A Framework to Integrate Prognostics and Health Management into Performance-Based Logistics

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Abstract. Performance-based logistics (PBL) has achieved widespread success as a new logistics strategy, but not all PBL projects have been successful. This article summarizes the reasons for the failure of PBL and the advantages of Prognostics and Health Management (PHM), furthermore, analyses the necessity of integrating PHM into PBL. The innovation of this article lies in the establishment of a process framework to integrate PHM into PBL, and a specific evaluation method is given to evaluate the effect of PBL after using PHM, which make PBL gain more benefits or turn into a victory.

1. Introduction
After-sales support and maintenance services have become a major source of revenue, profit and competitive advantage in manufacturing industries [1]. This is especially true for those firms selling capital-intensive products, such as aircraft engines, wind turbines, and oil pipelines, among others [2]. Customers of these systems are more concerned with the performance outcome (e.g. reliability, availability), and less sensitive to the costs [3]. In recent years, a new service paradigm named as performance-based logistics (PBL) has emerged. This new form of support strategy is often referred to as performance-based contracting (PBC) [4] in the business sector and Power by the Hour (PBH) [5] in the commercial sector [6].

Performance Based logistics (also referred to as Performance Based Life Cycle Product Support) is an outcome based product support strategy that plans and delivers an integrated, affordable performance solution that optimizes system readiness. PBL focuses on the ability of the support solution to affordably satisfy the user’s requirements, usually expressed in terms of availability, not on the consumption of resources or who performs the work. Measurable and manageable metrics that map to the customers established requirements are essential to properly structuring and executing any PBL. The Product Support Manager is the individual tasked with developing and executing the strategy on behalf of the PM. However, a successful PBL requires the participation of the PM, PSM, Contracting Officer, Systems Engineer, pricing team, and many others. PBL delineates outcome performance goals of systems, subsystems, and components, ensures that responsibilities are assigned, provides incentives for attaining these goals, and facilitates the overall management of system reliability, supportability, and life cycle costs [7]. In short, PBL focuses on delivering affordable performance, not transactional goods and services.

In practice, numerous examples of successful PBL exist. Among them, take the project of the F-22 as an example, the project team is composed of Lockheed Martin, Boeing, Pratt & Whitney and the US Air Force. After the implementation of the project, the US Department of Defense awarded...
the system-level PBL award. Through the implementation of the PBL support strategy, the team formed an effective joint force to promote the rapid maturity of the F-22 support system, provide excellent support to the combat forces in a timely manner, and ensure that the F-22 achieves optimal combat readiness. Through the implementation of the PBL strategy, the average maintenance interval of the entire fleet has been extended by 69%, the fighter mission rate has increased by 15%, the repair time has been reduced by 20%, and the cost savings reached US$14 billion, which accounted for more than 35% of the fighter’s entire life cycle support cost [8].

Although many cases of PBL have succeed, however, there are lots of projects failed to achieve the desired outcomes. In order to better implement PBL, this article has conducted an extensive investigation into the causes of PBL failure. Prognostics and Health Management (PHM) is developed for reducing the life-cycle cost and improving equipment system security, operational readiness, mission success rate, in the past years, it has been used in many fields. Through research on PHM technique and advantages, the author believes that some of the reasons for the failure of PBL can be solved by integrating PHM into PBL.

2. Motivation

2.1. Reasons for unsuccessful PBL

As the result of PBL is not always successful [9] so that customers and suppliers have called for explanations as to why some PBL succeed and others failed. Boyce and Banghart acknowledge that “there is a sentiment among some that PBL are more expensive than transactional alternatives.” Kratz and Diaz conclude that an “absence of a clearly defined business model and inadequate training was a significant factor in the failure of some managers to implement PBL successfully.” Others expressed concern that customers may not have the expertise to properly orchestrate the PBL initiative [10][11][12]. In fact, Behn [13] acknowledges several individual decision barriers (e.g., fear and new behavioural changes) that can influence PBL team effectiveness. A common theme within these criticisms is how the PBL business model is influenced by organizational factors of the company teams [14]. In short, the reasons are summarized in Table 1:

