A Framework for Optimizing Product Performance Through Using Field Experience of In-Service Products to Improve the Design and Manufacture Stages of the Product Lifecycle

Joel E. Igba, Kazem Alemzadeh, Paul M. Gibbons and John Friis

Abstract For many component sub-systems which make up the individual elements of a larger product system, the optimization of their performance in the system becomes more difficult through design modifications and/or manufacturing process improvements alone. The authors argue this can be improved if adequate field performance data has been fed back to the early stages of the product lifecycle. This paper presents a framework for an inclusive lifecycle approach to optimizing product performance through the effective use of field experience and knowledge to improve the design and manufacturing of sub-systems. The problem is presented alongside a taxonomic and captious review of literature of relevant subject areas, followed by a case study using wind turbine sub-system components as a basis to support the investigation. A framework is then developed through the combination of systems thinking and continuous improvement tools, applied to the conventional product lifecycle. The findings of the investigation indicate that sub-system performance can be improved through the accumulation of knowledge fed back to the design and manufacture stages of the product lifecycle using information from in-service product performance. The approach would be useful to practitioners and academics with an interest in applying an inclusive and holistic approach to product lifecycle management. This framework is particularly useful for companies that produce and/or operate systems whose sub-systems are manufactured by different suppliers.

J. E. Igba (✉) · K. Alemzadeh
Faculty of Engineering, University of Bristol, Bristol BS8 1UB, UK
e-mail: ji0905@bris.ac.uk; joigb@vestas.com

P. M. Gibbons
Visiting Fellow, University of Bristol, Bristol BS8 1UB, UK

J. E. Igba · J. Friis
Service Engineering, Vestas Wind Systems A/S, Hedeager 44 8200 Aarhus, Denmark

A. Azevedo (ed.), *Advances in Sustainable and Competitive Manufacturing Systems*,
Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-319-00557-7_2,

1 Introduction

Engineering product development has moved away from the traditional linear steps to a more integrated product life cycle development process [1]. This has led manufacturers to change their principles from designing and learning from failures and errors during the production stage of the life cycle to a more integrated approach to design and manufacturing. Well-known concepts such as Integrated CAD/CAM, design for reliability and maintainability, design for manufacture, concurrent engineering, etc. have led to more integrated, optimized and advanced product development techniques saving costs and reducing the lead time to make a product [1]. For complex systems which consist of several major sub-systems, there is a greater chance for one or several sub-systems to be designed and/or manufactured by different original equipment suppliers (OEMs). Once such a system is in service, it is expected to perform according to its design requirements and if there is a sign of deviation from the requirements, it can be put back to its running state through good operations and maintenance. This typically would be the case for most products until they reach their end of life or fail. However, in practice, companies who operate large systems and OEMs find it difficult to collect, feedback, and re-use field in-service knowledge for design improvements [2, 3].

Traditionally, manufacturers get most of their product usage and performance information through warranty and spare parts data, customer complaints, and information from service personnel [3]. Access to complete in-service data is rare because traditionally, in-service information is often collected by the customers who usually are unwilling to share such information [2]. Many supplying and designing companies are shifting to a product-service system (PSS) which Goh and McMahon [2] described as an integrated solution that fulfills functions and provides services to end-users without necessarily transferring the ownership of the product to them. In this case the traditional product offering companies offer more and more service packages comprising of installation, maintenance contracts, overhaul and repair, upgrades and training. This allows such companies to use insights gained from use and in-service to adapt their on-going support activities (through continuous improvement) and also to feed-forward the knowledge gained to new design projects [2]. Goh and McMahon [2] also gave examples of some high profile companies which have adopted PSS in diverse applications, including: Xerox, IBM, Canon, and Rolls-Royce. Unlike companies that are able to adopt PSS, other companies involved in designing, manufacturing and/or delivering part of a large system which is been put to service by a different company, do not have this luxury and ease of accumulating and feeding back in-service knowledge for product improvement. This paper presents a framework for a more integrated approach toward aligning, capturing, and the feedback of in-service knowledge for the purpose of optimizing product performance by improving the design and manufacturing stages of the life cycle.

