FMECA-Based Risk Assessment Approach for Proactive Obsolescence Management

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Abstract. One of the most critical issues that can affect the useful life of a product is the obsolescence of its components or functionalities. To minimize its effects and bring long-term benefits to systems, obsolescence must be proactively managed. A critical step in the process of proactive obsolescence management is the obsolescence risk analysis of critical components or functionalities. However, estimating the degree of obsolescence of multi-component systems is an area that is still under-explored, particularly when interdependencies exist between components. This estimation can be more complicated where there is no prior knowledge about the interaction between components. We used Weibull's distribution to model the components' interaction and calculate the obsolescence degree of the global system. This approach is evaluated using a numerical example based on a meteorological data acquisition system. The obsolescence of main components of this system is modeled while taking into account the interaction between them. Results are presented and discussed while clarifying the scientific issues that should be tackled in future works.

Keywords: Product Lifecycle Management (PLM), Proactive Obsolescence Management, Risk Assessment, Weibull.

1 Introduction

Nowadays, obsolescence has become an increasingly common problem in all sectors, whether in aeronautics, automotive, home automation, etc. This problem is mainly related to systems with a long-life cycle [13]. The system is designed to operate for a long period while some of its components are exposed to some kind of obsolescence and therefore the vulnerability and exposure to obsolescence of the system increases. Obsolescence or Diminishing Manufacturing Sources and Material Shortages (DMSMS) is defined as "the loss or imminent loss of original manufacturers of items or suppliers of items or raw materials" [2]. In [1], the authors clarified the difference between these two concepts by explaining that "obsolescence does not always lead to DMSMS problems, and not all DMSMS problems are due to obsolescence". As long as the product is still in production or available to meet future demands, it does not pose a DMSMS problem. But, if the spare parts are obsolete or if the know-how to perform the repair and the possibility to test the system (e.g. test equipment) after repair are not available, this causes a DMSMS problems. The authors in [3] explained the difference between obsolescence and discontinuance. By specifying that obsolescence occurs at a technological level, whereas discontinuance occurs when the manufacturer stops producing an item. However, in the industrial domain, obsolescence includes the cessation of production of a component if there are no other manufacturers for that specific component. This paper deals with the obsolescence problem which can be due to the technological evolution or the absence of support from manufacturers. The objective is to minimize its impact on life cycle costs, system performance, availability, maintainability and safety. Thus, it is necessary to focus on obsolescence management throughout the product life cycle. In [1], the authors present a multidisciplinary process for obsolescence management aimed at identifying the problems resulting from obsolescence; assessing their impacts; analyzing mitigation actions, and finally implementing the most cost-effective strategy.

Obsolescence syndrome concerns all kinds of systems, but its impact is more important in complex systems [18]. Indeed, complex systems are more exposed to obsolescence problems due to their multi-connected components. A complex system can be defined as a coherent set of different interconnected entities [21]. Thus, the study of its obsolescence depends on the obsolescence of each entity and the interactions between them. Components dependency refers to the fact that the obsolescence of one component can influence the life span of the other components of the system. In other words, if a component has become obsolete for various reasons, it may have an impact on the other components, which interact with it, by accelerating their obsolescence. Only a few studies, in the obsolescence literature, have been considered the complexity of systems and the interaction between their components [12,22]. This problem becomes more difficult when considering the obsolescence evolution over time. Up to our knowledge, conducted works and existing methods in the obsolescence domain do not address the evolution of obsolescence over time. Our research aims to develop an approach to predict system obsolescence over time while taking into account the interactions between its components. To do, the Weibull distribution is used to model the obsolescence evolution of components. Based on these distributions, the system obsolescence degree is calculated while taking into account the interactions of its components.

The remainder of this paper is organized as follows: Section 2 presents a brief overview of obsolescence concepts and reviews the different methods of obsolescence management. Section 3 describes the proposed methodology with the necessary assumptions. Under these assumptions, we illustrate our approach in section 4 by an example. Finally, conclusions and perspectives are given in section 5.

