Improving Maintenance Activities by the Usage of BOL data

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Abstract

Product Life-Cycle Management (PLM) defines the integration of different kinds of activities, from a technical, organizational and managerial point of view. These activities are performed by engineering staff throughout the entire life cycle of industrial products. To improve PLM, the information which is gained within a specific PL phase should be made available and used along the entire life cycle. This position paper describes how the No-fault-found (NFF) problem can benefit from transferring information from BOL into MOL. The application field of avionics is considered, in particular the generated information in the test process of BOL and the relevance of NFF. For this purpose, the article presents an approach by ARINC 672 for reducing NFF phenomenon. On basis of this approach the authors propose an extension to insert the information of test process' results proactive into the ARINC 672 approach. The extension has a visionary nature and does not consider technical background of the BOL and MOL of aircrafts. Finally the position paper motivates the next necessary steps to bring the proposed extension to its applicability.

Keywords: ARINC 672; NFF; Maintenance; Model Based Testing; BOL

1. Introduction

Product Life-Cycle Management (PLM) defines the integration of different kinds of activities, from a technical, organizational and managerial point of view. These activities are performed by engineering staff throughout the entire life cycle of industrial products. The entire life cycle includes the phases Beginning-of-Life (BOL), Middle-of-Life (MOL) and End-of-Life (EOL). In the Middle of Life, a product is used, can be upgraded and is maintained. Furthermore, most products are surrounded by services which increase the quality of usage [1]. The effort for the above mentioned MOL activities correlates e.g. to the type of the products, the quality and the planned obsolescence. The proportion of the maintenance of the MOL activities correlates e.g. to the complexity and the duration of Life of a product.”… The purpose of maintenance is to extend equipment lifetime or at least the mean time to the next failure whose repair may be costly…” [2]. The role of maintenance is very relevant to the application field of safety-critical systems. “…Safety-critical systems are those systems whose failure could result in loss of life, significant property damage or damage to the environment. There are many well-known examples in application areas such as medical devices, aircraft flight control, weapons and nuclear systems…” [3] Up to now, in safety-critical systems occur system errors during its operation time. In such a case, the system is removed from service and sent to the maintenance. During the maintenance activities, the error messages which contain the fault behavior are evaluated to identify the responsible components. In rare cases, the maintenance activities can't reconstruct the failure and can’t find the potential defect. In such a situation, the operating safety will be checked and finally, it will be allowed the continued use. This issue is known as No Fault Fond (NFF) In avionics the NFF problem is“...an age-old phenomenon that strangely enough has not yet been entirely successfully solved…” [4]. In this paper, the author demonstrates the relevance of NFF and counter-measures which includes the usage of BOL data. For this purpose, the degree of the NFF problem and one possible counter-measure are presented. Subsequently, it will be defined which information are contained in the BOL data regarding the functional testing.
The paper shows a closer look to information sources and their representation forms. Finally, it will be demonstrated how the information can be applied to reduce a NFF phenomenon.

2. No Fault Found phenomenon

The phenomenon of No Fault Found is known by a variety of names (e.g. No Trouble-Found (NTF) or No Defect Found (NDF)) and is a problem which has concerned operators and maintainers in all technology-dependent application fields which range from avionics over automotive to telecommunications. The central element of a NFF phenomenon is the intermittent occurrence of a fault.

A fault is “…the state of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources…” [5] A No Fault Found (NFF) defines the phenomenon that a fault which is detected during operation time can’t be reconstructed in maintenance activities afterwards. Reconstruction is a proceeding in which the faulty unit will be removed and tested under a lower level of maintenance. In the application field of avionics a NFF is defined as “…the result of testing when a unit removed as faulty at one level of maintenance is found to be fault free when tested at the next lower level of maintenance…” [6]

The commonality of the above mentioned definitions is that a fault has occurred and cannot be “…verified, replicated at will, or attributed to a specific root cause…” [1]. To handle this kind of occurred fault, the person responsible has to assume a cause. Subsequently, this person responsible initiates the repair work on basis of the assumed cause. Finally, the operating safety will be checked and the system will be allowed the continued use.

