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PROACTIVE OBSOLESCENCE MANAGEMENT: AN APPROACH OF MONITORING AND SOLUTIONS FOR MILITARY COMPLEX PRODUCT SYSTEMS IN OPERATION

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***Abstract* - Obsolescence has become a major challenge in the industry since the speed of technological developments and the lack of raw materials. In addition, the legislation's improvements for the environment and safety, has contributed for increasing the problem scale. This paper addresses a proactive obsolescence management methodology for military Complex Product Systems (CoPS) in operation, which can prioritize and monitor the entire product structure, and, offering the near and mid-term proposals for solution of obsolescence issue. The project is based on international standards, researches and, on the experienced engineers, whose are responsible for decision making of obsolescence management at all business levels: supplier, assembler and customer.**

***Keywords*- Supportability, Obsolescence, CoPS.**

I. INTRODUCTION

The speed of technological developments, shortages of raw materials and legislation's improvements for environmental are taunting a lot of changes in the mode of production and available technologies. These changes help the companies to ensure the entire life of a product but can also be a challenge regarding the management of obsolescence.

The obsolescence is unavoidable, it will happen, and the company need to have a proactive management of the issue, or, the obsolescence can cause the unavailability of a system and require high costs of new developments to mitigate the problems generated. In the industry, everything that is expensive cannot be ignored, but forecasting with a careful planning, can reduce its impact and costs [1].

Due to all the problems that obsolescence can cause, its management has recently become a requirement to purchase and develop new systems, as for example in the Brazilian Air Force, which incorporated this requirement in its standard operating procedure of Basic Technical, Logistics and Industrial Requirements (RTLIB), as informed by Coronel Eng. CERQUEIRA, F. in an interview [17].

Sierra Nevada Corporation's engineers believe that proactive monitoring can be extremely profitable, it can avoid countless hours of delay and potentially millions of dollars in unnecessary expenses. The Embraer engineers also remember that, in addition to protecting the product's operation, obsolescence management is an opportunity to develop new businesses.

In systems with a long life cycle, principally for defense systems, the proactive management is even more necessary, once it need to be supported for many decades and with exclusive items developed especially for that system, which means that, it is not available in the market [2].

A CoPS is different from a simple equipment or systems, because requires a generalist and high-volume management due to the number of systems that is composed and the peculiarity of each one. Then, it is necessary to develop methodologies that make the management procedural and standardized. When the management of obsolescence is required in the operation, the unpredictability of failures can also become a problem, because the demand for equipment and systems becomes a random variable, depending of the failure and not of the production's demand.

II. METHODOLOGY

Through field interviews with engineers and in-depth study in the existing researches, this paper proposes a methodology for proactive management of the obsolescence of military Complex Products Systems (CoPS) in operation, focus on monitoring and near and mid-term solutions, looking to be able to identify, anticipate and/or avoid an eventual system support problem in a timely enough for adoption of corrective actions.

The interviews were conducted with engineers from Embraer SA, Sierra Nevada Corporation and the Brazilian Air Force. The purpose of the interviews was to learn the methodologies used by them managing the obsolescence of theirs CoPS; to better understand the problems caused by obsolescence and the solutions applied.

Embraer SA is a Brazilian company, the third largest manufacturer of aircraft in the world. Operates in the area of commercial, executive, agricultural and military aircraft, aerospace parts, services and support. The author VIEIRA, F. conducted an interview on May 14, 2020 with the Product Support Engi-

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neering Supervisor, Eng. Fabrício Feres BATTAGLIN [17]. The engineer has extensive experience in customer support with a history of work in the aeronautical and aerospace industry.

Sierra Nevada Corporation is a leading American company in solving the world's toughest challenges through advanced engineering technologies in Space Systems, Business Solutions and Security and National Defense. The author conducted an interview on April 9, 2020 with the engineers Ashley STANFORD and Elizabeth MONARCH, both responsible for the Obsolescence Management program for American Air Force Super Tucano aircraft [17].

The Brazilian Air Force has the largest fleet of military aircraft in Latin America, including fighter planes, ground attack, transportation, aerial refueling, training, utilities, surveillance and helicopters. The author conducted an interview on May 6, 2020 with Coronel Eng. Fernando Marcus da Rocha CERQUEIRA, responsible for the AMX aircraft's Obsolescence Management program. Cel. Eng. Cerqueira has a large experience in Aerospace Engineering, with focus on Materials and Processes for Aeronautical and Aerospace Engineering [17].