2 Related Work

2.1 Life Cycle Models and In-Service Feedback

The concept of life cycle popularly used to describe the stages a living organism covers a period from the time of birth until death. Any engineering artifact goes through a similar "lifelike" analogy to a living organism: Conception-Birth-Growth-Adulthood-Death [4]. In general there is a life cycle that describes the stage of a product from its conception/design through its use up to its disposal. For the purpose of this research, several relevant literature themes which the authors have seen to be relevant to their argument are explored indicating different perspectives to the life cycle stages. Life cycle models, in engineering, are abstract functional models that represent the conceptualization of a need for the system, its realization, utilization, evolution, and disposal [4]. Typically, the generic life cycle model has the following stages as represented in Fig. 1.

In Fig. 1, the iterative feedback loops indicate that for an ideal product life cycle, it is possible to improve upon the early stages of product development, by feeding back acquired knowledge and experience from the later stages hence optimizing the performance of the product through the entire life cycle. This iterative feedback is easy to implement and manage if a single enterprise is responsible for delivering the majority or all of the life cycle stages. If on the other hand, one or several stages of the life cycle are delivered by different enterprises, it becomes more difficult to fully implement and manage this knowledge feedback process; it becomes even more complicated when a product consists of subsystems that are designed and/or manufactured by several enterprises. Figure 2 shows an example of some of the different perspectives of a product/system life cycle. From Fig. 2 it can be seen that in most cases, the life cycle of the commercial manufacturer may repeat several cycles for every one cycle of a large integrated system when both life cycle perspectives are compared. The logic behind this is that the life cycle stages of most systems integrators run for a longer period especially for systems with a design life of several decades.

However for the high tech manufacturer, the time span is shorter with most of its life cycle stages coming before the operations phase of the systems integrator. Manufacturers are mainly involved in the early stages of design and production and only provide support during the operation stage. In some cases new subcomponents of the system may have to be re-developed or provided as spares or design upgrades in order to keep the system running; hence repeating the

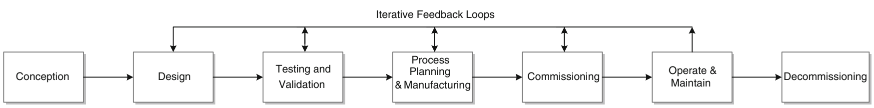

Fig. 1 Generic life cycle stages as described in [5]

Typical High-Tech Commercial Systems Integrator

Study Period				Implementation Period			Operations Period		
User Requirements Definition Phase	Concept Definition Phase	System Specification Phase	Acq Prep Phase	Source Select. Phase	Development Phase	Verification Phase	Deployment Phase	Operations and Maintenance Phase	Deactivation Phase

Typical High-Tech Commercial Manufacturer

Study Period			Implementation Period			Operations Period		
Product Requirements Phase	Product Definition Phase	Product Development Phase	Engr Model Phase	Internal Test Phase	External Test Phase	Full-Scale Production Phase	Manufacturing, Sales, and Support Phase	Deactivation Phase

ISO/IEC 15288

Concept Stage	Development Stage	Production Stage	Utilization Stage Support Stage	Retirement Stage

Fig. 2 Various perspectives of the life cycle stages [6]

production cycle several times before disposal of the system. In order for both the high-tech manufacturer and the systems integrator to fully optimize through-life product performance, they both have to understand how their respective life cycle stages interact. Understanding and managing life cycles is a key ingredient toward achieving optimization. There are several concepts by the help of which engineers and project managers oversee the entire life cycle of a product/system. Westkämper et al. [7] described the term "Life Cycle Management" (LCM) as a means of considering the product life cycle as a whole, by optimizing the interaction of product design, manufacturing and life cycle activities. This is also popularly known as product life cycle management (PLM). There is a huge focus by manufacturers on integrating and optimizing their design and production processes. This is discussed further in the next subsection.

