems are being received increasingly attention and applications (Ramakrishnan and Pecht, 2003). PHM mainly utilizes sensor integration with a variety of algorithms and intelligent models to predict, monitor and manage the state of product's health, including fault detection and isolation, failure prediction, and tracking the residual service life of component as well (Alford, 2001).
Currently, PHM system has been adopted in complex equipment systems popularly. PHMC, as a kind of PHM system, which integrates organization, personnel, process and information and manages health status during operation process, also has been paid enormous attention. Now days, PHMC is confronted with gigantic challenges. While developing diagnosis and prediction methods to combat the problem of uncertainty, it also should address the problem of complexity of PHM system for systematism equipment (Hess, 2005). At the same time, development of equipment SoS based on architecture framework provides PHMC beneficial practices. The architecture framework of SoS, working as design principles and guidelines, is the structure of various components of system units, relationships, as well as constraints, and it also performs as the basis for system developers to design the system (Meilich, 2006). Among all the architecture frameworks having been published, DoDAF is the most widely used, defining 26 architecture products, and proposing a number of guiding principles in architecture design (C^4ISR Architecture Working Group, 1997). It also provides a unified standard for description and modelling of SoS and complex systems.
This paper adopts architecture method to establish PHMC in a maritime enterprise. It effectively describes the systematic architecture of the PHMC for long-term storage and disposable product, which makes it be possible to record and evaluate all the healthy information during the process of usage and maintenance.

Please cite this article as: Pan X., Yin B., Ma L., Wen T., Xin Z., 2013, Research on framework of product health management center based on dodaf, Chemical Engineering Transactions, 33, 409-414 DOI: 10.3303/CET1333069

By absorbing the idea of combining the health management with SoS architecture framework, we establish an architecture framework of PHMC based on information-based platform, in order to achieve effective management for the healthy state of the product. The PHMC system provide data as well as information concerning the assessment of product healthy status. More importantly, based on the assessment and prediction of product healthy status, it not only further optimizes product testing cycle, spare parts categories, quantity and allocation strategy, but also analyses the current maintenance modes and offer proposals for rectification of existing regulations on organizational staff and its developmental schedule.

2. System Requirements Analysis

PHM is a process which comprehensively manages product and factors affecting health status of its components, aiming at ensuring product system's failure-free and effective operation by using a variety of management strategies, technical methods and optimizing the combination of personnel, technology, information, etc. The core idea of PHM is integrating product management regulations and business processes under the principle of simplicity, efficiency, practicality, and science, making the product health assessment the product for establishing product status monitoring and evaluation index system, undertaking product health management throughout the whole process and whole staff with the means of condition-based and regular maintenance etc. (Wang and Pecht, 2011).
It is of great significance for long-term storage and disposable product to determine its health state and discover its failure pattern. In regard of the fact that most of the time, this kind of product is in non-working state, like storage, maintenance, and testing, the product should be inspected, maintained or even be repaired during its storage time on a regular or irregular basis. Problems such as how to predict the reliability of the product at a certain moment throughout the whole storage process and how to determine the optimal detection interval to make the lowest maintenance costs which could guarantee required reliability, make it practically important to effectively monitor and manage the health status of the product during storage by the means of PHMC design and establishment.

3. Complex System and SoS Modelling Based on DoDAF

3.1 ABM-based Modelling Method

With the development and application of DoDAF, ABM has been widely used to develop equipment SoS (Baumgarten, 2008). ABM is a three-view method which designs SoS architecture with data as its center (Ring, 2004), supports intersections between different products, and can automatically generate some SoS architecture products (Pan and Yin, 2011). ABM features the corresponding relationship between objects in the collection of Operational View (OV) and System View (SV). It stipulates that the objects of the SoS architecture can be divided into the following three object categories: entities, relationships and attributes. Entities are the object stored and processed by SoS architecture data; relationships are the relation between entities; attributes are characteristics used to identify entities and relationships. Figure 1 illustrates the corresponding relationship between the operational view and the system view.