2 Obsolescence State of the Art

In this document and in its context, we adopt the definition of obsolescence given as "the loss or imminent loss of system functions due to the loss of items original manufacturers, items or raw materials suppliers, or technical support". The problem of obsolescence is particularly well illustrated by electronic components, but it is not limited to them. Authors in [4] gave a global view of obsolescence, specifying that obsolescence can affect other aspects such as mechanical components, software, materials, skills, tools, and test equipment. Obsolescence goes through different stages; upon notification of change or discontinuity, the company must immediately inform its customers so that they can prepare their obsolescence management plan [5]. Obsolescence can be relative or absolute [6]. When the product stops working (a technical problem), obsolescence is said to be absolute. If it still works and consumers, for example, have chosen to replace it, obsolescence is said to be relative [7].

2.1 Obsolescence Causes

There are many possible reasons for obsolescence. Some of them are related to technological evolution or innovation that makes a component obsolete even though it still works and can be produced and purchased. Other reasons are related to the supplier, such as the disappearance of original suppliers from the market for various reasons [8], or the original component manufacturer or original equipment manufacturer is not willing to continue producing a part for economic reasons for example; when the demand for a component or technology decreases and the manufacturer considers it uneconomic to continue production. Obsolescence can be caused by directives, rules and other laws imposed by governments such as the restriction of the use of certain hazardous substances (RoHS) directive [9] such as the ban on the use of Freon because of its ozone-depleting characteristics. Products may also become obsolete if they are no longer durable due to the ageing process of stored parts, which make their use impossible [10].

2.2 Obsolescence Consequences

Obsolescence is a significant cost generator and can affect products during all their life cycles. Obsolescence consequences can be divided into three main categories: (i) product's requirements, (ii) ecologic and (iii) economic consequences. Requirements consequences imply the no respect of system requirements which can be classified according to [11], in four categories, namely; functional system requirements (the suitability of the component to fulfill its function in its environment); non-functional requirements (maintainability, viability, vulnerability, testability...); performance requirements (efficiency, execution time, transport speed...); constraints (dimensions, supply voltages...). Moreover, obsolescence has strong effects on the environment. In fact, obsolete products result in a huge volume of hazardous waste that intensify the greenhouse gas emissions and pollution. In addition, the replacement of these obsolete products implies an increased use of non-renewable resources. From economical point of view, obsolescence can result in an important life cycle costs that call into question the depreciation of systems. There is a clear evidence that a robust obsolescence management strategy can significantly reduce the impact of these consequences. Thus, many obsolescence management strategies have been proposed in the literature.

2.3 Obsolescence Management

While obsolescence is inevitable [5], its anticipation with a careful planning can minimize its impact and potentially high cost. Sandborn [15] has defined three types for obsolescence management: (i) Reactive management which involves taking action when obsolescence has already occurred, (ii) proactive management is put in place for critical components that are at risk of be- coming obsolete and (iii) strategic management complements proactive and reactive management and includes determining the optimal combination of mitigation approaches and design refreshes.

To carry out these management strategies resolving and mitigating methods are used. Resolving techniques are applied to solve the obsolescence problem when it arises. While mitigation methods are applied proactively to minimize the impact of obsolescence. Table 1 identifies these methods.

Table 1. Methods for resolving and mitigating obsolescence [4].

	Method	Description
RESOLUTION	Redesign	Redesign obsolete parts to improve the performance, reliability, and maintainability of the system.
	Last Time Buy	Purchase and store components following a supplier's product discontinuation notice.
	FFF equivalent	Replace the obsolete component with a component that will work fully (in terms of form, fit, and function)
	Emulation	Develop an item with identical form, fit, and function to replace the obsolete parts using advanced technologies.
	Cannibalization	Keep products by using components and subassemblies from other unserviceable systems.
MITIGATION	Lifetime buy	Purchase and store components and spare parts, before production, from the original component manufacturer to meet the system’s needs.
	Use Multi-sourced Components	Check that the components included in the BOM can be provided by several suppliers to minimize the number of critical components. Applicable at the design stage

	Technology Road-mapping	Help to identify, evaluate and select technological alternatives in order to solve and prevent obsolescence problems caused by technological change.