2.2 Integrated Design and Manufacturing Systems

The process of developing and introducing a new product into the market has radically evolved, with the last five decades in particular seeing new manufacturing and management strategies beginning to surface, reflecting the dynamic nature of improvements in manufacturing applications [8]. Some noteworthy examples include Lean Manufacturing (LM), Just-In-Time (JIT), Concurrent Engineering (CE), Cellular Manufacturing (CM), agile manufacturing, responsive manufacturing, holonic manufacturing, distributed manufacturing, and collaborative manufacturing. Nagalingam and Lin [8] suggest that even though these new approaches were being developed every few years in the past decades, the concept of computer integrated manufacturing (CIM) is a far broader approach. Nagalingam and Lin [8] argued further that CIM is still able to embrace all these new approaches and provide the required features offered by these concepts or strategies.

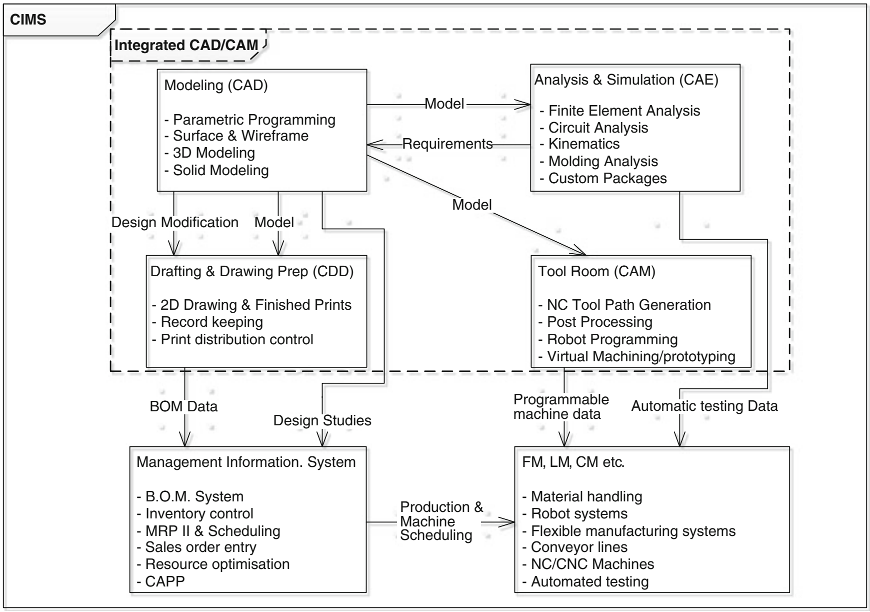

Fig. 3 The concept of a computer integrated manufacturing system CIMS

The concept of CIM, which was initially proposed by Dr. Joseph Harrington in 1973 in a book published by the name "Computer Integrated Manufacturing" [9] but the acronym became well known in the 1980s [8]. CIM is the integration of the total manufacturing enterprise by using integrated information technology (IT) systems and data communication coupled with managerial philosophies that improve the efficiency of a manufacturing enterprise and its personnel. Another directly related concept is computer integrated manufacturing system (CIMS), which was described by Rzevski [10] as a system whose aim is to add value to manufacturing business by employing IT with a view to achieving an effective integration of all planning and control activities within an organization. This is achieved by integrating advanced technologies in various functional units to achieve corporate objectives [8]. Hence, having a CIMS as a manufacturing organization will help to drive other key manufacturing strategies (such as: CE, LM, FM etc.) that are vital to a business' competitive advantage. Figure 3 shows the authors' interpretation of CIMS from relevant literature, including Nagaligam and Lin [8], Rzevski [10], Beeby [11] and Harrington [9], in the area of integrated design and manufacturing. This consists of the integrated computer-aided design, manufacture and engineering (CAD/CAM/CAE) as well as additional managerial, planning and control activities.