To develop the methodology, were adopted the needs for an airplane system, considering the interviews and the author's experience with the obsolescence management of the C-390 Millennium, cargo and multi-mission aircraft, and Super Tucano, light attack turboprop aircraft and advanced training, both developed by Embraer SA for the use of various air forces in the world .

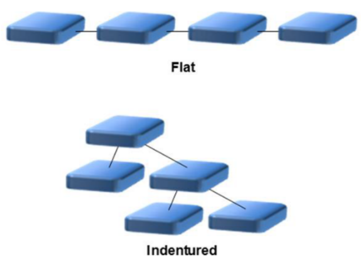
III. COMPLEX PRODUCT SYSTEMS

A Complex Product System (CoPS) is a special class of system, composed with a lot of components which may interact and be integrated with each other. For example, if all parts of a car are organized in a specific way, then we have the functionality of a vehicle. When these systems interact with each other, in a hierarchical structure, of different scales, affecting each other, we consider then a Complex Product System. The CoPS are usually products, systems, networks and constructions of high cost and with a complex engineering [2].

A CoPS is formed by the structured set of other systems and components. To identify this systems and components, the CoPs needs to have a list, called Bill of Material (BOM). The BOM can be a simple list with the items used in a system, called "flat", or a hierarchical list that presents the relationships between items, called "indentured" [3].

The figure 1 shows how the product structure can be represented.

Figure 1: BOM types [3].



Each item in the product structure has a universal code that represents it, called Part Number (PN). This code can consist of numbers, letters and characters.

IV. OBSOLESCENCE

Bartels et al. (2012) define obsolescence as "the status assigned to a part when it is no longer available from the original manufacturer". In the military context, obsolescence is also known as Diminishing Manufacturing Sources and Material Shortages (DMSMS).

In military systems, the systems life cycle is longer than the technology life cycle, making DMSMS inevitable [4]. Several factors can lead to the obsolescence of an item and will be studied in this paper. To study the main reasons to turn a CoPS item obsolete is extremely relevant, as these factors must be used to create an effective monitoring process.

Challenges such as: new aerospace rules, environmental and safety standards, evolution of manufacturing processes and methods, as well as shortage of raw materials and evolution of operating systems, are the main causes indicated by Wilkinson.

The American standard DMSMS requires that the problem of obsolescence be addressed proactively, that means, anticipating problems and solving them in the most economical and satisfactory way for customers [3]-[4]. But there is also a reactive approach, which is when the company decides to do not monitor the system. The lack of monitoring or process for quick decision making can turn the obsolescence management process reactive.

According to BATTAGLIN, F., proactive monitoring is extremely important to minimize costs and avoid interruption of activities:

> Anticipating problems is a question explored in all sectors of industry, seeking to avoid interruption of activities (which can cause fines, penalties) and minimize expenses in the operation, if this is done in a proactive way, the negative consequences (...) can be minimized or even avoided (BATTAGLIN, F).

V. DATABASE STRUCTURE

For an effective proactive monitoring, it is necessary that several variables are studied in order to predict the impact that the obsolescence of a product can cause on the system, as well as the probability of this product becoming obsolete soon. The objective of using variables to monitor a system is to prioritize products, since monitoring can become an exhausting and inefficient job when applied to all BOM.

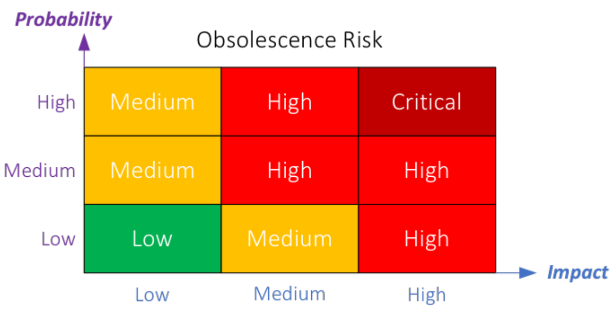
This project proposes that the monitoring variables be divided into two classes:

- Impact variables: able to measure the impact of the lack of an item for the CoPS, these variables are used to prioritize the items to be monitored.

- Forecasting variables: used to perform a predictive analysis of each component, in order to predict the obsolescence of this item. This analysis must be done for the items prioritized in the previous topic.

With the impact and forecasting (probability) data, it is then possible to create a matrix, where it is possible to manage the items with the highest risk of obsolescence, as shown in the example in figure 2.

Figure 2: Risk matrix [6].



Obsolete items must then be analyzed, and a strategy of solution defined and applied.

