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Integrated model for Maintaining Operational Conditions and managing obsolescence

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Abstract: Maintenance in Operational Condition (MCO) covers all technical and logistical support activities aimed at guaranteeing the availability of systems to carry out their missions. For complex systems, the management of MCO and obsolescence is a strategic issue to ensure their long-term performance and reliability. Although these two areas are often treated separately, the link between MCO and obsolescence remains little explored in research work. The aim of this article is to demonstrate that MCO, without systematic monitoring of the health of critical components, is a limited and ineffective discipline. Since obsolescence is inevitable, it is essential to couple MCO activities with specific remediation strategies. This article uses Structured Analysis and Design Technique (SADT) models to formalise and structure the interactions between obsolescence management and MCO practices. These models can be used to optimise decision-making and operational processes, integrating technical and regulatory imperatives to ensure more resilient and proactive management of complex systems.

Keywords: Obsolescence Management, Maintenance in Operational Conditions, Technical support, Logistics support, SADT model.

1. Introduction

Maintaining complex systems in Operational Condition (MCO), while taking into account technical, operational and economic imperatives, has always been aimed at ensuring the operational availability of these systems [Merchadou *et al.,* 2012]. This means optimizing the cost-effectiveness ratio for maintenance, while minimizing the effects of their operation (management of failures, breakdowns, requirements for consumables, spare parts, etc.). These constraints are linked to the ageing of functions, the quality of the maintenance policy adopted, and initial or emerging requirements (insufficient reliability, new regulatory requirements, etc.). Traditionally, MCO relies heavily on reliability-based approaches to maintenance activities, while integrating logistical imperatives to keep systems running smoothly throughout their lifecycle [Vieira *et al.*, 2016]. Conventional MCO models are thus showing their limitations in the face of this problem. Indeed, obsolescence makes systems more vulnerable, creating a new constraint associated with reliability. This new vulnerability is not directly linked to failures or immediate lifespan problems, but to the gradual scarcity or disappearance of the components and technologies required for their logistical support [Baron *et al.*, 2021].

The increasing obsolescence of electronic components, software and other integrated technologies introduces a fragility to MCO that can no longer be effectively managed by traditional techniques alone [Vrignat *et al.*, 2024]. Systems then find themselves in a state of latent vulnerability, where critical components or functions can become obsolete without immediately failing, but potentially impacting the cost and availability of technical support over the long term. Thus, the complexity of modern systems calls for a reassessment of the way obsolescence is integrated into MCO strategies. The adoption of new approaches and techniques should enable the system to retain its robustness. Faced with this situation, it becomes essential to model the relationship between MCO and obsolescence management in a structured and systematic way. This contribution proposes to explore this relationship through the SADT model, thus formalizing the complex interactions between MCO activities and the challenges posed by component obsolescence. The proposed approach builds on previous work, notably by Vrignat *et al.*, (2024), who have modeled certain aspects of obsolescence management in the context of MCO.

This article aims to go further in understanding the mechanisms underlying this interaction, focusing on the specific aspects of obsolescence that affect the viability and availability of systems throughout their lifecycle. The main objective is to provide a detailed vision and an analytical framework for anticipating and proactively managing the impact of obsolescence on MCO. This work involves identifying the action levers needed to minimise system fallibility while optimising maintenance and technical support costs. This modelling, based on the SADT model, will enable processes to be mapped more accurately, interdependencies to be defined, and critical points to be monitored or adapted to ensure sustainable and effective systems support to be identified.

The article is structured as follows: Section 2 reviews MCO and obsolescence management concepts. Section 3 details the SADT models illustrating their interdependence. Section 4 analyzes their links, and Section 5 concludes with future prospects.

2. Related works

2.1. In service support

The MCO corresponds to the technical and logistical support activities for equipment to ensure its availability to carry out its missions [karaani *et al.,* 2024]. Technical support includes maintaining, managing, updating, restoring and configuring equipment. It also consists of providing assistance to users, whether remotely or on site, in order to optimise the use of infrastructures. Logistical support involves the replacement, maintenance and installation of equipment in the event of a breakdown.