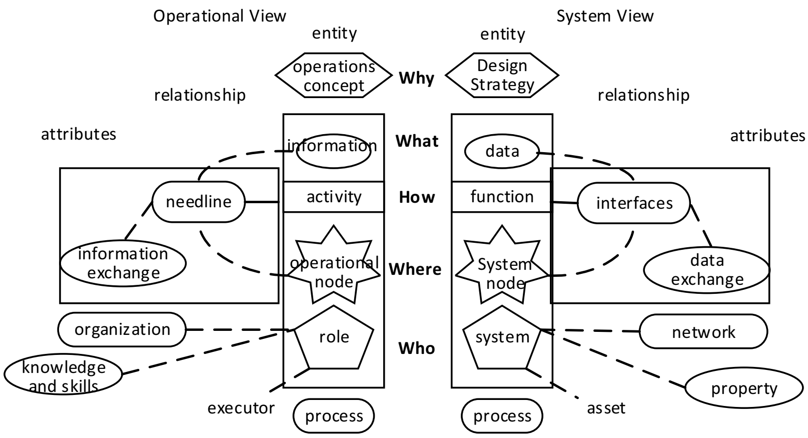

Figure 1: Relationship between operational views and system view

ABM models SoS architecture within the framework of DoDAF, utilizing DoDAF data-centred feature to guarantee the consistency of the data in the process of design, which makes automatic generation of system entities and attributes a possible. In OV, information exchange and need-line can be automatically generated after activities, information input and output in OV-5 and operational nodes in OV-2 are got. In SV, system data exchange and interface can be automatically generated after we have determined the function, the data input and output of the SV-4 and system node of the SV-1. Some DoDAF view products can be automatically generated in ABM as well. In OV, OV-2 is generated by information exchange while its need-line is generated by 4 operational SoS architecture entities. The OV-3 file reports can be automatically generated after the integration of all information exchange within the SoS architecture model. Similarly, in terms of SV, the SV-1 is depicted after the completion of system data exchange and system interface is generated by 4 operational SoS architecture entities. Once the integration of system interface and information exchange is accomplished, the system resource flow matrix (SV-6) file reports would be automatically generated. Figure 2 shows relationships among OV views and SV views.

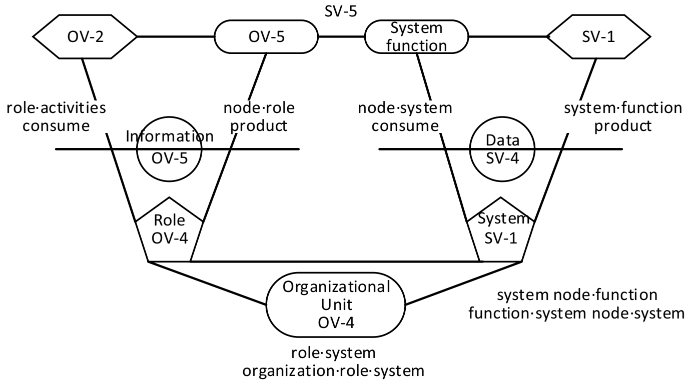

Figure 2: Relationship between views in ABM method

3.2 Steps of ABM-based SOS Modelling

The ABM models system architecture from the idea that operational activities mapping to system functions, specifically, a one-to-one correspondence between operational view and system view. In operational architecture, the framework are composed of operational resource flow description (OV-2), operational resource flow matrix (OV-3) and operational activity model (OV-5), while in system architecture, system interface view (SV-1), the system functionality description (SV-4), and the systems resource flow matrix (SV-6) are working as its framework. They are mutually associated through core entity object and operational activities and system function traceability figure (SV-5) and organizational relationships figure (OV-4). Table 1 indicates the modelling processes of system architecture based on ABM.