The NFF phenomenon has been relevant for more than 15 years. In 1990 a study showed that 21-70% of the total fault were classified as NFF [1,7]. 10 years later, another study determined a rate of 50-60% of NFF reported by commercial airlines and military repair depots [1,8]. A more detailed itemisation is given in Fig. 1.

As the above mentioned frequencies show, the relevance of NFF is still high and resulted in different approaches to reduce the amount of NFF occurrences. One of the major activities in the application field avionics led to the ARINC 672 initiative. The objective of the initiative was to develop a process to reduce the impact of NFF phenomenon and resulted in a report. This report defines a structured process to identify, analyze and resolve NFF issues [4]. It was identified that the source of NFF is not only limited to the operation and its corresponding kind-of-use. Rather, it was discovered that the entire life cycle of an aircraft is a possible source of NFF. Meyer [4] summarized the NFF sources, which is shown in Fig. 2.

Fig. 2 shows a schematic illustration of a generic “Hierarchical System Life Cycle”, which is oriented to the avionics environment. The Hierarchical System Life Cycle distinguishes two product life cycle phases of an aircraft, namely Design/Production and Operation/Support. In a space of a product life cycle phase, it focuses on the following four levels Component, System, Aircraft and Fleet. This kind of abstraction level defines which entity is affected in the corresponding phase. The Develop/Production phase has a significant impact on the Operation/Support phase, because it determines all requirements, constraints and restrictions to guarantee a safety operation time. A safety operation time means, that fault can occurs but the safety of creatures is in danger at any time. For this purpose, the task of development activities is to ensure, among others, that all possible fault behavior can be detected, can be treated and can be classified how critical the fault is. These objectives are in contrast to the NFF phenomenon. To detect all fault behavior, Meyer [4] mentioned that modules for built-in testing (BIT), diagnosis (BITE), and troubleshooting are specified.
and implemented in an aircraft during the Design/Production phase. All systems together, are the foundation to detect fault behavior and to gain so much information to prevent the occurrence of the NFF phenomenon. Furthermore, the modules determine the cornerstones of the operation time and maintenance activities afterwards. The thesis of the authors is, the higher the quality of the tool chain is, the less NFF cases should occur. Apart from the tools, the underlying process and the involved skilled employees of the aircraft’s life cycle have a direct impact of the NFF. Meyer [4] summarized the operation processes, service processes and the involved stakeholders, which is presented in Fig. 3.

![Fig. 3. Stake-holders in the Operation/ Support Phase, Source: [4]](image)

Fig. 3 depicts the process steps regarding the interaction and the involved stake-holders of the operation/support phase of an aircraft’s life cycle, which is shown in Fig. 2. To reproduce a fault/failure, all four levels of the Hierarchical System Life Cycle have to be considered. At each level another abstraction level of an airplane is focused. Therefore, specific documents and specific skilled employee are deployed. For example, the maintenance of component level requires e.g. as documents the repair manual and as a skilled employee a component tester.

When reproducing a fault, it may happen that the fault behavior cannot be fully adjusted within a level. The reason for this is that a fault behavior can detect in one level but the trigger is located in one another level. Furthermore, the trigger and the cause can lie in different layer. In the worst case, the fault behavior, the trigger and the cause lies in different levels. To resolve such kind of failures, the interaction between the levels, the information sources and the involved stuff are necessary. The combination of all sources enables an efficient and complete failure search. The weakness of the above mentioned process lies in the fact, that failures can only be resolved on basis of the measured data, the maintenance documentation and the experience of the stuff. In cases in which a NFF is occurred this set of information sources is insufficient. In the following, an approach is presented to enrich the information density in the case of a possible NFF. It will be presented which additional information can be applied to identify the inexplicable behavior of the system.

3. Approach

The objective of the approach is to support the skilled employees in cases in which a reported fault would be classified as a NFF. Through the supporting a higher information density is achieved and enables a deeper comprehension of possible failure sources and corresponding failure chains. For this purpose, the strict division of the Design/Production phase and the Operation/Support phase of the above mentioned Hierarchical System Life Cycle should be softened. This article supports the hypothesis that knowledge from BOL can enrich the comprehension for the system/components for maintenance activities.