It is in this sense that the second component of MCO plays an equally critical role in the success of its operations. It is therefore implied that MCO is linked to the quality of maintenance (curative, preventive and predictive) for these items of equipment, which often have a long service life [Droff, 2013]. Verhoeff *et al.,* (2015) define MCO for military equipment along three dimensions: availability (ability of equipment to be immediately usable), operational capability (functionality of all systems) and durability (period of use without new maintenance). These three aspects provide a more comprehensive vision of MCO, aimed at guaranteeing not only immediate use, but also the durability and performance of equipment. The success of MCO is measured by indicators such as the availability rate, expressed, for example, as the ratio of functional equipment to total available equipment (i.e. equipment under repair or at end-of-life, but still part of the base inventory) [Sénat, 2005]. The overall cost of MCO operations is a particularly constraining factor and often exceeds the initial estimate. This is particularly due to the challenge of exhaustively identifying both direct and indirect costs. The age of equipment, combined with the conditions and intensity of use - sometimes extreme in the context of overseas operations - necessitate the extensive use of spare parts. The potential or actual obsolescence of the latter poses serious problems for their replenishment (via approved channels) and for the performance of technical support operations, and consequently for the operational availability of equipment. This results in their more or less pronounced unavailability. In its most common sense, obsolescence means that a component or function is no longer manufactured or marketed according to its original specifications. Under these conditions, it is clear that obsolescence, whether proven, announced or predicted, must be taken into account as early as possible in order to minimize its impact on availability.

2.2. Obsolescence Management

The obsolescence of a product, a function... refers to the fact that it becomes outdated, loses some of its use value or interest, even if it remains perfectly functional [Baron *et al.,* 2021]. This can be the result of technological evolution, a change in fashion or any other similar factor [Trabelsi *et* *al.,* 2021]. According to the standard [IEC 62402], obsolescence can be translated in fine, by the transition from the state of availability to the state of unavailability of an entity from its original manufacturer. Although many definitions of obsolescence exist, the aim here is not to list them exhaustively, but to clarify the phenomenon. It is essential to distinguish obsolescence from scarcity. Obsolescence can be interpreted as the consequence of events affecting the use, utility or function of a product [Boissie, 2019]. Rarefaction is a process that results in a shortage or breakdown of a component. In the United States, and particularly in Department of Defense (DoD) documentation, the accepted term is "Diminishing Manufacturing Sources and Material Shortages" (DMSMS). This term refers to the reduction of manufacturing sources and material shortages [SD-22, 2021].

Obsolescence can affect hardware objects, services, technical know-how, knowledge and aesthetic styles. It can involve products beyond software and electronic components, such as materials, structure, mechanics and electrics (referred to as Hardware-MaSME in SD-22). Compliance with strict regulations on hazardous materials is also covered. What's more, knowledge and data can become obsolete as soon as they lose their usefulness or relevance. For this reason, it has become evident that obsolescence management is a key factor to be incorporated into program plans and systems engineering strategies, in order to support the goals of reliability, availability, maintainability, producibility, and supportability of complex systems. Three classes of obsolescence management methods can be distinguished [Mellal *et al.,* 2020]: reactive, proactive and strategic. Reactive management takes charge of determining the most appropriate solution (often following the publication of an end-of-manufacture notice for electronic component manufacturers). Proactive management must be able to anticipate the occurrence of obsolescence, thus increasing the potential of the envisaged solution while controlling the financial risk. Proactive management may require re-design, which is generally more costly than solutions identified through reactive management. Finally, strategic management consists in considering global market parameters, the manufacturer's long-term needs, and the desire for innovation or technological renewal.

2.3. Motivation and research gap:

The vital nature of equipment availability makes the study of MCO-Obsolescence links more necessary than ever. These studies are all the more important as any failure in the management of MCO operations can have serious impacts. So, after positioning the problems of MCO and obsolescence, this article positions itself at the crossroads of MCO and obsolescence, by proposing an initial series of detailed SADT models to highlight the link between these two domains. The aim is to demonstrate that MCO without the systematic application of health monitoring of critical components and modules is an ineffective discipline. It is then a question of linking obsolescence remediation methods (i.e., obsolescence is inevitable) and the activities defining MCO. To date, little research has addressed this crucial coupling, despite its importance in ensuring system sustainability.