Table1: Modelling processes in ABM

Operational View	Manual	*Step* 1	Creating operational activity model (OV-5)
		Step 2	Creating organizational relationship model (OV-4)
		Step 3	Determining operational resource flow description (OV-2)
		Step 4	Associating the relationship of activity-node-role
	Automatic	*Step* 5	Mapping ternary relationship to activity-node-role
		Step 6	Mapping information exchange requirements to need-line
		Step 7	Drawing need-line of OV-2
		Step 8	Generating operational resource flow matrix (OV-3)
System View	Manual	*Step* 1	Creating system functionality description (SV-4)
		Step 2	Creating Systems-Systems matrix (SV-3)
		Step 3	Creating system interface description (SV-1)
		Step 4	Associating the relationship of function-node-system
	Automatic	*Step* 5	Mapping ternary relationship to function-node-system
		Step 6	Mapping data exchange cable to the system node
		Step 7	Drawing connection line of SV-1
		Step 8	Generating system resource flow matrix (SV-6)

The ABM method provides certain processes and standards to DoDAF products. Steps of system architecture modelling are divided into two parts: modelling operational architecture and modelling system architecture. Each part consists of eight steps. In each part, the first four steps are manually created, while the last four steps can be achieved automatically and generates corresponding architecture products. After accomplishing the steps above, an architecture framework of a SOS are finally finished. In SoS architecture model, OV-2 and SV-1 describe the logical components of the architecture; SV-4 illustrates the functional components of the architecture; and OV-5 reflects the process of activities and changes of system architecture; OV-3 and SV-6 depict the information flow and data flow of the system architecture. These OV views and SV views can describe the whole architecture of the system in a comprehensive way.

4. System Framework of PHMC

4.1 System Conceptual Design

In this paper, we utilized DoDAF to establish PHMC system of a maritime enterprise. Take the coordination and implementation of management framework, hierarchy, duties and powers of departmental functions and their relationships into account, a PHM organization system has been set up, to further standardize the regular and irregular maintenance and testing during the product storage and accumulate the data to monitor product health status. Through careful analysis on demand of development of the enterprise's product supportability capacity under the framework of DoDAF, we designed an architecture of PHMC in accordance with organizational design, activity analysis and information exchange. We also determined relevant duties and missions of the component departments of the PHMC and on the basis of organizational design. Through activity analysing, we are able to obtain all input and output information of activities and sub-activities in product health management system, and the relevant departments responsible for the activity, the technical support and constraint rules of the activity. Through information exchange analysing, we can understand the information flows and business flows between the various departments in the PHMC. Through above analysis, we can establish the association among organizations, personnel, resources and abilities in the enterprise's PHMC system.

In order to describe the mission task, the main task nodes and capability in the PHMC from a macro and direct perspective, we should first depict the high-level conceptual diagram of the architecture of the PHMC, as Figure 3. From the high-level conceptual diagram, we are able to conclude the interactive relationships between the enterprise health management system architecture and inner environment, the system architecture and external systems.

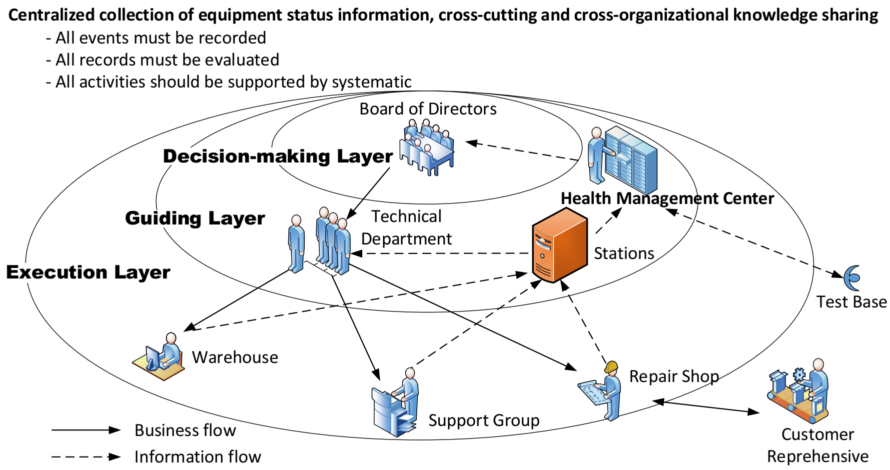

Figure 3: High-level conceptual diagram (OV-1)