VI. IMPACT VARIABLES

Impact variables are used to measure the impact of an item's obsolescence on the system. It is common that these variables are collected internally at the OEM (Original Equipment Manufacturer), the goal is to measure what consequences the OEM will have if the item becomes unavailable to supply the aftermarket.

Before to start any monitoring process, it is necessary to define priorities, because may not be financially viable to monitor all items of a CoPS. Cel. Eng. CERQUEIRA, F. emphasizes the need to prioritize components:

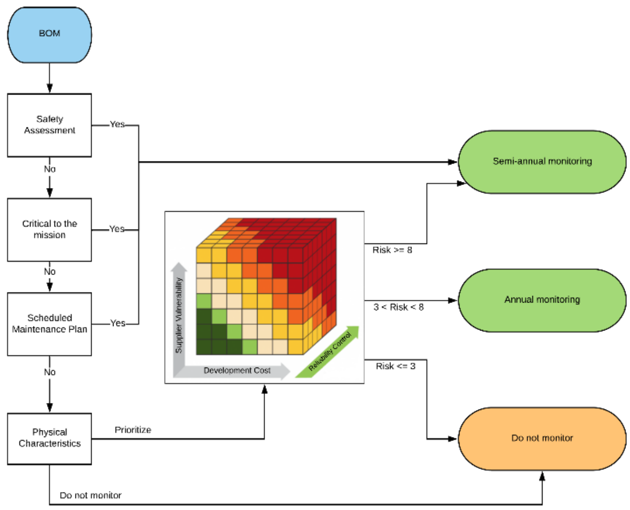
> It is important to note that we were unable to predict everything. Eventually, even with a robust obsolescence management system, we may be surprised by some serious problem to be addressed. It is a risk management problem, with characteristics of a risk equation: more/less expenditure implies less/more risk (CERQUEIRA, F).

The prioritization criteria need to be customized regarding the purpose of the OEM and the characteristics of the CoPS. This project will address prioritization criteria for an airplane system. Figure 3 shows the prioritization flow of the items that make up the plane.

The first step is to survey all the items of the CoPS. From the BOM, all items will go through a primary selection filter, where all items with specific characteristics will be allocated to the semiannual monitoring. The primary filter is safety assessment, critical to the mission and belonging to the scheduled maintenance plan.

After that, it is necessary to check the physical characteristics of the item to select which one go through a second prioritization and which will be not monitored. The second prioritization will use data of supplier vulnerability, development cost and reliability control. The following sections will better explain the variables mentioned.

Figure 3: Component prioritization flowchart, the author.



A. *Safety Assessment*

The system safety assessment is responsible to analyze the systems with the goal to determine whether the associated hazard events have been adequately addressed.

It is common in the aeronautical industry, and in several other industries, to carry out this safety analyzes of subsystems and systems, these analyzes take place during development and throughout the product's life cycle.

B. *Critical to the mission*

The Minimum Equipment List (MEL) is a very important document for the operation of the aircraft, as it presents the critical items for a given mission, in other words, it is a list with the fundamental items of the airplane, which it cannot take off without. The International Civil Aviation Organization (ICAO) defines MEL as the "list that provides for the operation of aircraft, subject to specific conditions, with specific equipment inoperative" [7].

Items like mentioned above should be monitored more frequently, as the lack of it can cause the unavailability or limitation of a CoPS.

C. *Used in the scheduled maintenance plan*

Kinnison and Siddiqui (2012) define that "maintenance is the process that ensures that a system continuously performs its function with the same levels of reliability and security for which it was designed". Every engineering project has physical limitations and is not perfect; the limitations can be production, economy, time, among others. And precisely because of the imperfection of the projects and the degradation of the products over time, there is a scheduled maintenance, also known as preventive [8].

If any of the items used during scheduled maintenance are obsolete and required for mandatory maintenance, then the aircraft may be on Aircraft on Ground (AOG) status. For this reason, it is very important to monitor these items frequently.

D. Physical characteristics

There are different types and categories that an item of a CoPS can be classified. The entire BOM should be categorized regarding the characteristics of each item, since some of them do not make sense to monitor with a low frequency, while others, require monitoring with high frequency.

Each CoPS can have peculiarities and a list of categories, among the main ones are structural assembly items, mechanical items, electrical items, painting, gluing and sealing items, machined and/or welded items, electronic hardware and software.