In the following, a series of models will be proposed to clarify the role of obsolescence management in an OLS approach. The aim of this article is to clarify the role of obsolescence management in an effective MCO approach, by proposing an intuitive and extensible modeling framework to help players in the field anticipate and manage obsolescence-related risks. This approach is referred to as "MCO+".

SADT models are chosen for their clear representation of complex, interdependent processes in technical systems. Their simple, visual structure makes them easy to understand and use by industry professionals while remaining highly adaptable to specific needs.

3. Synergy between MCO and Obsolescence: An Analysis using the SADT Model

3.1. MCO model

Before beginning to describe the links to be built between obsolescence management and MCO technical and logistical support activities, it is possible to model the way in which these two activities can be linked together (Figure 1).

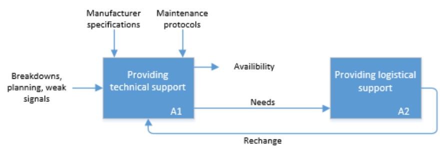

Figure 1. Classic MCO model [Vrignat et al., 2024]

Technical support must ensure that the equipment in question regains its level of operability. To achieve this, the various events that have occurred are exploited, as are systematic (preventive) maintenance schedules and weak signals describing potential operating and/or performance drifts. Spare parts requirements are then assessed, and it is then that logistics support must guarantee the quality of spare parts availability (i.e. repair workshops), at the right times and under acceptable integration conditions (for example: quality and performance). In this way, equipment will be in optimum working order, ensuring its availability, performance and reliability to meet operational requirements.

3.2. Model detailing major MCO technical support activities

Figure 2 shows an actigram modeling technical support activities. The model below distinguishes between three types of maintenance activity. The first stage, A1-11: Fault Diagnosis and Analysis, uses fault data and equipment history to produce a diagnostic report. This step relies on the manufacturer's specifications and considers safety constraints, involving the maintenance team and specialized diagnostic tools to identify the root causes of malfunctions.

Next, A1-12: Curative Maintenance takes the necessary corrective action based on the diagnostic report. It generates spare parts and Human Resources or Technical Resources (HR/TR) requirements. It follows maintenance protocols to ensure the conformity and effectiveness of corrective actions. However, component obsolescence can make it more difficult to replace defective parts, due to stock shortages or difficulty in obtaining the necessary parts. This can extend repair times and affect equipment availability. In addition, obsolete technical documentation and a lack of qualified personnel can slow down fault diagnosis and identification.

In corrective maintenance (Figure 3), when preparing to carry out work (A121), the maintenance team must first identify the risks of obsolescence by checking whether parts or equipment are end-of-life or hard to find, and if necessary, anticipate their replacement before they become unobtainable. When diagnosing the fault (A11), it is crucial to assess whether the faulty parts are still available or obsolete and, if so, look for alternative solutions such as compatible or second-hand parts. In repair or replacement (A122), if an obsolete part must be used, it is often replaced by a compatible part or a substitute technology. If these solutions are not viable, the entire equipment may be replaced. Finally, during verification and validation testing (A123), it must be ensured that the replacement parts or alternative solutions are compatible and function correctly through performance and durability testing, thus guaranteeing the reliability of the repaired or upgraded equipment.

To ensure that preventive maintenance is well planned, A1-21: Define the Intervention Schedule draws up a preventive maintenance schedule, taking into account the equipment specifications, the frequency of maintenance and the usage report. This planning is facilitated by management tools and requires the collaboration of maintenance technicians to ensure consistent execution.