The high-level conceptual diagram of the PHMC is divided into three levels, from the inside to the outside: decision-making layer, guiding layer, and execution layer. Decision-making layer includes the board of directors; guiding layer includes technical department, observatories and health management center, and executive layer includes warehouse, support group and the repair shop. Customer representative offices as well as the test bases are all included in executive layer. The warehouse, the support group and the repair shop of executive layer gather information to the observation station of the guiding layer, and then upload it to the center of health management. After that, the PHMC will deal with the information. Together with the data uploaded from test base to the center, all the information acts as a support for the decisions made by the board of directors of the decision-making layer to guide activities. After the board of directors has made certain guidance or decision, it will be issued to the technical department of the guiding layer. Then, this decision or guidance will be distributed to the warehouse, support group and the repair shop in executive layer after being refined by the ordnance department. Therefore, according to the above processes, we can depict the high-level conceptual diagram of health management system architecture, which can be seen in Figure 3. Based on the ABM method and through selecting several views from the DoDAF, the organizational structure of the health management center can be comprehensively described to further guide the construction of the enterprise's PHMC.

4.2 Activity View Modelling

In order to improve product health state, this enterprise utilizes ABM method and selects active views in DoDAF to establish the PHMC and clarifies the duties and tasks of the PHMC and departments. By analysis requirement quo of the maritime enterprise, we can conclude that data storage, data processing and data acquisition are the three functions of PHMC, among which, data acquisition collects state information of product from activities like maintenance, testing and usage. Figure 4 shows the relevant relationship between these activities. That is to say, all data collected are stored under the constraints of certain specifications and manuals. Then, the data stored should be processed and its result is adopted to direct testing, maintenance and using activities, which makes the data of maintenance and testing timely and effective, thereby improving the usability of the product. Meanwhile, the adoption of the DoDAF can also stretch activities in OV-5 for detailed analysis, which will not be discussed here. OV-5 diagram can definitely determine the task of the system and then assigns each task to various departments for modelling the organization diagram (OV-4) and operational node connection diagram (OV-2), as shown in Figure 5 and Figure 6. After following the steps of ABM modelling mentioned above, the establishment of the active view of the system is accomplished. This active view is primarily used to describe the main tasks of the PHMC and the activities carried out to complete the corresponding task.

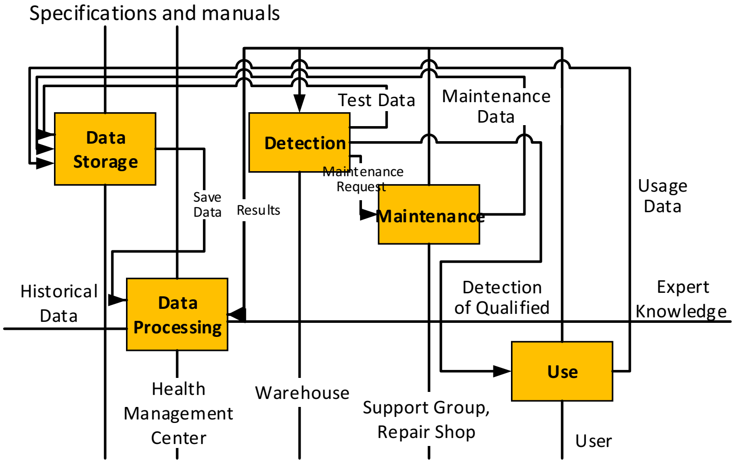

Figure 4: Activity model (OV-5)

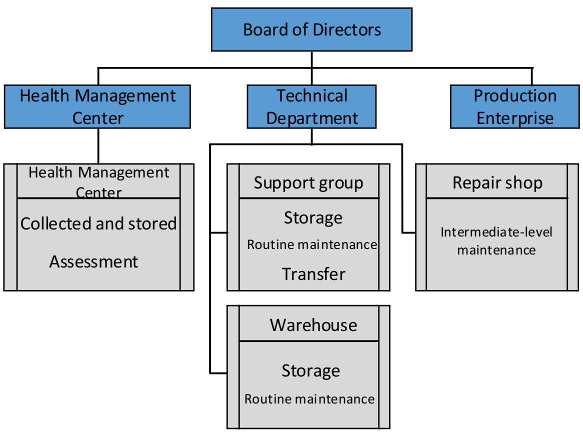

Figure 5: Organization relational model (OV-4)