2.3 Feedback and Re-Use of In-Service Data

Antecedent research by Markeset and Kumar [3], Goh and McMahon [2], and Hallquist and Schick [12] has also argued that the feedback of field experience data is necessary for product improvement. Markeset and Kumar [3] stated in their paper that this feedback is the key to improved products, product design and related work processes; while Goh and McMahon [2] argued that it is important to capture in-service knowledge, manage it, and make it available, from the product, system and people perspective, so as to improve new design projects. Markeset and Kumar [3] went even further by arguing that a product's reliability, availability, maintainability, and safety (RAMS) characteristics are an important part of product quality since these characteristics determine if the product performs according to specifications. This implies that product reliability is closely related to both product quality and the quality of the processes involved in delivering the product, hence agreeing with Madu [13]. However, in-service data does not include only RAMS data; it includes other forms of informal information such as customer satisfaction indices and communication between designers and service engineers. Recent work [14] by the authors of this paper proposed a framework for holistic life cycle approach for reliability centered maintenance (RCM) of in-service assets. Figure 4a depicts the proposed framework that summaries the findings from the paper, which emphasizes the importance of integrating RCM with other stages of the product life cycle. In the paper, Igba et. al. [14] argued that the integration can be achieved through design input to maintenance planning and feedback of in-service data to design through a product life cycle management (PLM) database. This can be achieved by a continuous knowledge accumulation cycle which follows the product life cycle framework from birth through to the disposal of systems. The vital steps in the learning process begin with in-service feedback through updating the PLM database with operational data. After this, the new designs are updated through redesign prompted by field knowledge and

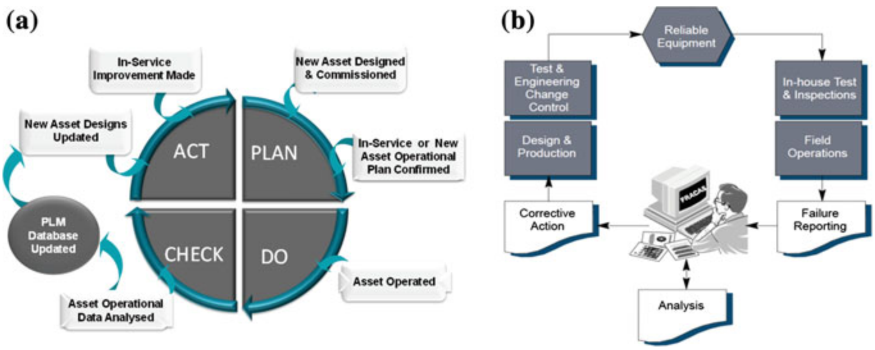

Fig. 4 **a** Framework for holistic life cycle approach to RCM for assets [14], **b** high level FRACAS process [15]

experience and finally the design changes are implemented in the field either as upgrades or in an entirely new system.

Of relevance to this continuous knowledge accumulation is the process of feeding back in-service data, which Goh and McMahon [2] suggest can be achieved via two different means. The first being the personalization approach which is essentially concerned with the development of communities of practice and socio-technical models for enhancing company performance; while the second approach, codification, is concerned with an explicit form of knowledge through its capture and formal representation which allows it to be reused. This paper focuses on the codification approach to in-service feedback since they allow knowledge gained to be codified into suitable representation, stored and organized so that the information can be used at a later stage [2]. Figure 4b presents one key example of a structured and systematic way of documenting and utilizing field failure data. This technique is called "Failure Reporting and Corrective Action System" (FRACAS) and it is widely used in industry especially in military applications. FRACAS is a closed-loop process for in-service feedback and is commonly known as the closed-loop analysis and corrective action tool. Hallquist and Schick [12] identified three common issues surrounding the implementation of FRACAS in an organization—lack of prioritized goals, complex organizational interaction, and poor data traceability—and presented an eight step process as best practices for implementing FRACAS. The authors agree with Goh and McMahon [2], Hallquist and Schick [12], and Markeset and Kumar [3] who have all emphasized the importance of in-service feedback and have all outlined several issues surrounding the feedback process in their papers. Consequently, the authors will now attempt to take the findings from literature explored in this section further by proposing a framework for through-life optimization of large integrated systems.