Once the schedule has been drawn up, the role of A1-22: Preventive Maintenance is to carry out maintenance not on the basis of breakdowns, but according to a schedule defined on the basis of the manufacturer's specifications and the equipment usage report. Relations with logistical support remain identical to the previous case. However, the obsolescence of the tools and equipment required for these interventions can make this maintenance more difficult to carry out. For example, a lack of spare parts, such as a specific lubricant, can make it impossible to comply with the manufacturer's recommendations, thereby increasing the risk of breakdown even if the equipment is still working. In addition, obsolescence can lead to shortages of qualified human resources to carry out these interventions.

With a view to advanced maintenance, A1-31: Identify Prognostics and Health Management (PHM). PHM (data-based) exploits weak signals measured by acquisition systems in order to estimate the state of degradation of a piece of equipment. An analysis algorithm processes this data into a monitoring report, considering performance thresholds and maintenance alerts. This report serves as the foundation for predictive or condition-based maintenance. Finally, A1-32: Predictive Maintenance is based on the monitoring report to anticipate and avoid potential failures. It involves carrying out analyses of weak signals, the role of which is to detect drifts and take action before any potential malfunctions occur. However, obsolescence can hamper this approach, as current diagnostic equipment may not be compatible with ageing

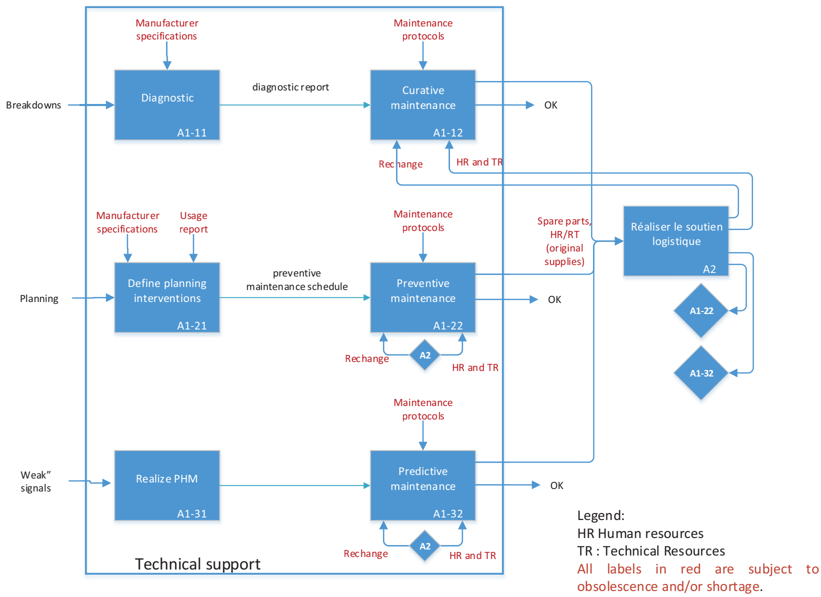

Figure 2. Model detailing major MCO technical support activities

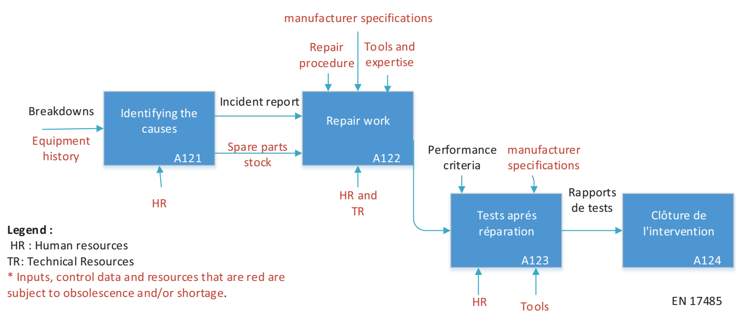

Figure 3. Detailed model of activity A12

equipment. Similarly, the shortage of qualified personnel and the obsolescence of technical documentation can make this proactive monitoring less effective, slowing down the detection of drifts and delaying the necessary interventions. The maintenance management process culminates in A2: Carry out Logistical Support. This mobilises the resources and spare parts identified as necessary for maintenance operations to run smoothly. This logistical support ensures that resources are available at the right time to respond effectively to the needs of the various maintenance phases.

