A Cost Estimating Framework for Materials Obsolescence in Product-Service Systems

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Abstract:

Obsolescence happens when a component becomes no longer available from stock of own spares or being procurable or produced by its supplier or manufacturer. This is an issue that will definitely affect long-life support systems. The rapid change in technology during the last few decades has exacerbated this problem, especially for EEE (electronics, electromechanical and electrical) components, as their life-cycle is becoming increasingly shorter. This is the reason why most of the research on obsolescence carried out so far has been focused on dealing with EEE components obsolescence. However, the impact that obsolescence will have on materials for the structural and mechanical components of the system should not be disregarded. Materials are frequently becoming obsolete due to new regulations from the government related to the environment and health safety. Another reason is that during the support phase, little amounts of material with unique specifications are required, and hence, the suppliers stop producing them as this is not profitable.

The defence and aerospace sector is well known for having to support systems for many decades. The defence budget has being squeezed over the last few years, and this is triggering a search for the most cost-effective solutions to the military needs. Therefore, the contracting model for the life-cycle of these systems is moving towards new types of agreement such as availability contracts, which is a form of Product-Service Systems (PSS), where the prime contractor is in charge of supporting the system and assuming responsibility for new risks derived from it. Obsolescence is one of those risks, and hence, it is necessary to accurately estimate its cost at the bidding stage, so it can be included in the contract.

This paper describes a cost estimating framework for materials obsolescence within a PSS environment. The framework is based on a set of concepts developed out of combining a literature review and information gathered from industry. Those concepts are namely the materials/components complexity levels, the materials/components criticality levels and the materials obsolescence cost metrics. For the aerospace industry, the cost metrics are developed by applying the Analytic Hierarchy Process (AHP) in order to assess the relative weight of each parameter that defines an obsolescence issue, and subsequently calibrating it with historical data. The methodology for the usage of this framework is divided into five steps, and the framework is designed with the flexibility required to provide a cost estimate based on whichever level of information is available. The framework has been customized for ammunition and air platforms. Four industrial experts from the defence sector have participated on the validation of this framework.

1. Introduction

Many engineering companies are currently undergoing a paradigm shift from product delivery to through-life support, also known as Product-Service Systems (PSS), which is defined in academia as "an integrated product and service offering that delivers value in use" (Baines et al., 2007). This shift applies across a range of different sectors, including defence, civil aerospace, oil and gas, nuclear and construction. For the purpose of this paper, the research has been focused on the defence industry, which is a representative example of PSS, where systems need to be maintained for 30 years or more into the future. Such a long life-cycle assures that the system will face obsolescence issues in different areas, such as EEE components, software and materials (Romero Rojo et al., 2010). A part becomes obsolete when it is no longer available from the original manufacturer to the original specification (Feldman and Sandborn, 2007).

Faced with constrained budgets and rising maintenance costs, the British Ministry of Defence (MoD) has spent the last several years creating new business models such as "contracting for availability" (Johnsen et al, 2009; Stein and Wadey, 2008). This new type of through-life support framework provides better value for money to the MoD than traditional spares/repair type contracts, and transfers full technical risk to the contractor ((Romero Rojo et al., 2009a; Webb and Bil, 2010). The PSS can be designed and adapted to the characteristics of each project, so that best practice in risk management is implemented by sharing the risk across the supply chain to reduce overall whole life cost (Roy and Cheruvu, 2009). However, one of the new challenges associated with the implementation of this type of contracts is the need to forecast at the bidding stage the cost of managing and solving the obsolescence issues that will arise during the life cycle of the system. By incorporating this cost in the bid, we make sure the flexibility to adapt over time is built in.

For the last two decades there has been a significant amount of research on the area of EEE components obsolescence, because the increasingly short life-cycle of this type of components is hindering the sustainability of the systems if not managed properly. However, the obsolescence problem is not restricted to EEE components, and although materials have usually longer life cycles, they are still likely to become obsolescence during the in-service phase (Howard, 2002).

Currently there is a lack of research in the area of materials obsolescence to understand the causes, impact, and mitigation and resolution strategies to manage it. This paper aims to provide and insight into these issues and presents a novel framework to estimate, at the bidding stage, the cost of solving materials obsolescence issues during the contracted period within the in-service phase. This framework is further developed into an MS Excel-based application named “Materials - Framework for Obsolescence Robust Cost Estimation” (M-FORCE). It has been developed in collaboration with several organizations in the defence and aerospace sector in UK, and has been customized for two different types of platforms: aerospace and ammunition.

The remainder of the paper has been organized as follows. Section (2) explains the concept of obsolescence in materials and how it can be managed and solved. In Section (3), the materials obsolescence cost estimating framework (M-FORCE) is presented, describing the logic developed for ammunition and air platforms. The validation process and analysis of this framework is described in Section (4). Finally, a set of conclusions are presented in Section (5).