![Fig. 4. Extended version of the Hierarchical System Life Cycle [4]](image)

In Fig. 4 the approach is shown how the Hierarchical System Life Cycle can be extended to satisfy the above mentioned objective. During the Design of an aircraft which includes a developing and a testing phase, a set of documents are created. The documents’ range spans from requirements,
over drawing to formal models. Accordingly to the high diversity, the representation form varies from informal to formal. The criterion representation form has a significant impact on the suitability for the usage in the Operation/Support phase due to the access and interpretation of the information in an automated way. These documents describe in their entirety the product-specific and general assessments and the specific properties of the implementation of the developed system. The test process which is a part of the Design/Production phase has to satisfy the DO-178B in the application field of avionics. This standard postulates that aircrafts are tested against the criterion MCDC [9] in the field of safety critical systems. That means that the following common criteria of the System under Test (SuT) must be tested: All States, All Transitions, Modified Condition/Decision Coverage (MCDC) [10]. The criterion All States defines that all possible states which a SuT can accept has to be considered during the testing. This characteristic feature of testing results in a detailed and complete view of the SuT and it reflects the information density of the test relevant documents. To resolve a presumably NFF phenomenon, the test relevant documents could be used to enrich the information density for the maintenance activities. This promising approach is presented in the following.

3.1 Test relevant documents

Hierarchical System Life Cycle (see Fig. 2) addresses a test process with the three levels (Component, System and Aircraft) of the Develop/Production phase. Nowadays, many companies develop their products according to the V-model, which is shown in Fig. 5.

![Fig. 5: The V-model of the Systems Engineering Process [11]](image)

Fig. 5 describes the development process of a system. It is divided into two main phases, the development activities on the left side and the test process on the right side of the V-model. The objective of a test process is to “…take the responsibility for the functionality, reliability and operational safety of their products. …” [12]. To satisfy this strict requirements, there are two strategies available: proof of the correctness or a verification on basis of successful executed test cases. Up to now, “…the proof of the correctness of these functions cannot be realized in a formal, analytical way…” [12]. That means that the test process is realized with the aid of test cases. This premise leads to a test process in which the main tasks are e.g. the identifying of parameters, the identifying of value ranges and the modeling of the behavior and finally a reduction to a relevant subset. This relevant subset will be completed to a set of test cases and used to verify a SuT against its requirements. Therefore, a test case aims to provoke an error condition and subsequently, check whether the system behaves according to the requirements. This kind of information contained in the test process (e.g. as test models) provides the deepest understanding of the system and in conclusion is the best information source for resolve a probably NFF phenomenon. In the following it is presented how such kinds of information can be represented in test models and how the information can be applied.

Within a test process two types of information can be explored over the SuT, namely structural property and behavior. Structural property describes the fixed structures of the SuT. It belongs to e.g. which components are installed, which properties have the components, in what range the components receive or send information. Test engineers can model such types of information in different representations forms which comprise a corresponding degree of formal. In relation to the intended usage, a more formal representation form enables an automatic access and an automatic interpretation of data for possible search request. A common method accepted by industry is to model the structural information regarding relevant parameters and relevant value ranges is the Classification Tree Method (CTM) [13]. The objective of the CTM is to identify the relevant parameters and corresponding values for a test. A test can address a SuT function and satisfies the correct behavior on critical system states. In the application field of avionics, for example, an asymmetry of both wings position is a critical state. An example of a classification tree is given in Fig. 6.

![Fig. 6: Example of a classification tree [12]](image)

Fig. 6 gives an example of the classification tree how relevant parameters and values can be modeled. The grey nodes represent the values which are considered during the development of test cases. Each of the values is an and contains a set of values. The assumption is that for each value of an equivalence class it provokes the same SuT behavior and can so be summarized in accordance with a value. The information which parameter and which equivalence classes
are relevant is very important information for resolving a NFF phenomenon. The skilled employee needs no longer to consider all possibilities, but he can use the classification tree in advance to exclude options. An option is in this case a set of values of a parameter or a SuT state. The excluding would accelerate sustainable the failure search. Furthermore, the classification tree grants an overview over the relevant parameters and the relationship between them. So, the skilled employee can check easily whether he has considered all relevant components (parameters, values) in his inquiries.