The most commonly used type of management is the reactive one because of its easy implementation and also because companies are often far from being able to implement any proactive or strategic managements. However, it is advisable to use it only if the cost associated to the obsolete component is low [16]. However, if the obsolescence likelihood and the associated costs are high, proactive obsolescence management strategies are recommended to minimize the risk of obsolescence and the associated costs [14, 17]. Various authors [18, 19] have advised the use of obsolescence surveillance to obtain early notification of any risk of obsolescence. For that purpose, in this paper we focus on the proactive obsolescence management by proposing a risk analysis tool to predict the obsolescence over the time.

3 Methodology and Tools

Dealing with obsolescence involves a lot of trade-offs, risk assessment, and long-term planning. The key enabler to successful proactive obsolescence management is to predict the exposure degree to obsolescence. The objective of this section is to describe our proposed approach to predicting the evolution of obsolescence over time by taking into account the interactions between components. As shown in Fig. 1, the proposed method consists of three main steps:

1. Obsolescence risk analysis: in this step, the FMECA tool is used to identify main components and their exposure to obsolescence. The FMECA tool is used because it is extremely widespread in all domains that affect the safety, reliability, availability, and maintainability of a product or system [22].
2. Obsolescence modelling: The Weibull distribution is chosen to model the evolution of obsolescence over time because of its generality and flexibility.
3. Manage component interactions.

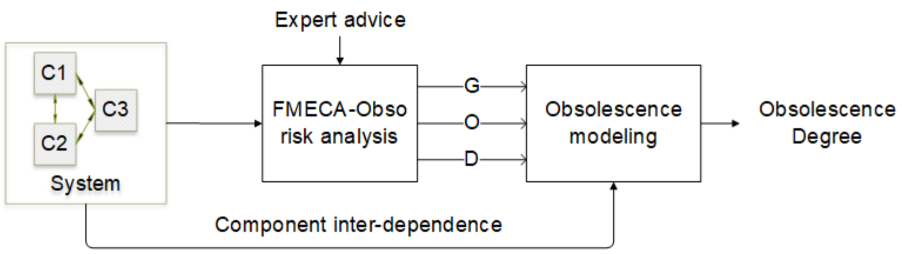

Fig. 1. Illustration of the FMECA-Obso methodology

3.1 FMECA-Obso: Risk Analysis

Obsolescence risk assessment using the Failure Modes, Effects and Criticality Analysis (FMECA-Obso) tool is conducted to analyze the sensitivity of the product to obsolescence and to prioritize risks to manage the components proactively or reactively. Thus, critical entities (components, functions and functionalities) with a high risk of obsolescence are identified, prioritized and managed throughout the system lifecycle. The FMECA-Obso criteria are presented below:

- Gravity: Gravity in this sense refers to the level of risk of the effect of obsolescence. The point here is to prioritize the gravity of the effects of obsolescence.
- Occurrence: The index of occurrence refers to the degree of occurrence of product obsolescence, which depends primarily on the characteristics and functions of the product. For microelectronic components, the occurrence can be classified as frequent because these components are highly subject to technological development.
- The detection: The assigned index is used to identify the non-detectability of obsolescence.

The evaluation of the obsolescence risks for each entity results in the calculation of the Degree of Obsolescence DO, based on the estimation of the Gravity, Occurrence and Detection indices. An expert on the system domain fixes these parameters.