| Author   | Year | Reasons                                                                 |
|----------|------|-------------------------------------------------------------------------|
| Boyce    | 2012 | More expensive than transactional alternative                           |
|          |      | Absence of a clearly defined business model                             |
| Kratz    | 2012 | Inadequate training                                                     |
|          |      | Significant financial risk on industry                                 |
| Behn     | 2012 | Fear                                                                    |
|          |      | New behaviour changes                                                   |
| Guajardo | 2012 | Organizational factors of the company teams                             |
| Brucker  | 2011 | Do not have the expertise to properly orchestrate                      |
|          |      | More to reduce costs than to improve service                            |
| Kant     | 1999 | Do not provide for start-up cost                                       |
|          |      | Output is too complex                                                  |
|          |      | Funding                                                                 |
| Others   |      | Statutory-Regulatory Requirements                                       |
|          |      | Cultural Paradigms                                                     |
|          |      | Existing Infrastructure or Organization                                |
|          |      | Technical Data Rights                                                  |

2.2. Technique and advantages of PHM

PHM is an enabling discipline of technologies and methods with the potential of solving reliability problems that have been proved due to complexities in design, manufacturing, environmental and operational use conditions, and maintenance [15]. According to statistics, the adoption of PHM
technology can reduce the aircraft's fault recovery rate by 82%, maintenance manpower by 20% to 40%, logistic scale by 50%, dispatch rate by 25%, and aircraft use and support cost ratio. In the past, the model number was reduced by more than 50%, and the service life reached 8000 hours.

PHM has a total of five modules, namely: condition monitoring module, diagnosis and prediction module, analysis and decision module, task management module and data storage module. The system workflow is as follows: after the sensor is qualified, the sensor obtains device status information processing, and then transmits the data to the status prediction module, combined with historical data to predict the possible state at a certain time. The fault detection module receives real-time status data or predicted status data and compares it with a threshold to determine whether the status of the device is abnormal at the current or predicted time. If abnormal, abnormal information and trend information are provided to the fault diagnosis and prediction module, which infers, recognizes, classifies, and interprets the abnormal state information to determine the abnormal mode failure mode, cause, and location. Combined with prior knowledge, analyse and calculate the severity and development trend of the fault and the remaining service life of components, etc., and provide diagnosis and prediction results to the analysis and decision module. Finally, the analysis and decision module analyses the comprehensive diagnosis prediction results, FMECA table, the current and future task nature and related information of the equipment, judges whether to continue operation, whether to compensate, whether isolation or emergency shutdown is needed, etc., and takes control measures and provides maintenance demand information. The analysis and calculation results of each module will be stored in the storage module for query and offline analysis. PHM system functional structure diagram is shown in Figure 1.

Figure 1. PHM system functional structure diagram.

Actively adopting PHM technology in system maintenance support can achieve the following three goals: First, reduce maintenance support costs by decreasing the need for support resources such as spare parts, support equipment, and maintenance manpower; Second, by reducing maintenance, especially the number of unplanned repairs, shortening the maintenance time and improving the
readiness rate; Third, through health perception, reduce the risk caused by faults in the task process and improve the success rate of the task.

2.3. The necessity for integrating PHM into PBL

To a vendor the prospects for achieving the result specified in a performance contract may appear quite uncertain [16]. And all organizations, public and private, abhor uncertainty. It is difficult for suppliers to predict future results during the contract formulation process, thereby greatly reducing the possibility of obtaining the maximum payment specified in the contract. At the same time, the mutual distrust brought by uncertainty will further limit the operating space of PBL implementation. PHM can use various technical means (such as expert systems, neural networks, fuzzy logic, etc.) to predict future needs and trends, to ensure Activities provide decision support, which greatly reduces the impact of uncertainty and mistrust.