E. Supplier vulnerability

The goal of to measure the supplier vulnerability is to verify how vulnerable the company is with its suppliers in contractual terms, and for this is necessary to map which items are provided under a contract signed between both companies and their clauses regarding obsolescence.

In order to map obsolescence contracts, it is necessary to check the main information that would affect the availability of the item, in case the supplier does not proactively collaborate to solve the problem, it is a way to make quantitative the information that was only qualitative and textual.

F. Development cost

There are several methods to calculate the development cost of an item. One of the most effective ways to use this variable to create a ranking of higher cost items, is to use the purchase price of the item, which naturally has a relation to its development cost. Large companies usually use Life Cycle Cost (LCC) to calculate the cost of a product's life cycle.

G. Reliability control

Reliability is the ability of an item to perform a required function under specified conditions, over a given period [9]. In other words, reliability is linked to the future, with data from the past, it is a probabilistic projection that shows the chances of the equipment working perfectly in a specific period.

This variable is used to measure the impact of obsolescence, as it helps to forecast the purchase or repair demand for an item in the future. There are two variables normally calculated by the reliability team, they are the Mean Time Between Unscheduled Removal (MTBUR) and Mean Time Between Failure (MTBF).

VII. FORECASTING VARIABLES

Forecasting variables are used to predict the probability of an item become obsolete in the system, by studying the market and the specific characteristics of a product and its supplier. Saunders (2006) and the author provide recommendations for variables capable of predicting the imminent loss of manufacturers or suppliers of items or raw materials. The goal is to monitor the main root causes of product obsolescence [3]. The following sections present the variables studied and suggested for this project:

A. Hazardous materials and environmental restrictions

Hazardous materials are normally used in industrial manufacturing processes. Global laws and regulations on hazardous materials are regularly becoming stricter. Such materials can be banned completely or become difficult and/or expensive to use or obtain. The prohibition of a raw material or substance can cause the obsolescence of all products that use it, for this reason, global laws must be constantly monitored.For this reason, it is extremely important to monitor it, so that companies have time to modify or request the modification of products from their suppliers.

B. Low demand

The supplier's business case is no longer viable. This can occur with low-demand products, potentially containing exotic materials that are difficult to manufacture or involve major disruptions to more profitable commercial activities.

C. Shortage of raw materials

The diminishing supply of energy and minerals, essential for the industry, cannot meet the growing global demand. The high demand for commodities is being driven by three main factors: the growing world population, an increase in global wealth and a sharp trend towards urbanization [10].

The growing imbalance between the growing demand for resources and the fall in the supply means that commodity prices are likely to continue to rise substantially and, thus, making them financially unfeasible.

D. Technological evolution

It is very common for electro-electronic components to evolve rapidly from technology, the evolutions is mainly driven by the wars and sovereignty of the countries [11]. A great example of the technological evolution driven by the war and that continues until today, are the processors. Technological evolution is usually linked to new generations of technology that improve the performance or functionality of a product.

E. Technological revolution

Different of Technological Evolution, which evolves the technology of a product using the same method or solution, in the Technological Revolution, a new technology, method and format are developed to solve the same problem. A great example of a technological revolution is the portable data storage systems, which started with floppy disks, including CDs, DVDs and pen drives, and today have been transformed into files stored directly from the "cloud". Aircraft, for example, have undergone a major technological revolution in the last decade, with the replacement of analog radios by digital ones.

F. World and local crises

Events such as the 2008 World Economic Crisis, Cold War, World War II and pandemics such as Coronavirus and H1N1 lead us to reflect on the impact of crises, both global and local, in the supply chain of all productive sectors. In fact, these crises are extremely difficult to predict in a timely manner for a solution and will certainly cause problems for supplying raw materials and components for any type of complex system.

G. Software Evolution

The companies generally do not find it sufficiently profitable to apply resources to support older versions of software, they prefer that customers upgrade to the latest products. Consequently, the reduced ability to use the software can occur when newer versions of the software are available or there is no longer the ability to read the digital media on which the software is delivered. In addition, there is a diminished ability to use the software when its support ends. Software support includes product enhancements to increase capacity or decrease vulnerability to malicious attacks, error correction and general support for your application in specific environments [3].

VIII. OBSOLESCENCE SOLUTIONS

It is important for the OEM to find the best solutions for obsolescence, avoiding the need to develop a new product. For this, technical and logistical solutions must be used to prevent a redesign.

There are short or medium-term solutions that can meet OEM demands momentarily, or even completely solve the problem. This chapter will propose solutions that were analyzed in interviews and with the author's experience.