3.2 Prediction Method

In this part, we are interested in predicting the obsolescence of systems. Predicting is seen as a scientific challenge for the implementation of such a proactive management strategy in which estimating the date of obsolescence is important. To do, we consider the degree of obsolescence (DO) as a Weibull distribution. This probabilistic model is used due to its generality, flexibility and wide applicability in the system life cycle domain [23]. The Weibull probability density function is given by equation (1):

$$f(t, \theta, k, \lambda) = \frac{k}{\lambda}\left(\frac{t-\theta}{\lambda}\right)^{k-1} e^{-\left(\frac{t-\theta}{\lambda}\right)^{k}} \quad (1)$$

where t, θ, k, and λ are strictly positive parameters. k and λ are the shape and scale parameters respectively, and θ presents the position parameter. These parameters define the probability distribution and model component obsolescence. We assume that the predictions were done at the same time for all system components, i.e. $\theta = 0$.

To estimate the Weibull parameters from the FMECA indices, we assume that the shape parameter k is proportional to the indices of gravity and non-detection. In fact, more gravity is high and there is no way to detect the problem (high non-detection index), more the risk of exposure to obsolescence is high: $k = a.G.D$ where a is a constant, G and D are the indices of gravity and detection.

As for the scale parameter λ, it is inversely proportional to the occurrence index; because with more frequent occurrence, the risk of obsolescence is accelerated (λ small): $\lambda = \frac{b}{O}$ where b is a constant and O is the index of occurrence.

The degree of obsolescence DO is therefore given by the following formula:

$$\text{at t= to ;} \quad DO = \int_0^{to} \frac{k}{\lambda}\left(\frac{t}{\lambda}\right)^{k-1} e^{-\left(\frac{t}{\lambda}\right)^k} dt \tag{2}$$

t_o corresponds to the date of observation.

To analyze the interactions between the components and to correctly monitor their state of obsolescence, it is good practice to represent each component by its cumulative distribution. The cumulative distribution function CDF of Weibull's law is:

$$F(t; k; \lambda) = 1 - e^{-\left(\frac{t}{\lambda}\right)^k} \tag{3}$$

Interaction Rate. The interaction principle considers that the obsolescence of one component induces the obsolescence of the other components that interact with it. The state of obsolescence of the affected component C_a is accelerated with an interaction rate $\rho_{i \to a}$, which generally depends on the state of the influencing component C_i.

The interaction rate is given by the following formula:

$$\rho_{i \to a} = 1 + \frac{F_i(t, \lambda_i, k_i)}{1 - F_a(t, \lambda_a, k_a)} \tag{4}$$

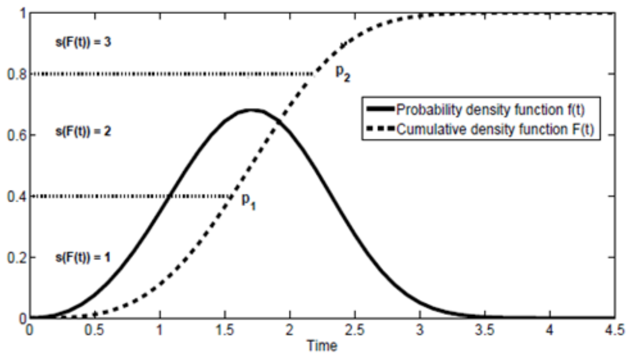

Fig. 2. CDF with different obsolescence states

Consider s(t) the function that indicates the obsolescence status of the component, e.g. "nominal", "critical" or "obsolete" (see Fig. 2) given by:

$$s\big(F(t)\big) = \begin{cases} 1 & F(t) < p_1 \\ 2 & p_1 < F(t) < p_2 \\ 3 & F(t) > p_2 \end{cases} \tag{5}$$

Weibull Model Taking into Account Interactions. In characterizing the effects of the interaction between entities in the system, the dependence model is described by the evolution of the obsolescence of the CDF as follows:

$$F(t;k;\lambda) = 1 - e^{-\left(\frac{t}{\lambda'}\right)^{k}} \quad (6)$$

where $\lambda' = \frac{\lambda}{\rho(t)}$

To set up this model, we consider the following assumptions:

- Without taking into account the dependency, the Weibull parameters are calculated from the Gravity, Occurrence and Detection indices by the following formulas:

$$k = Gravity * Detection\,; \quad \lambda = \frac{1}{Occurrence} \quad (7)$$

- The analysis of the degrees of obsolescence for all system components was done at the same time.
- The rate of interaction depends on the state of obsolescence of the influencing component.
- Obsolescence is assumed to be unidirectional (No mutual interaction).