3 An Integrated Framework for Through-Life Optimization

Optimizing a certain design variable during manufacturing can play a tremendous role in improving product performance during in-service operation. Considering an example where this may occur, in the manufacture of gearboxes for wind turbines, which are subjected to heavy contact loading, increasing the case-hardening depth of the gears can have a significant improvement in the number of load cycles the gearbox can withstand. The hardening depth specification is only as accurate as the specified design load which in most cases includes a safety factor. In a situation where failure of a gear during operation is linked with the case hardening depth, questions can be raised about the design load specification and the gearbox manufacturing process. In some cases, the design loads might have been underestimated leading to a lower hardening depth, while in other cases, this could reveal a potential flaw in the manufacturing process such as the heat treatment process or the gear teeth grinding, which led to the hardening depth being out of specification. Furthermore, the flaw might not be in the entire manufacturing process but in a certain batch which perhaps had some quality issues (perhaps due to wrong ambient conditions). Hence, being able to link field failures to a certain batch of the manufacturing process will not only help to improve quality control but also help to proactively monitor or replace the affected items while in the field preventing potential failure. In a situation where the design load has been overestimated, and where several years of field knowledge about operation conditions have been accumulated, proactive decisions can be taken to reduce the case hardening depth if it is known that the operating loads are well within the design loads and thus a smaller hardening depth is required. Reducing this depth implies savings in lead time and costs during the manufacturing process without affecting product performance.

Although the example above can be easily related to several engineering disciplines, it is however difficult to implement some of the changes in design and manufacture if adequate knowledge from the field operation is not fed back. The dilemma many companies face is how to capture, feedback, and re-use this knowledge when their sub-systems are manufactured by several suppliers. The following subsection presents a framework that will help manufacturers and system integrators understand how to feedback in-service data for life cycle optimization.

3.1 Integrating Multi-Perspective Systems with an Architecture Model Framework

The proposed framework for integrated life cycle optimization has been modelled by combining a high-level SysML[1] use case diagram with the data flow model diagram[2] concept so as to capture both the flow of data and the interaction of the key stakeholders that are involved in the different stages of the lifecycle. Figure 5 shows the framework for setting up in-service data feedback in a formal and systematic way through integrating the already existing computerized maintenance management system (CMMS) of the customer with the CIMS of the manufactures through a central and shared engineering database. The framework also suggests some generic inputs and outputs for data flow and stakeholder communication and gives a high level overview of where ownership limits to the databases are for both the customer and manufacturers. This framework has been simplified and represented on the highest level and only serves as a guide toward capturing the whole picture. The key interactions that may exist between several departments within each enterprise (e.g., management, finance, and engineering) will depend on the

[1] SysML means Systems Modeling Language. For more visit http://www.omgsysml.org/.

[2] http://en.wikipedia.org/wiki/Data_flow_diagram.