Product redesign and modification is the long-term solution; however, it is not the scope of this project and the feasibility must be analyzed by the OEM.

The solutions presented below are the provisioning of stock, cannibalization of items, the use of alternatives or equivalents and to buy in the aftermarket.

A. Inventory provisioning

Last Time Buy (LTB) is usually the best solution to deal with the obsolescence of an item. It is the moment when the company can guarantee the stock to supply the demand of the next years, thus avoiding a redesign or other high cost solutions.

The biggest difficulty of the companies is knowing how many items to buy in order to provision their stock, since the failures of an item are random, and demand can change at any time. This project then proposes to use the Poisson Distribution, The Poisson distribution is popular for modeling the number of times an event occurs in an interval of time or space [15].

A discrete random variable X is said to have a Poisson distribution with parameter > 0, if, for k = 0, 1, 2, ..., the probability mass function of X is given by:

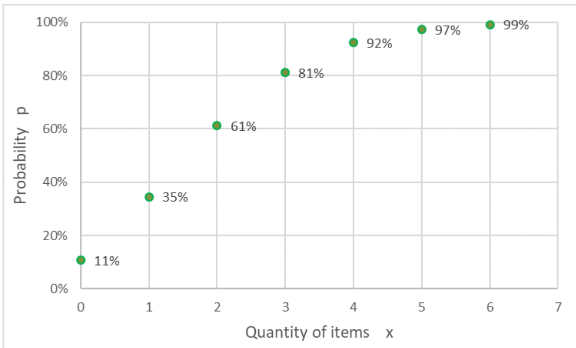
$$f(k;\lambda) = \frac{e^{-\lambda}\lambda^k}{k!} \tag{1}$$

The positive real number is equal to the expected value of X and to its variance.

This project studied the case of an aeronautical equipment declared obsolete by the supplier, where it is necessary to define the quantity of items to be purchased at LTB. This item is installed in a program whose fleet has 25 aircraft with an average flight of each aircraft is 40 hours/month. Each aircraft has 1 item installed. The time required to stock the item is 47 months.

From the Poisson analysis using the equation 1, the conclusion shown in the graph in figure 4 was reached. Therefore, the best decision is to purchase 6 items, these items will be enough to supply the entire fleet of 25 aircraft for 47 months, with a certainty of 99%.

Figure 4: Result of Poisson Analysis, the author.



B. Cannibalization

The Maintenance Regulation of Portuguese Air Force Aircraft states that:

> (...) a component is cannibalized when it is removed from an aircraft to satisfy a need for another aircraft, making it operational and the other inoperative. It happens when there is no material in the warehouse to satisfy the needs of operation [13].

Cannibalization has its costs, as does additional labor, as it requires, at a minimum, that the component to be cannibalized be uninstalled from one aircraft and installed in another. Another factor is that there is always the expense of other materials used in the installation. It is also impossible to rule out the risk of losing the component in good condition by uninstalling and reinstalling [14].

Even with the expenses involved, cannibalizing items may be the only solution of obsolescence and the decision to cannibalize should consider the possibility of making other aircraft unavailable, performing a priority analysis.

The figure 5 show the crashed aircraft C-150, after cannibalization.

Figure 5: C-150 after cannibalization [16].

C. Alternatives or Equivalents

Alternative equipment is a technically acceptable item (another acceptable PN), that means, with technical characteristics that can replace the obsolete item. Alternative equipment does not necessarily have the same physical characteristics.

The equivalent equipment must be FFF (same form, fit and function). It can be installed in the system, replacing the obsolete item, without any change or concern regarding fittings and function, as stated by Cel. Eng. CERQUEIRA, F [17].

D. Aftermarket

The aftermarket are resellers (non-OEM), who buy large inventories of items with the goal to resell, these resellers also usually buy used items and resell them, most often after some type of repair. In the industry they are called "brokers". They have intelligence services that map the market to stock items at risk of shortage.

IX. CONCLUSION

This paper presented strategies for prioritizing, monitoring and mitigating obsolescence in CoPS, while they are in operation. Proactive obsolescence management can, in addition to saving millions of dollars for companies in the long run, guarantee the availability of their systems and present great opportunities to develop new businesses.

Obsolescence management is a very broad activity, and the monitoring and search for best solutions is only a part of the activities. The suggestions for future projects that complement this, are cost analysis, management in the scope of manufacturing and production line, adaptation to other global standards and the study of feasibility and development of a redesign process, for situations in which short or medium-term solutions are not effective, and a definitive solution is needed.

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