2. Obsolescence in Materials

As shown in Figure 1, the different types of materials can be broadly classified into two categories: metallic and non-metallic. Metallic materials are grouped by chemical composition, and their characteristics (e.g. fatigue, strength, corrosion resistance…) are usually tabulated. Non-metallic materials can be classified into four categories: structural (e.g. glass fibre, carbon fibre composite and Kevlar), non-structural (e.g. PTFE, phenolic and acrylic), fluids (e.g. fuels, oils and lubricants) and others (e.g. paints, sealants, rubbers and adhesives). In the ammunition context, two additional categories can be considered: energetic components (e.g. fuzes, primers and detonators) and energetic materials (e.g. propellants and explosives).

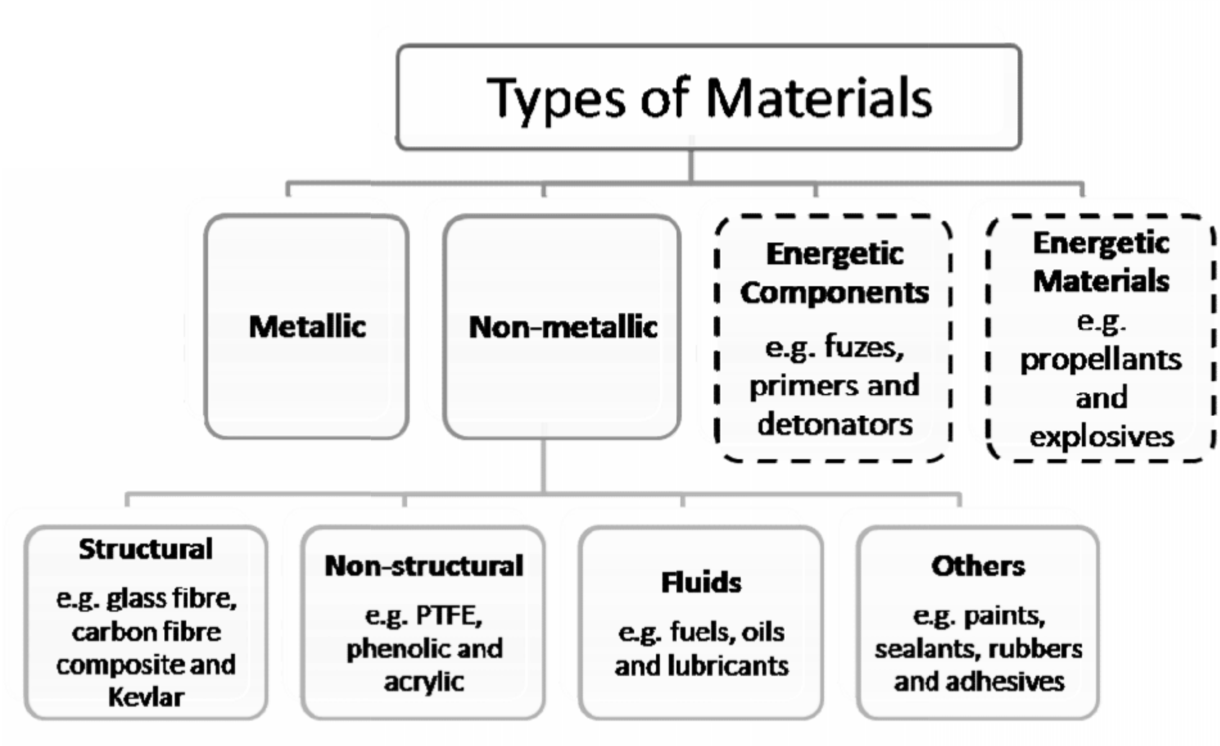

Figure 1 Materials Classification

2.1 Obsolescence Causes

A material becomes obsolete when it is no longer available from the original manufacturer to the original specification, or its procurement is not affordable. The main reason why materials become obsolete during the in-service phase is that just small amounts are required. This lack of demand for a particular material's specification makes it no longer profitable for the supplier to produce it. Manufacturers are unwilling to pull resources from high volume, high demand, high margin businesses to serve a historically low volume, low demand, low margin business. Another reason is that the minimum order quantity (MOQ) can be far larger than the amount of material required. New government regulations, related to Safety Health and Environmental legislation, can trigger obsolescence issues because the material usage is directly banned or because the use of other materials or substances, such as oils and lubricants, required in the manufacturing process of that material is banned (Howard, 2002). This is quite common for non-metallic materials. Additionally, changes in suppliers that imply a loss of skills or modifications in the manufacturing process can derive on changes in the original specifications (specially for non-metallic materials). There are different standard specifications (e.g. British, American and European) which are continuously evolving, so that a superseded specification turns into a new obsolescence issue for the materials that conform to it.