4 Case Study

4.1 Description of the Case

The example illustration used is an environment observation link to earth (EOLE) system (Fig. 3), a weather balloon system whose main purpose is to provide meteorological data to various scientific users. This system is used as a case study in various previous works on obsolescence, as in [12]. It is composed of two subsystems; the first represents the in-flight acquisition subsystem, it is composed of a Helium-filled balloon, a temperature sensor, a pressure sensor, a sensor carrier (nacelle) and a nanocomputer where the data provided by the sensors are collected. This computer will, in turn, transmit them to the processing subsystem on the ground.

In our first work, we dealt with the obsolescence of VHF transmission technology. It was pointed out that the upgrade from VHF to UHF will result in changes to the physical architecture of the system, in particular the replacement of the radio transmitter and receiver. We assume that the transmission technology and the transceiver are the most critical components of the system where the antenna is the influencing component and the transceiver is the affected component. The obsolescence interaction is manifested in the cumulative distribution functions of these interdependent components.

To show the impact of the interaction on the obsolescence process of the system, we will consider two simulations. In the first simulation, the model does not take into account the interactions between the components. While in the second simulation, the interactions between the components of obsolescence will be studied. After a first analysis FMECA_Obso, the estimates of the Gravity, Occurrence and Detection indices are listed in Table 2.

The components are presented by the probability density functions $f_{VHF}(t)$ and $f_{Radio}(t)$ quoted in (8), where k and λ are the Weibull parameters and to observation time.

$$f_{VHF}:\begin{cases} k_i = 9 \\ \lambda_i = \frac{1}{7} \\ t_o = 1.5 \end{cases} \qquad f_{Radio}:\begin{cases} k_a = 6 \\ \lambda_a = \frac{1}{7} \\ t_o = 1.5 \end{cases} \tag{8}$$

Table 2. Obsolescence risk analysis FMECA_OBSO

Temporal Horizon: 2 years				Obso. value		
Entities	Availability or Suitability	Obsolescence classification	Effect	G	O	D
Technology VHF	Suitability	Technological	Syst. usability	9	7	1
Radio Emitter and Receiver	Suitability	Functional	Syst. performance	6	7	1

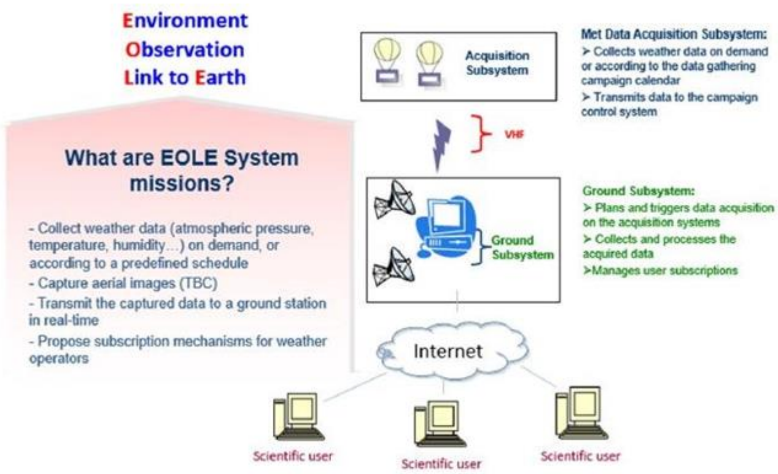

Fig. 3. Simplified specifications of the “EOLE” system [20]

According to Weibull's model, obsolescence is well modeled by the cumulative function F(t) as in Fig. 4. It is assumed that initially the interaction rate is equal to 1: $\rho_{i \to a} = 1$ which implies that the interactions between the components have not been taken into account. Generally, the rate of interaction depends on the state of obsolescence of the influencing component. It is very important when the state of obsolescence of VHF technology is serious. To study the impact of the interaction rate on the degree of obsolescence, we consider two levels for the interaction rate; $\rho_{i\to a} = 2$ when the obsolescence status of the VHF is critical and $\rho_{i\to a} = 3$ when the VHF is considered obsolete (see Fig. 5).