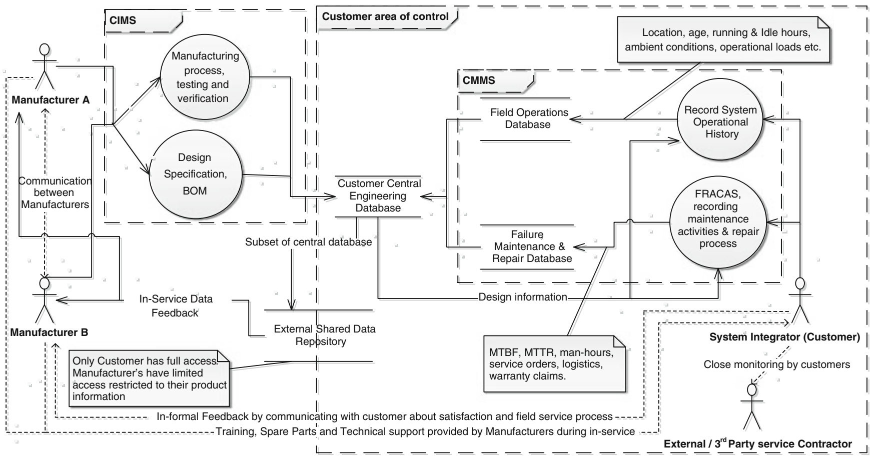

Fig. 5 Framework for in-service knowledge feedback

organizational structure and culture in each enterprise. Furthermore the type and direction of the arrows indicate the type and direction of data flow respectively. The solid arrows represent the formal and codified data while the dotted arrows represent the more in-formal communication between the stakeholders. In-formal in this context implies that there is no formal and detailed documentation process (e.g., FRACAS) for such data flow, e.g., manufacturers may offer training and support to the service teams but may not fully document the entire process, however there will be an inherent flow of knowledge in both directions.

4 Discussion

4.1 Enablers for In-Service Data Feedback

The first and most critical enabler is having the infrastructure for in-service data collection, feedback, and utilization. With the degree of complexity and large size of data, computer-aided tools have to be used for data collection. During service, a useful tool for feedback is a CMMS which consists of the daily RAMS records and also several operating data such as the ambient conditions, operational loads, temperatures, and running hours. Some industries have a separate system for condition monitoring which has a unique database that is linked to the central database. The ability to integrate a CMMS to the CIMS of manufacturers will accelerate the feedback of in-service data and this can be achieved by having one central engineering database which contains the CMMS and CIMS data as subsets and serves as a knowledge repository; hence making it possible to transfer data through the life cycle. Another critical enabler is the process of collecting, analyzing, and utilizing in-service data. The authors have argued that FRACAS is a useful method for reporting, analyzing, and utilizing operational data. However, FRACAS cannot be a stand-alone process and should be integrated with other processes such as RCM.

Also important as an enabler for this framework is the issue of governance with regards to ownership, accessibility, and interoperability of large integrated databases. This perhaps is the most important, especially when it comes to the willingness of customers to give manufacturers access to their data. Manufacturers should be willing to make their database structure compatible with their customers for better interoperability. Creating a shared database between the system integrator and key OEMs with different levels of access can be of great advantage. In a case where there are issues of accessing rights to a customer's database, data can be exchanged through an external source but in a unified format which can be easily uploaded to the manufacturer's database. Otherwise a web based portal access to selected data for each manufacturer can be created by the customer. For such a shared system to work, stakeholders must be willing to share the costs for setting up and maintaining the database or web portal. In a situation where the customer contracts a third party for the service of part or the entire system, service information and knowledge can still be captured by the designers through a similar online platform. However, the third party company may not necessarily have access to view critical design data since they are not explicitly involved in the design. This can be aided by specifying the need for mandatory data reporting as a key requirement before the third party service agreements are reached. The final enabler revolves around how to incentivize service engineers and technicians to document and report maintenance procedures and service information. Service engineers are concerned with resolving issues and bringing back a system to its running conditions as soon as possible, often being under time pressure [2]. This makes it more difficult for them to document service procedures given that their main definition of success is a system which is always running. Incentivizing the service engineers for data collection is a huge task and is worthy of separate research, perhaps building on the concepts presented in this paper. However, several methods such as those proposed by Hallquist and Schick [12] can be employed to enable good quality data collection. One way to address this issue is to establish other key performance indicators (KPIs) which would additionally measure the performance of service teams with respect data collection and help to motivate them. Equally important, companies must be willing to provide service engineers with the necessary tools and gadgets for making the process easy and quicker.