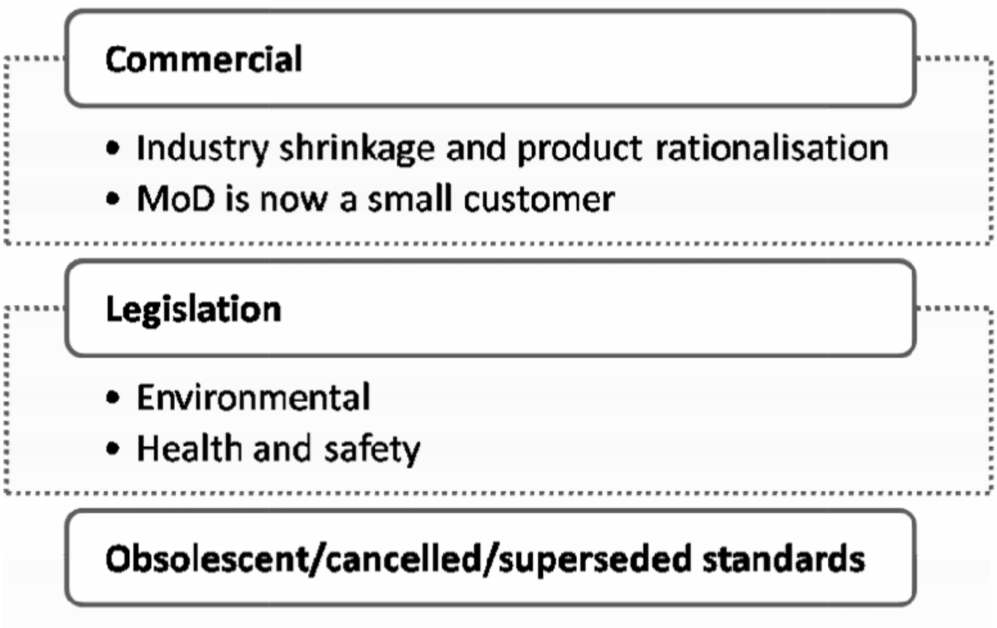

Figure 2 Common causes of materials obsolescence

2.2 Obsolescence Management

Currently in the defence sector, few organisations have standard procedures in place to manage materials obsolescence proactively. Materials obsolescence is commonly managed reactively and as a result, readiness and supportability effects are not apparent until component managers try to buy the part (Howard, 2002). As a result of this research, it has been identified a set of mitigation strategies:

- Plan ahead – Use of technology roadmaps
- Participate in committees – Find out about new regulations earlier
- Keep good relationships with suppliers
- Design the system endeavouring to use well established materials – Minimising the risk associated with using bespoke materials

These strategies may reduce the risk of having an obsolescence issue and allow extra time to tackle the problem.

In order to solve an obsolescence issue, there are mainly two possibilities: to find a form, fit and function (FFF) replacement or to redesign it. The resolution applied will depend on the remaining life of the system and the characteristics of the obsolete material. A priori it is preferred to find a FFF replacement, for which it is necessary to take some considerations:

- Make sure it keeps the same performance requirements.
  - Fabrication/application constraints
  - Mechanical
  - Operating environments
- Make sure it complies with health, safety and environmental legislation.
- Ensure continuation of future supply
  - Open specification
  - Specify performance requirements
- Consider that it may not be a single solution for all uses

3. Obsolescence cost estimating framework for materials

The literature review and discussions with five experts (average of 6 years of experience in this area) from different organisations in the defence and aerospace sector and members of the Component Obsolescence Group (COG) have revealed a need for a framework that can be systematically used to estimate the cost of materials obsolescence during the in-service phase at the bidding stage (Romero Rojo et al., 2009b). The diagram that represents the framework developed is shown in Figure 3.

Figure 3 Materials Obsolescence Cost Estimating Framework (M-FORCE) Diagram

For the development of this framework it was necessary to properly define the following concepts:

3.1 Obsolescence Issue

An obsolescence issue arises when the material becomes obsolete, that is to say, it is no longer procurable from suppliers or it is not affordable to do so, and there is no stock available of that material. In general, it is challenging to store enough stock of material during the in-service phase in order to overcome possible obsolescence issues due to the following reasons:

- Most of the non-metallic materials are affected by the "shelf-life", which is defined by the United States Department of Defense (DoD) Shelf-Life Program as "the total period of time beginning with the date of manufacture, date of cure (for elastomeric and rubber products only), date of assembly, or date of pack (subsistence only), and terminated by the date by which an item must be used (expiration date) or subjected to inspection, test, restoration, or disposal action; or after inspection/laboratory test/restorative action that an item may remain in the combined wholesale (including manufacture's) and retail storage systems and still be suitable for issue or use by the end user" (DoD, 2003). This prevents the purchase and storage of enough material to cover the whole in-service phase, as this is usually a lengthy period (30 years or more).