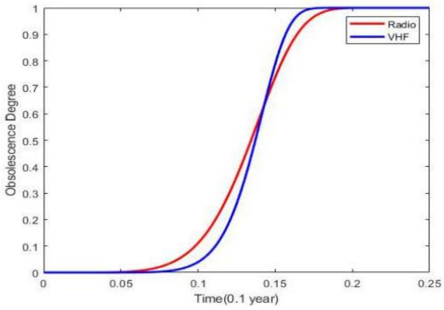

Fig. 4. CDF of the components

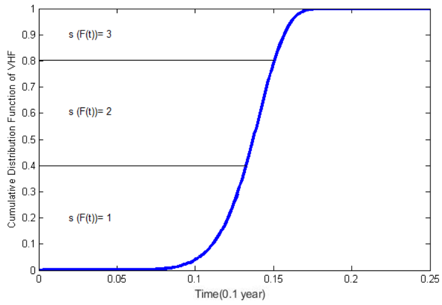

Fig. 5. Obsolescence states of VHF

4.2 Results and Discussions:

The degree of obsolescence of the system increases as the rate of interactions increases and this is well illustrated in Table 3. Regardless of the inter-dependency, VHF technology is considered the most critical element that its obsolescence causes system obsolescence. However, considering the interactions between the components, the degree of obsolescence of the system will depend on the degree of obsolescence of the radio transceiver. Fig. 6 shows the change in the degree of radio obsolescence.

Table 3. Simulation results

$\rho_{i\to a}$	**DO** $_{\text{VHF}}$	**DO** $_{\text{Radio}}$	**DO** $_{\text{System}}$
1	0.8	0.75	0.8
1.5	0.8	0.98	0.98
2	0.8	1	1

In this example, the Weibull distribution quoted in (6) was considered to vary the scale parameter as a function of the interaction rate. But really, the shape parameter also influences the variation in the obsolescence degree. Hence, in future work, we will consider that the shape parameter k will be affected by the interaction between the components.

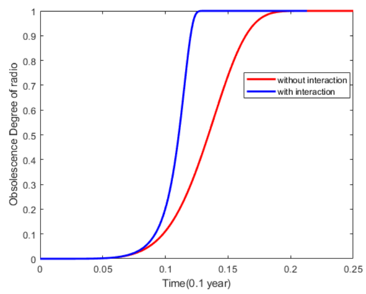

Fig. 6. Obsolescence degree of radio taking into account interaction

5 Conclusions and Outlook

In this paper, we presented FMECA-Obso for analyzing the risks of obsolescence. This tool consists of an in-depth analysis of the system to identify critical components and functions that can lead to system obsolescence. We also presented a model for predicting the obsolescence of a complex system where there are interactions between its components. From FMECA-Obso we can calculate both the degree of obsolescence and focus on the effect of the interaction between components on system obsolescence. The model is illustrated with a numerical example with a comparison between the different degradation models.

In this study, we considered that obsolescence is unidirectional, but in practice the interaction between the components could be mutual, i.e. obsolescence can propagate in both directions. Thus, not all components present the same risk of obsolescence and some are resilience, but they remain vulnerable. The challenge is to find a model for each component that integrates all these factors. These are our goals in future work to better align this obsolescence prediction using machine-learning techniques that could increase the prediction accuracy.