In summary, the obsolescence of equipment and resources (parts, tools, qualified personnel) makes maintenance management more complex, whether curative, preventive or predictive. It increases repair and maintenance times, while reducing the availability and durability of equipment. Proactive obsolescence management is therefore essential to maintain the efficiency of systems and limit the negative impact on performance (e.g. armed forces).

3.3. Macroscopic MCO+ model

In the first MCO+ model, spares requirements go through a structured process in which each stage is clearly defined. In A1 (Carry out technical support), spares are first analysed to separate those with known or suspected obsolescence problems from those with no such problems. Spare parts that do not present a risk of obsolescence are then transferred to A2 (Provide logistical support), where they are managed, including procurement, storage and distribution.

On the other hand, spare parts identified as obsolete or potentially obsolete are directed to A3 (Manage obsolescence). In this activity, these spares are subjected to an in-depth analysis, and a remedial solution is chosen, such as finding new suppliers, manufacturing new parts or replacing them with alternative components. This model enables spares to be processed in a way that is adapted to their obsolescence status, guaranteeing equipment availability while effectively addressing the challenges associated with obsolescence (Figure 4).

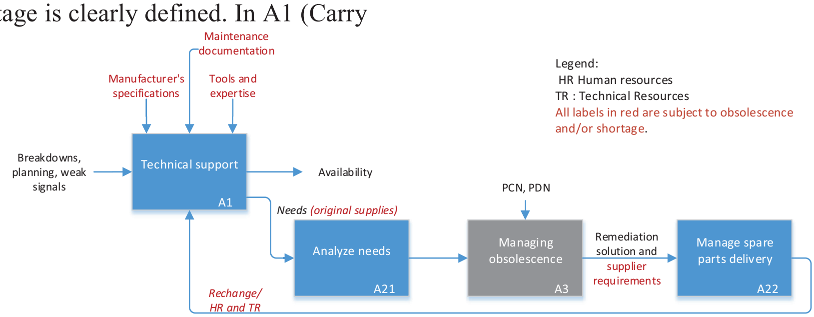

Figure 4. Non-detailed macroscopic model MCO+ integrating obsolescence management

3.4. MCO+ microscopic model

As detailed in section 2.1, obsolescence remediation solutions are classified into 3 broad categories of Reactive Management, Proactive Management and Strategic Management. The model below (Figure 5) clarifies the place of these three management modes. The model describes a spares management process, structured around a number of activities to meet the challenges of obsolescence and ensure equipment availability. Following the assessment of spares requirements in A1: Carry out technical support, spares are sorted according to their obsolescence status. Spare parts affected by obsolescence are sent to A3: Manage obsolescence, which comprises three sub-activities:

A31: Reactive obsolescence management, which intervenes to provide immediate solutions to obsolescence problems, such as finding replacement parts or substitution by alternative components.

A32: Proactive obsolescence management, which anticipates obsolescence risks by identifying components at risk and preparing replacement solutions before they become a major problem.

A33: Strategic obsolescence management, which deals with long-term management by redesigning products, adapting design to technological developments and establishing partnerships with suppliers to ensure the longevity of solutions.

Spare parts that do not present obsolescence problems are transferred to A2: Provide logistical support, which is divided into two sub-activities:

A21: Analysing needs, where specific spare parts requirements are assessed and validated.

A22: Managing the supply, storage and distribution of parts. For this activity, it is essential to take into account solutions for redesigning parts, by analysing their cost, as well as possible logistical solutions, such as optimising stocks or finding new suppliers, in order to guarantee fluid supply at lower cost. Long-term solutions for obsolescence are addressed in A41 and A42, which concern the specification, design and development processes. These processes enable short- and long-term solutions to be devised to maintain the availability of spare parts, whether this involves finding immediate alternatives or developing new products.