In other approaches both the structural properties and the behavior of a SuT are modeled in one model. An example is given in Fig. 7.

![Diagram](image)

Fig. 7. Example of a blinker behavior of a car [14]

Fig. 7 illustrates the behavior of a blinker in a car. A blue rectangle/node represents a state. In this example, a system state consists of the current states, of the left and the right blinker. The activity of a blinker is modeled as an integer, in which the value 0 represents the state for out. A transition between states is modeled as arrows. An arrow can contain a constrain, which defines the case for a transition from state1 to statei+1. For example, the blinker can switch from the IDLE state to the ACTIVE if the value of til is greater than 0. Such modeling approaches were researched and resulted in different modeling language. Common languages are Time Partition Testing, a UML notation for state machines, a UML notation for sequence diagrams and so on. The main difference to above mentioned approach lies in the fact, that such kinds of diagrams have their focus on the behavior. A skilled employee can extract the behavior easily of the model and get a good overview how the system reacts in a specific situation. To resolve a NFF phenomenon, the fault state could be located in such a model. On basis of the located position, a skilled employee can identify which chain of states had to occur to reach the fault state. This knowledge is necessary to detect faults which have a fault behavior, a trigger and a cause which occurs at different times. In such a case, the fault behavior, the trigger and the cause could be found at the worst in different states of the behavioral model. The weakness of this kind of models lies in the missing overview over the relevant parameters and corresponding values. Such kind of information is spread over the whole model. Furthermore, the model is unsuitable when a skilled employee has to identify whether the measured failure state was covered by the test models.

To enable an efficient dealing with the model based knowledge of a test process, the article proposes a two stage procedure. The procedure is shown in Fig. 8 and could resolve a NFF phenomenon if the current methods are not sufficient.

![Diagram](image)

Fig. 8. Procedures to resolve a NFF phenomenon with aid of test models

The Fig. 8 depicts a two stage procedure. The first stage is on the left side and the second stage is on the right side. The second stage is only necessary if the detected fault behavior can’t be found within the behavioral model. In such a case, the behavioral model does not consider all parameters or values. To find the state, a classification tree can be used. The usage of a classification tree is the second stage of the procedures. The search within classification tree clarifies whether the measured failure state was considered during the test process or not. This information is an essential information for a test engineer. In both cases, the skilled employee has to get in touch with the test engineers to discuss the impact of the search result.

**Conclusion**

At the beginning of the article the authors presents the relevance of the NFF phenomenon in the application field of avionics. The relevance is given by a rate 50-60% NFF in the set of detected faults. To reduce the number of NFF, the ARINC Workgroup 672 developed a process. This process was taken and extended with an exchange layer between the Develop/Production phase and the Operation/Support phase. The exchange layer serves the exchange of documents from the Develop/Production phase to the Operation/Support phase. It was conclusively justified that the test process could provide all relevant information to resolve a probably NFF phenomenon. The sufficient quality can be guarantee by the usage of formal models. Models have the advantage that the save the information formal and enable an automatic access.
and interpretation to it. Finally, the article defined a procedure how the models could be used to resolve possible NFF phenomena. The presented procedure has just a vision nature. That means, the following issues e.g. are still open:

- It does not consider the concrete process of possible NFF analysis.
- It does not consider the characteristics of a specific application domain.
- The articles didn’t evaluate whether an application domain uses both kinds of models for their test process.
- The article didn’t evaluate whether the exchange of information is technically possible.
- The article didn’t evaluate which effort would be necessary to combine both life-cycle phases.

The further research should focus on the implementation of the mentioned procedure for a concrete application domain. This includes the evaluation of a specific NFF analysis and the possibilities to integrate the additional information sources seamless into the analysis.

Acknowledgements

This article was written within the research project BreTeCe and was sponsored by the WFB Wirtschaftsförderung Bremen GmbH and European Regional Development Fund (ERDF). The strategic partner is the High Lift department of Airbus Bremen.

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