Another important reason for need is the selection of measurement indicators is crucial to the successful implementation of PBL, and the measurement indicators selected at the beginning of the contract are not necessarily optimal. After the implementation of PBL, it is necessary to observe as many parameter indicators as possible and continuously improve to find the best. Good measure. PHM can analyse the effectiveness of various indicators through data fusion and automatic inference decision-making technology, and finally determine the most reasonable measurement indicators.

At present, most of the methods and theories for solving PBL problems are mainly empirical and qualitative analysis, and lack of accurate quantitative analysis. PHM can collect and process data through data collection and sensor technology, and then conduct status monitoring, health assessment, and fault prediction to solve the PBL problem. Provide accurate and quantitative judgment basis.

3. The proposed framework

3.1. Main framework

This section presents the analysis and judgment process of integrating PHM into PBL, so that suppliers can better solve the problem of PBL. The specific process is shown in Figure 1:

1) Determine whether PBL is successful? Success or failure will continue to determine whether the PHM technology is applied?

2) If PBL is successfully implemented and PHM is used, maintain the status quo.

3) If PHM technology is not used in a successful PBL, then the implementation of PHM will be evaluated to determine whether it will produce greater benefits after implementation? If it cannot produce greater benefits, then maintain the status quo; If it can produce greater benefits, analyse the specific implementation steps.

4) If PBL fails meanwhile PHM is used, determine whether the cause of the failure is caused by the PHM application? If it is not because of PHM, analyse other reasons, and if it is the cause of PHM, further judge whether the problem can be solved by improving PHM? Improve if we can solve the problem, and redesign PBL if we can not solve the problem.

5) If PBL fails but PHM technology is not applied, determine whether the problem can be solved if PHM is applied? If we can solve the problem, add PHM technology and improve the PBL strategy; If we can not solve the problem, look for other reasons.
3.2 Evaluation process
Evaluation is a key step in the integrating process, this step is conducted in three phases: data collection, data analysis and recommendation generation. The specific process is shown in Figure 3.

Data collection requires the development of a data collection plan that lists the data required for the evaluation activities and should collect data in the most original form possible. The collection plan does not have to be detailed, but it should be comprehensive. After collecting the data, you need to verify whether the necessary information has been collected, and finally refine and summarize the key information.

Data analysis mainly includes four activities: evaluate data collected relative to other factors, analyse feasibility, analyse timing and estimate cost savings and performance improvement. Evaluate data collected relative to other factors evaluate the collected data and judge whether PHM could be applied; analyse feasibility check if PHM is feasible; analyse timing evaluate whether the system can achieve a certain goal within the life cycle; estimate cost savings and performance improvement determine if you can save cost and improve performance by applying PHM.

Recommendation generation through comprehensive collection and analysis of data to form recommendations. If feasible, a more detailed analysis is required; If not feasible, consider other options.
4. The directions of future research

Although the framework proposed in this article can help solve the problems of failed PBL, there are still some points worth improving due to related limitations. First of all, this article gives a comprehensive summary of the reasons for unsuccessful, but the reason basically comes from the relevant literature rather than the author's collection; secondly, this article has fully considered the method and process, but because of the difficulty of verification, it is impossible to prove the effectiveness of this method.

In the future, when researchers carry out related research, it is recommended to conduct extensive research on companies that have recently implemented PBL strategies to understand the latest failure reasons; After completing the research, cooperate with enterprises as much as possible, participate in the formulation of PBL strategies, and verify effectiveness of the proposed method; Another point is that the process framework proposed in this article can be more specific, such as which technologies of PHM can be used to solve different problems, this requires researchers to have deep insights into the causes of PBL failure and PHM technology.

5. Conclusion
As the field and scope of PBL applications continue to expand, people's understanding of PBL has also deepened. This article discusses the unsuccessful factors of PBL and the advantages of PHM, meanwhile, discovers the necessity of integrating PHM into PBL. Through the establishment of flow chart and evaluation process, this paper help suppliers better implement PBL. Finally, by analysing the shortcomings in this article, the directions of future research are given.

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