References

1. SD-22. (2016). Diminishing Manufacturing Sources and Material Shortages (DMSMS) A Guidebook of Best Practices for Implementing a Robust DMSMS.

2. Sandborn, P. (2007). Designing for technology obsolescence management. In IIE Annual Conference. Proceedings (p. 1684). Institute of Industrial and Systems Engineers (IISE).

3. Pecht, M. G., & Das, D. (2000). Electronic part life cycle. IEEE Transactions on Components and Packaging Technologies, 23(1), 190-192.

4. Rojo, F. J. R., Roy, R., & Shehab, E. (2010). Obsolescence management for long-life contracts: state of the art and future trends. *The International Journal of Advanced Manufacturing Technology*, *49*(9-12), 1235-1250.

5. IEC-International Electrotechnical Commission. (2007). IEC 62402.
6. Granberg, B. (1997) The quality re-evaluation process: product obsolescence in a consumer-producer interaction framework, Swedish Environmental Protection Agency.
7. Cooper T. (2004), Inadequate life ? Evidence of consumer attitudes to product obsolescence, Journal of Consumer Policy, 27, 421-449.
8. Atterbury, R., Component Obsolescence Group, United Kingdom; Minenfeld Obsolescence, A Guide to Tackling Disappearing Products, Issue 2, 2005.
9. Brewin, A. (2005). The Pb-free minefield: a guide to mitigating risk during the transition to RoHS compliance.
10. Bartels, B., Ermel, U., Sandborn, P., & Pecht, M. G. (2012). *Strategies to the prediction, mitigation and management of product obsolescence* (Vol. 87). John Wiley & Sons.
11. Glinz, M. (2007). On non-functional requirements. 15th IEEE International Requirements Engineering Conference (RE 2007), 21–26. IEEE.
12. Soltan, A., Addouche, S. A., Zolghadri, M., Barkallah, M., & Haddar, M. (2019). System Engineering for dependency analysis-a Bayesian approach: application to obsolescence study. *Procedia CIRP*, *84*, 774-782.
13. Zolghadri, M., Addouche, S. A., Boissie, K., & Richard, D. (2018). Obsolescence prediction: a Bayesian model. *Procedia CIRP*, *70*, 392-397.
14. Meng, X., Thörnberg, B., & Olsson, L. (2014). Strategic proactive obsolescence management model. IEEE Transactions on Components, Packaging and Manufacturing Technology, 4(6), 1099-1108.
15. Sandborn, P. (2013). Design for obsolescence risk management. Procedia CIRP, 11, 15-22.
16. Pingle, P. (2015). Selection of obsolescence resolution strategy based on a multi criteria decision model.
17. Rojo, F. J. R., Roy, R., & Shehab, E. (2010). Obsolescence management for long-life contracts: state of the art and future trends. The International Journal of Advanced Manufacturing Technology, 49(9-12), 1235-1250.
18. Meyer, A., Pretorius, L., & Pretorius, J. H. C. (2004, October). A model to manage electronic component obsolescence for complex or long life systems. In *2004 IEEE International Engineering Management Conference (IEEE Cat. No. 04CH37574)* (Vol. 3, pp. 1303-1309).
19. Sandborn, P., Mauro, F. and Knox, R., 2005. A Data Mining Based Approach to Electronic Part Obsolescence Forecasting. Proceedings of the 2005 DMSMS Conference, 11-15 April, Nashville, TN.
20. Roques, P. (2017). Systems Architecture Modeling with the Arcadia Method: A Practical Guide to Capella. Elsevier.
21. Bian, L., & Gebraeel, N. (2014). Stochastic modeling and real-time prognostics for multi-component systems with degradation rate interactions. *Iie Transactions*, *46*(5), 470-482.

22. Carmignani, G. (2009). An integrated structural framework to cost-basedfmeca: The priority-cost fmeca.Reliability Engineering & System Safety,94(4):861–871.

23. Weibull, W. (1951). Wide applicability.Journal of applied mechanics,103(730):293–297.