- The stock of metallic materials is usually classified into different sizes, thicknesses and shapes. Therefore, the amount of stock required for each material becomes much higher due to the huge variety of shape characteristics.

3.2 Criticality

The DoD defines that an item is considered critical when one or more of the following criteria are met (DoD, 2003):

- **Critical chemically**. Items which are of such nature that any degree of deterioration (in the form of corrosion, stain, scale, mold, fungi, or bacteria) caused by oxygen, moisture, sunlight, living organisms, and other contaminants which are time or temperature dependent, will result in premature failure or malfunction of the item or equipment in which the item is installed or with which the item interfaces.
- **Critical physically**. Items that would become unfit for use as a result of physical action on the item or any integral surfaces thereof. This includes, but is not limited to items having a surface finish of 64 microinches root mean square or less, items which have surfaces that mate with surfaces of other parts, optical and reflective devices having highly polished surfaces, items requiring a high degree of cleanliness, and items requiring special protection against shock, vibration, or abrasion.
- **Critical application**. Items that, either in assembly or operation, provide an essential attribute to attaining critical military objectives.

According to this, the criticality level can be based on the application of the item for an air platform:

- **High Criticality**. Items that provide an essential attribute to attaining critical military objectives
- **Medium Criticality**. Items that are required but not essential for the operation of the system.
- **Low Criticality**. Accessory items, which are not required but not essential for the operation of the system.

In the ammunition environment, all of the components/materials can be considered critical, based on the application, in that there is nothing that can be removed that would allow the product to continue to be sold or used. Therefore, in the ammunition context, the level of criticality is defined as in terms of the function of the product or its safety and storage:

- **High Criticality**. Items critical to function.
  e.g. Energetic materials, Energetic Components, Metallic components
- **Medium Criticality**. Items critical to safety/storage.
  e.g. Paints, Lacquers, Adhesives, Chemicals
- **Low Criticality**. Manufacturing aids.
  e.g. Non metal parts (paper discs, O rings)

3.3 Complexity Level

Complexity is defined according to the type of material. The complexity level classification for materials in the aerospace industry is as follows.

- **Low Complexity**
  - Common Metallics
  - Non-Metallic Non-Structural
- **Medium Complexity**
  - Exotic Metallics (e.g. Aluminium-Lithium alloy, Beryllium alloy, Titanium)
  - Non-Metallic Structural
  - Fluids (Fuels, Oils, Lubricants)
  - Others (Paints, sealants, rubbers, adhesives) with standard specifications

- **High Complexity**
    - Others (Paints, sealants, rubbers, adhesives) without standard specifications

The types of materials used in the aerospace industry differ from those used in the ammunition environment. Therefore, it is convenient to make another complexity level classification specific for ammunition. Complexity is assessed in terms of ease of procurement, potential suppliers, specification and tolerance within the specification (e.g. for energetics, even variations within a specification can cause a production process to fail or require qualification).

- **High Complexity** (high specification, tight tolerances, limited suppliers)
    - Energetic materials
    - Energetic components
- **Medium Complexity**
    - Exotic Metallics
    - Non-Metallic
    - Others (Paints, Lacquers, Adhesives)
    - Chemicals (chemical mixtures, explosive compatible materials)
- **Low Complexity**
    - Chemicals (e.g. solvents)
    - Common Metallics

According to experts in materials obsolescence (Figure 4), the level of proactiveness deployed in managing materials obsolescence does not have a significant impact on cost at the project level. However, if materials obsolescence is managed proactively across several projects, this can result in a cost reduction because resolutions can be shared.

There are several differences between ammunition and air platforms, which make the cost estimation process different for each one. The key difference is that the parameters that define the characteristics of an obsolescence issue for ammunition are correlated, while the parameters that define the characteristics of an obsolescence issue for air platform are independent. Therefore, the range of different obsolescence issues for air platforms is much wider than for ammunition.

4. Materials - Framework for Obsolescence Robust Cost Estimation (M-FORCE)

A total of five experts have participated on the development of this framework, and four of them have validated it. Their details are indicated in Figure 4, including year of experience and job role. The framework has been customized for the aerospace industry and for ammunition. The details related to each one are provided as follows.