4.2 Utilizing Information and Knowledge Feedback

Data has no value if it is not used for a purpose [3] and information re-use occurs when information is assimilated and used in new applications, yielding useful insights and knowledge [2]. In their paper, Goh and McMahon [2] discussed two key techniques that aid the re-use of in-service data. These are the information classification technique, and statistical analysis and data mining. The former uses taxonomy or classification to structure and organize in-service information making it easy to retrieve data. The use of similar terminologies between the manufacturers and customers is also a key for easy retrieval so that the manufacturers do not need to worry about translating vocabularies before analyzing in-service data and also it is easy to copy from one database to another if similar terms are used. Traceability of data is another key to data re-use. Markeset and Kumar [3] suggest that if data is time stamped and it has a well-defined context and background, it helps in understanding the process. Having time stamps and also linking records to individuals or teams can help track data quality to ensure that the source of poor or incorrect data is known. It can also help link operational data to service and maintenance records which can be used to identify trends and other attributes that can aid decision making toward continuous improvement and proper data analysis.

Although understanding the key enablers for data re-use can be vital to the feedback process, there are however, some pitfalls which if not identified or tackled will reduce the potential of data re-use through either poor data quality or poor interpretation. These pitfalls have been identified in literature as the existence of ineffective maintenance data management and a lack of knowledge in data processing techniques [2]. Companies should provide their employees with the necessary skills to be competent in each aspect of data feedback if not all the processes and enablers would have been put in place with no benefit.

4.3 Through-Life Optimization of Integrated Systems

The preceding section presented a framework with key enablers for the collection, feedback, and re-use of in-service knowledge. Developing this further, the authors of this paper propose a model of a more holistic approach to through-life optimization of integrated systems. From the reliability point of view, the life of a component is described by the bathtub curve which relates the failure rate of the component to its age. This helps engineers to predict how long the component has until its useful life ends.

The system engineering domain adopts a unique life cycle model for designing and delivering integrated engineering systems called the “Vee model” Fig. 6a. The Vee model is widely used in the systems and software engineering field for designing and delivering complex integrated systems starting with the high level system requirements and system design through the detailed design and production of each sub-system/component. The left hand side of the Vee can also be seen to be the stages of defining/designing while on the right hand side are the stages of delivery. The authors have found the Vee model to be very useful in delivering the whole life of large systems. However, it is difficult to know the right time to commission a system and the right time to begin the redesign for upgrades or new

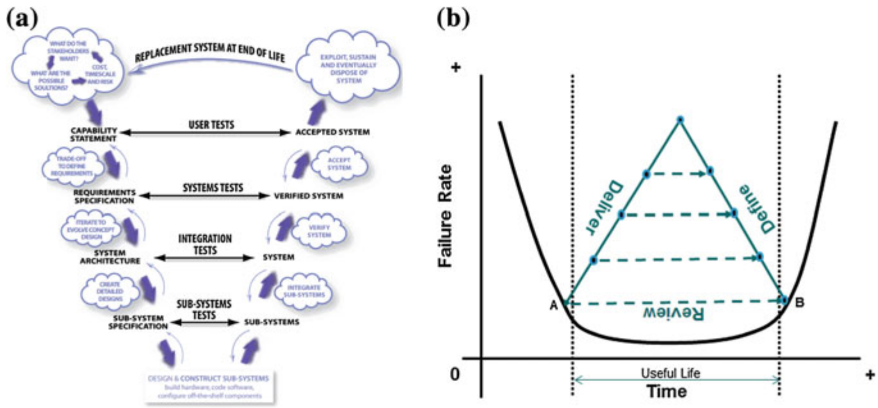

Fig. 6 **a** The original "Vee" model [16]; **b** combined Vee and bathtub curve needed to support the proposed framework

systems, hence not fully utilizing the potential of the Vee model. Figure 6b shows an inverted Vee combined with the bathtub curve which the authors have chosen to illustrate the ideal through-life continuous optimization of engineering systems. In the bathtub curve, the best time to commission a system is just before its useful life phase (point A), where the burning-in failures have all been known and designed out. Here, the failure rate is within the constant and acceptable zone. This implies that the right end "deliver" of the original Vee model should end just before the beginning of the useful life. Furthermore, the best time to start redesign or new system design is when the useful life is about to end (just before wear out begins, Point B). This implies that the left end "design" of the original Vee model should begin just before the useful life ends. This aligns the time at which a new system is delivered to the time the old one is decommissioned saving costs and time. This also applies to sub-system redesign. This model can be used for life extension plans where critical sub-systems can be redesigned at the end of the useful life to keep extending the life time of the system by shifting the bathtub curve more to the right.