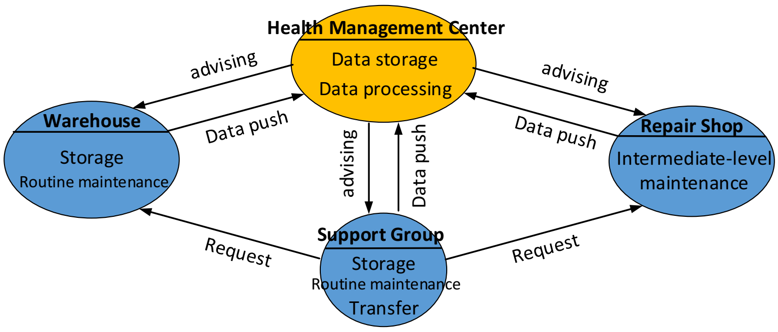

Figure 6: Operational node model (OV-2)

5. System Operation Effect

The PHMC of a maritime enterprise, designed and developed based on DoDAF, has already begun trial operation and has achieved obvious application effect. The system can immediately be put into use due to the clear distribution of positions and responsibilities. Meanwhile, during trial operation, the system does accomplish its task to record all events, evaluate all records and support all activities. Through the rational allocation of spare parts and product failure diagnosis function, the enterprise have succeed to optimize the cost and supportability in system-wide and the life cycle under the condition of satisfying the requirements of maintainability and supportability. It ensures health data collection and prediction ability of condition-based maintenance, as well as the maintenance planning design and support analysis, and improves maintenance efficiency, operational readiness and mission success of the product.

6. Conclusion

In this paper, specific to the characteristic that incomplete and delayed test data of product in a maritime enterprise affect product health, we use DoDAF to describe the product health management system and to establish PHMC. Based on our proposal, we realized our goal to conduct comprehensive supervision and monitoring to the health state of product during the process of storage, ensuring the collation of healthy data, which provides powerful support for subsequent maintenance planning design and supply support analysis, and moreover, improves the availability of product.

Acknowledgements

This work is supported by the National Natural Science Foundation of China under Grants No. 71171008, the China Scholarship Council and the Fundamental Research Funds for the Central Universities.

References

Alford L.D. Jr, 2001, The problem with aviation COTS, Aerospace and Electronic Systems Magazine IEEE, 16, 33-37.

C^4ISR Architecture Working Group, 1997, C^4ISR architecture framework version 2.0, DOD.

Hess A, 2005, Joint Strike Fighter - real prognostics, Challenges, issues, and lessons learned: chasing the big “P”, 1st International Forum on Integrated System Health Engineering and Management in Aerospace, 3610-3619.

Meilich A, 2006, System of systems (SoS) engineering & architecture challenges in a net centric environment, IEEE/SMC International Conference on System of Systems Engineering, 5.

Ramakrishnan A, Pecht M, 2003, A Life Consumption Monitoring Methodology for Electronic Systems, IEEE Transaction on Components and Packaging Technologies, 26, 625-634.

Steven J Ring, Dave Nicholoson, 2004, Activity-based methodology for development and analysis of integrated DoD architectures - The art of architecture, 2004 Command and Control Research and Technology Symposium.

Wenbin Wang and Michael Pecht, 2011, Economic Analysis of Canary-Based Prognostics and Health Management, IEEE Transactions on Industrial Electronics, 58, 3077-3089.

Xing Pan, Baoshi Yin, 2011, Modelling and Simulation for SoS Based on The DoDAF Framework, Proceedings of the 9th International Conference on Reliability, Maintainability and Safety, 1283-1287.