Expert Reference	Platform	Job Role	Years of Experience in Materials	Years of Experience on Obsolescence
A	Aerospace	Obsolescence Manager	26	4
B	Aerospace	Materials Engineer	26	10
C	Aerospace	Materials Engineer	45	10
D	Ammunition	Obsolescence Manager	23	4
E	Ammunition	Obsolescence Technician	5	2

Figure 4 Details of Experts on Materials Obsolescence

4.1 M-FORCE for Air Platform

The usage process for this framework is divided into five steps, as shown in Figure 5. The user can feed the cost estimating framework with the data available from the system to be supported, by means of the first 3 steps. In step 4, the user can customise the obsolescence resolution profile, and finally in step 5, the user can customise the obsolescence cost metrics. These two concepts are explained further down in this section. The output will be a cost estimate of the materials obsolescence in the system during the contracted period.

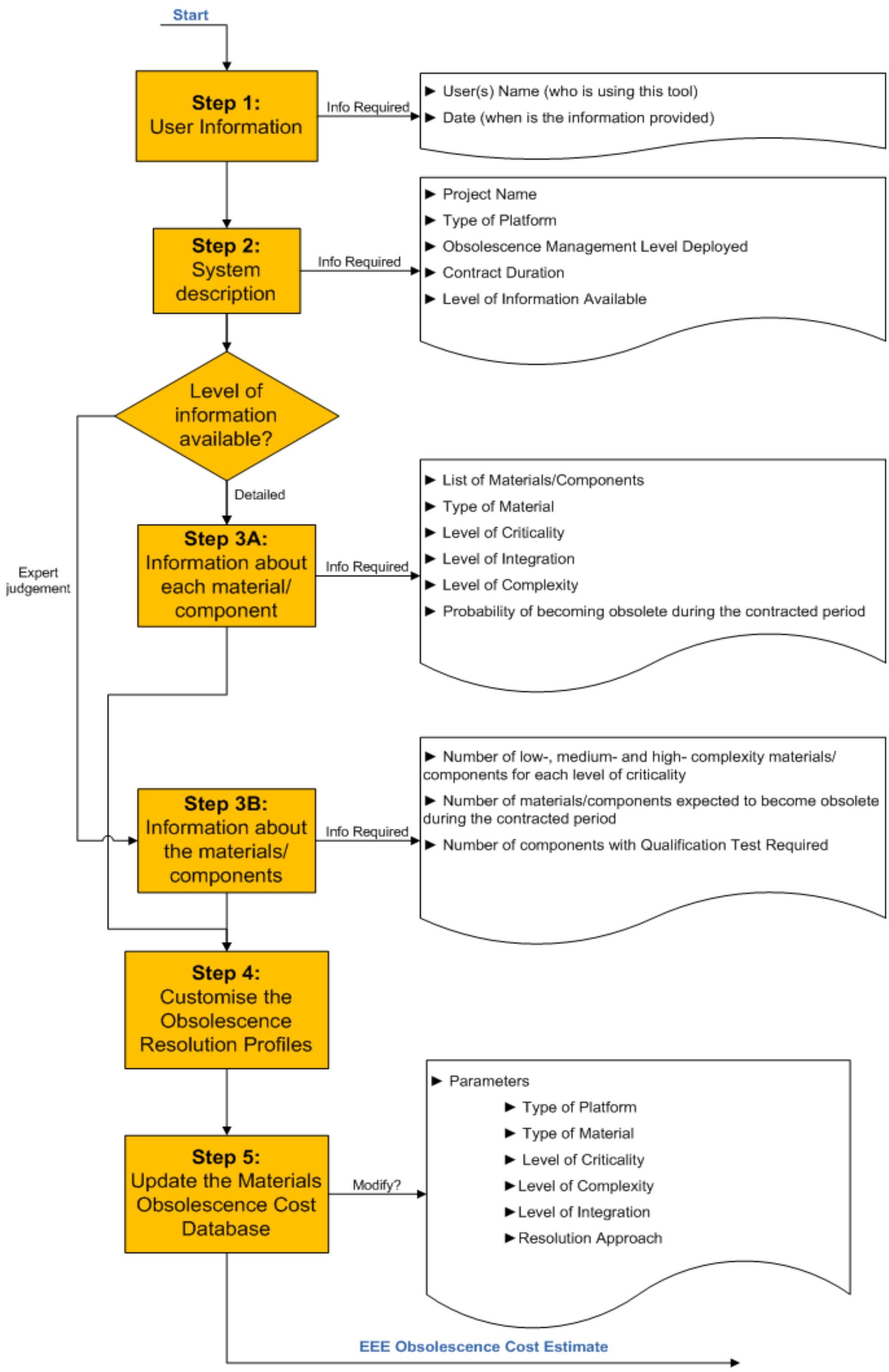

Figure 5 M-FORCE Process

The process depicted in Figure 5 is described in more detail as follows.

STEP 1

The first step requires information about who is going to use the framework and when. This allows more traceability of the origin of the information input to the framework.