5 Conclusion

This paper has presented a framework for the through-life performance optimization of a system through the feedback and use of in-service data for design and manufacturing continuous improvements. The paper has presented and discussed relevant literature in the context of in-service feedback and life cycle optimization and also highlighted the key challenges many manufacturing enterprises and system integrators face in collecting and using in-service data for design improvements. The framework is proposed as a guide in decision making toward setting up a link between the formal and informal in-service data sources and integrating them to already existing integrated manufacturing, maintenance, and management systems. Future research should look to operationalize the concepts presented in this paper, perhaps through a case study to better understand the detailed process of the proposed framework's implementation and application.

Acknowledgments This work was supported by the EPSRC funded Industrial Doctorate Centre in Systems, University of Bristol and University of Bath (Grant EP/G037353/1) and the Company-sponsor Vestas Wind Systems A/S.

References

1. Poeth DF (1990) Concurrent engineering—key to cost-effective product reliability, maintainability and manufacturability. R&M CAE in concurrent engineering workshop
2. Goh YM, McMahon C (2009) Improving reuse of in-service information capture and feedback. J Manuf Technol Manag 20(5):626–639
3. Markeset T, Kumar U (2003) Integration of RAMS information in design process—a case study. In: Proceedings of reliability and maintainability symposium, 2003
4. ISO/IEC (2008) ISO/IEC 15228: systems and software engineering—system life cycle processes, 2008
5. Thimm G, Lee SG, Ma Y-S (2006) Towards unified modelling of product life-cycles. Comput Ind 57:331–341
6. INCOSE (2007) INCOSE systems engineering handbook version 3. In: Proceedings of international council on systems engineering, 2007
7. Westkämper E, Alting L, Arndt G (2000) Life cycle management and assessment: approaches and visions towards sustainable manufacturing (Keynote Paper). CIRP Ann Manuf Technol 49(2):501–526
8. Nagalingam SV, Lin GC (2008) CIM—still the solution for manufacturing industry. Robot Comput Integr Manuf 24:332–344
9. Harrington J Jr (1973) Computer integrated manufacturing. Industrial Press Inc., New York
10. Rzevski G (1987) The concept of computer integrated manufacturing system architecture. In: Proceedings of 4th European conference on automated manufacturing, Bedford, 1987
11. Beeby W (1982) The future of integrated CAD/CAM systems: the Boeing perspective. IEEE Comput Graphics Appl 2:51, 52, 54–56
12. Hallquist EJ, Schick T (2004) Best practices for a FRACAS implementation. In: Proceedings of reliability and maintainability annual symposium, 2004
13. Madu CN (1999) Reliability and quality interface. Int J Qual Reliab Manage 16(7):691–698
14. Igba J, Alemzadeh K, Anyanwu-Ebo I, Gibbons PM, Friis J (2013) A systems approach towards reliability-centred maintenance (RCM) of wind turbines. In: Conference on systems engineering research, Atlanta, Georgia, 2013
15. Villacourt M, Govil P (1994) Failure reporting and corrective action system. In: Proceedings of SEMATECH, 1994
16. RAEng (2007) Creating systems that work: principles of engineering systems for the 21st century. In: Proceedings of Royal Academy of Engineering, 2007

Springer

http://www.springer.com/978-3-319-00556-0

Advances in Sustainable and Competitive
Manufacturing Systems
23rd International Conference on Flexible Automation &
Intelligent Manufacturing
Azevedo, A. (Ed.)
2013, XXIII, 1693 p. 611 illus., 379 illus. in color. In 2
volumes, not available separately., Softcover
ISBN: 978-3-319-00556-0