These processes enable short- and long-term solutions to be devised to maintain the availability of spare parts, whether this involves finding immediate alternatives or developing new products. The model therefore combines technical, logistical and obsolescence management activities (A1, A21, A22, A31, A32, A33), as well as design and development

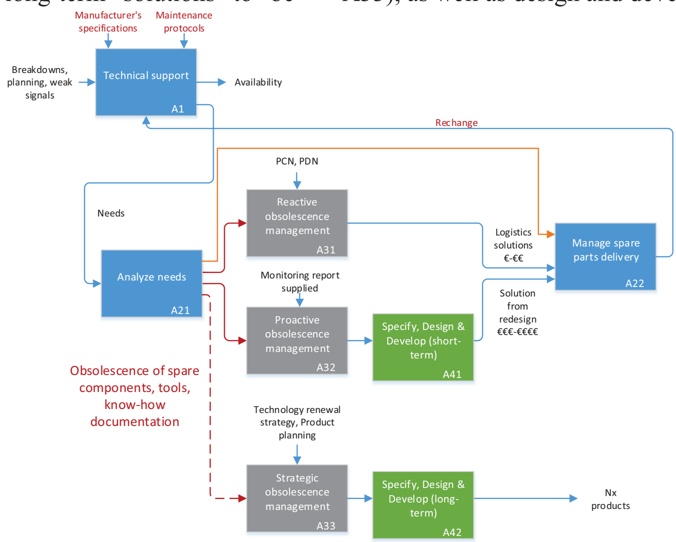

Figure 5. Obsolescence management in MCO+, detailed model

processes (A41 and A42), to meet the challenges posed by obsolescence while guaranteeing continuity of operations.

4. Discussion on the Links between MCO and Obsolescence

Being able to guarantee mission accomplishment or service continuity is the challenge assigned to MCO via logistical and technical support. However, when certain components or modules become unavailable, either because the manufacturer stops producing them, or because stocks run out, it becomes impossible to guarantee an adequate level of availability for the system. This situation seriously affects the supply chain, which can no longer provide the necessary spare parts, thereby undermining the entire technical support system. This unavailability poses a particular challenge for very high-responsibility systems, where mission success is essential, and failure is not an option. Examples include military equipment in overseas operations or nuclear-based power generation facilities, where the consequences of a supply failure could be disastrous.

In such cases, monitoring the state of health of equipment cannot be limited to traditional indicators of breakdown or weak signals anticipating potential failure. It must also take into account the obsolescence dimension, i.e. the difficulty of obtaining critical parts for which failure or wear are not immediately observable, but whose unavailability may introduce a ‘fault’ in the system. Obsolescence is a particularly sensitive concept in complex systems, where guaranteed safety and reliability are imperative. Obsolescence occurs when a supplier decides to stop manufacturing a part or a solution, or to withdraw it from its catalogue, thereby depriving users of the possibility of renewing components in accordance with the original specifications. This obsolescence phenomenon does not immediately affect the operational performance of equipment, but it does compromise long-term maintainability and reparability. The inability to guarantee the supply of critical parts can turn a simple maintenance operation into a major difficulty or even lead to the immobilisation of equipment that is still potentially functional.

The consequences of obsolescence are particularly acute in extreme environments, such as theatres of external operations for military forces or nuclear reactors. In such contexts, even the slightest failure can jeopardize human life, harm the environment, or threaten national security. This is why MCO strategies in these sectors must include anticipation of the risks associated with obsolescence. This includes providing replacement or alternative solutions for critical components, developing alternative procurement strategies (such as re-qualification of parts), and even designing technical adaptations where possible to enable the integration of new components into existing systems.

To prevent obsolescence, MCO teams must monitor component life cycles, track industry trends, and anticipate supply chain changes. Reverse engineering and partnerships with specialized suppliers also help replace obsolete parts.

5. Conclusions and perspectives

The integration of obsolescence into MCO is now essential for critical systems. This article highlights the use of SADT models to formalise and structure the interactions between obsolescence management and MCO practices. These models enhance the efficiency of decision-making and operational processes by integrating technical and regulatory requirements, thereby enabling more robust and proactive management of complex systems. As part of future work, the authors will undertake mathematical modelling of the relationship between MCO and obsolescence management. This approach aims to quantify the impact of obsolescence on the reliability, maintainability and, consequently, the operational availability of systems. It will identify and analyse the effects of technical incompatibilities and resource reductions on business continuity.

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