STEP 2

The information required at this step is related to the project, obsolescence management level deployed, type of platform that will be supported and the duration of the supporting contract. The user is requested to indicate the level of information available.

If the list of materials/components is available, the user will provide it at step 3A. Otherwise, step 3B shall be used instead.

STEP 3A

The list of materials/components shall be input at this step. The information required for each component is related to the level of complexity, the level of criticality, the level of integration and the probability of becoming obsolete during the contracted period. This assessment would be based on the information available from technology roadmaps, committees and experience.

STEP 3B

If the list of materials/components is not available, it is necessary to base on experience and/or supplier information. The information required is related to the number of components estimated for each level of criticality, complexity and integration. It is also necessary to indicate the percentage of them that is expected to become obsolete during the contracted period.

STEP 4

The obsolescence resolution profiles represent the probability of using each resolution approach to tackle an obsolescence issue for a material/component. This probability depends mainly on the level of complexity, that is to say, the type of material. The default figures represented in these profiles have been derived from a workshop with three experts (A, B and C from Figure 4) on the materials obsolescence area from industry, and subsequently refined and validated on another workshop with experts (A and B) from different organisations (see Figure 6). However, the user has the possibility to customize the probabilities if necessary.

AIR PLATFORM	COMPLEXITY LEVEL		
	Low	Medium	High
FFF replacement - Low effort	90.0%	50.0%	30.0%
FFF replacement - High effort	9.0%	40.0%	50.0%
Minor Redesign	0.9%	9.9%	19.8%
Medium Redesign	0.1%	0.1%	0.2%

Figure 6 Obsolescence Resolution Profiles

STEP 5

The four key cost drivers identified are:

- Complexity Level (Low / Medium / High)
- Criticality Level (Low / Medium / High)
- Integration Level (Low / Medium / High)
- Type of Resolution Approach
    - FFF replacement – Low Effort
    - FFF replacement – High Effort
    - Minor Redesign
    - Major Redesign

The 108 different combinations of these parameters represent the range of possible obsolescence issues. It has been carried out an exercise with an expert on materials obsolescence (B from Figure 4), applying the Analytic Hierarchy Process (AHP) in order to assess the relative weight of each parameter. Two steps were followed in this process. Firstly, a pairwise comparison was undertaken between the four cost drivers. Subsequently, a pairwise comparison was performed between the different levels for each cost driver. The combination of weights resulted in a weight matrix, which varies proportionately to the obsolescence cost.

The obsolescence cost metrics can be derived from the weight matrix by applying a calibration point. This would be a known cost of solving a particular obsolescence issue characterized by the four cost drivers. For instance, the calibration point could be the cost of solving an obsolescence issue finding a FFF replacement (with low effort) for a low complexity, low integration and low criticality material.

4.2 M-FORCE for Ammunition

The usage process for this framework is divided into four steps. The user can feed the cost estimating framework with the data available from the system to be supported, by means of the first three steps. These three steps are analogous to those described for the air platform. The only difference in Step 2 is that the user can indicate the life cycle for each type of material. The default life cycle duration for each type has been derived from a workshop with two experts on materials obsolescence (D and E from Figure 4) and is shown as follows.

- Long Life-Cycle materials (25 years life-cycle)
    - Metallic (Shell bodies; Containers)
    - Non Metallic parts (Cotton bags; Plastics)
    - Energetic Components (Fuzes; Primers; Detonators)
- Medium Life-Cycle materials (12.5 years life-cycle)
    - Energetic Materials (Propellants; Explosives)
- Short Life-Cycle materials (5 years life-cycle)
    - Other Materials (Adhesives; Paints; Lacquers; Chemicals)

STEP 4/5

As it was indicated above, there is correlation between the parameters that define an obsolescence issue in ammunition. The type of platform and the type of material are the independent variables, and the rest of parameters are defined accordingly. There are three types of ammunition platform:

- Large Calibre Ammunition (Artillery, Tank, Mortar)
- Medium Calibre Ammunition (20-40 mm)
- Small Calibre Ammunition (5.5-7.62 mm)

There are five types of material:

- Metallic (Shell bodies; Containers)
- Non Metallic parts (Cotton bags; Plastics)
- Energetic Components (Fuzes; Primers; Detonators)
- Energetic Materials (Propellants; Explosives)
- Other Materials (Adhesives; Paints; Lacquers; Chemicals)

Therefore, in theory, the 15 combinations of these parameters define the range of possible obsolescence issues. However, in reality, some of those combinations can derive in different set of parameters (Complexity Level; Criticality Level; Integration Level), and hence, a different resolution approach and different obsolescence cost.

By means of a workshop with two experts on materials obsolescence for ammunition (D and E from Figure 4), it has been defined the spectrum of feasible combinations of parameters, resulting into 23 different combinations (Figure 7 – The costs are not presented in compliance with the confidentiality agreement with industrial collaborators). There are seven combinations of type of platform and type of material that will define univocally the rest of parameters, resolution approach and cost. Each of the other eight combinations split into two different sets of parameters, resolution approach and cost. The probability associated to each set of parameters has been defined by the experts based on their experience.

	Type of Platform	Type of Material	Level of Criticality	Level of Complexity	Level of Integration	Resolution Approach	Non-Recurring Cost	Probability
1	Large Calibre	Energetic Components	High	Medium	High	FFF - High effort	xxxxx	100%
2	Large Calibre	Energetic Materials	High	Medium	High	FFF - High effort	xxxxx	100%
3	Large Calibre	Metallic	High	Medium	High	FFF - High effort	xxxxx	90%
4	Large Calibre	Metallic	High	Medium	Medium	FFF - High effort	xxxxx	10%
5	Large Calibre	Non Metallic parts	Low	Low	Low	FFF - Low effort	xxxxx	85%
6	Large Calibre	Non Metallic parts	Low	Low	Medium	FFF - Medium	xxxxx	15%
7	Large Calibre	Other	Medium	Medium	Low	FFF - Low effort	xxxxx	85%
8	Large Calibre	Other	Medium	Medium	Medium	FFF - Medium	xxxxx	15%
9	Medium Calibre	Energetic Components	High	Medium	High	FFF - High effort	xxxxx	100%
10	Medium Calibre	Energetic Materials	High	Medium	High	FFF - High effort	xxxxx	100%
11	Medium Calibre	Metallic	High	Low	High	FFF - High effort	xxxxx	60%
12	Medium Calibre	Metallic	High	Low	High	FFF - Medium	xxxxx	40%
13	Medium Calibre	Non Metallic parts	High	Medium	High	FFF - High effort	xxxxx	60%
14	Medium Calibre	Non Metallic parts	Low	Low	Low	FFF - Low effort	xxxxx	40%
15	Medium Calibre	Other	Medium	Medium	Low	FFF - Low effort	xxxxx	75%
16	Medium Calibre	Other	High	Low	Medium	FFF - Medium	xxxxx	25%
17	Small Calibre	Energetic Components	High	Medium	High	FFF - High effort	xxxxx	100%
18	Small Calibre	Energetic Materials	High	High	High	FFF - High effort	xxxxx	100%
19	Small Calibre	Metallic	Medium	Low	High	FFF - High effort	xxxxx	100%
20	Small Calibre	Non Metallic parts	Low	Medium	Low	FFF - Low effort	xxxxx	90%
21	Small Calibre	Non Metallic parts	Low	Medium	Medium	FFF - Medium	xxxxx	10%
22	Small Calibre	Other	Medium	Medium	Low	FFF - Low effort	xxxxx	80%
23	Small Calibre	Other	Low	Low	Low	FFF - Medium	xxxxx	20%

Figure 7 Materials Obsolescence Cost Metrics for Ammunition

5. Validation and Discussion

In order to validate the framework, it has been developed a MS Excel-based tool (M-FORCE) that follows the framework rationale and can process inputted data and deliver a materials obsolescence cost estimate as an output. This tool has been assessed by four experts from industry in materials obsolescence (A, B, D and E from Figure 4). They have validated and verified the utility of this tool in order to estimate the cost of materials obsolescence. The analysis carried out has been qualitative for both areas (air platform and ammunition), and additionally, a quantitative assessment has been performed for the air platform. For this purpose, a case study has been applied. Details about the validation carried out are provided as follows.

5.1 Air Platform

The tool has been applied to estimate the materials obsolescence cost for the airframe of a large military aircraft platform (This case study is an ongoing project at the Manufacturing stage of the CADMID cycle). The information available was a full specified materials list, containing 353 different materials, including metallics and non-metallics, plastics, adhesives, oils and lubricants. The experts input the data required, assessing each material in terms of:

- Level of Complexity
- Level of Criticality
- Level of Integration
- Probability of becoming obsolete during the contracted period

The default obsolescence resolution profiles were applied in Step 4. In Step 5, the Analytic Hierarchy Process (AHP) was applied in collaboration with the experts and the weight matrix was derived from it. Subsequently, the cost of solving an obsolescence issue finding a FFF replacement (with low effort) for a low complexity, low integration and low criticality material was applied as a calibration point to derive the cost metrics from the weight matrix. This cost (CostCP) is not presented in compliance with the confidentiality agreement with industrial collaborators. In order to run a Montecarlo simulation to obtain a distribution on the output rather than a single-point estimate, it has been introduced uncertainty in the cost metrics, by means of allocating uncertainty to the calibration point. The calibration point follows a normal distribution with the following attributes:

$$Mean\ = \mu = CostCP$$

$$Standard\ Deviation\ = \sigma = 0.078 \times CostCP$$

The constant (0.078) applied to calculate the standard deviation is derived from considering the 90% percentile as 10% higher than the mean.

$$90\%\ percentile = 1.1 \times \mu$$

The output of the tool is the following cost distribution, which in this case fits to a “Student’s t-distribution” (Figure 8) (after running 1000 trials for the Montecarlo simulation). The distribution shows the mean (μ), standard deviation (σ) and 80% percentile, which is commonly used to fix the agreed cost in the bid negotiations. Note: In Figure 8, the costs are concealed in compliance with the confidentiality agreement with industrial collaborators

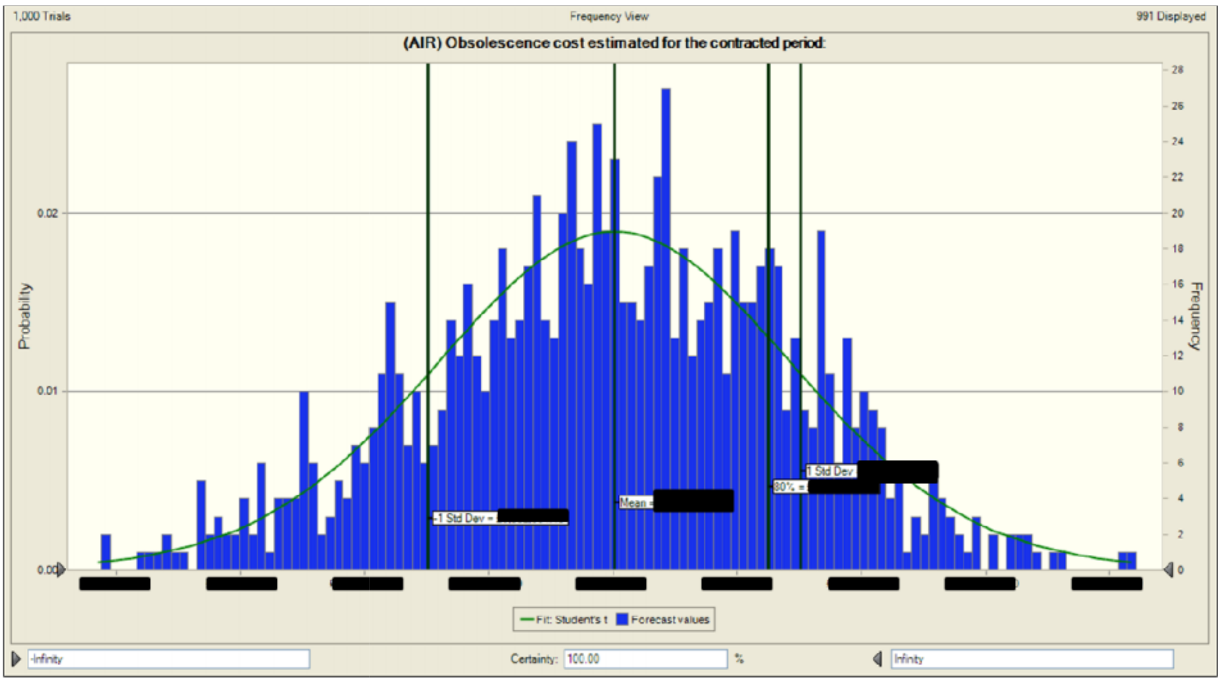

Figure 8 Cost Estimate Distribution – Output from Montecarlo Simulation

A semi-structured questionnaire has been used to capture the analysis and validation of the tool from two of the experts in this area (A and B from Figure 4). A summary of the responses and its analysis is presented as follows.

- Both experts agree that the logic (process/rationale) to build the cost estimate is valid (8 out of 10), although it is highlighted the simplification of the complexity of materials obsolescence that this framework makes. It also does not consider the fleet size, which may influence the result.
- They also agree that the framework is suitable for the bid stage (8 out of 10). This framework is very useful because it provides the bidding team with an idea about the cost of obsolescence and supports contracting for availability. However, the drawback of the framework is that it relies on experience rather than real data.
- The cost estimated by the M-FORCE tool for the case study is slightly lower than expected by the experts. It is argued that the reason for this is that the cost data applied in the calibration of the cost metrics is lower than in reality.
- One limitation of this case study is the lack of real cost data to compare the estimations with. The reason is that it is an ongoing project and there is no historical data available.
- The Obsolescence Management Level does not have a significant impact on the Non-recurring engineering (NRE) cost of resolving obsolescence issues for materials. This assumption is corroborated by both experts.
- This cost estimating framework is truly generalisable to different defence and aerospace platforms, although it requires adjusting and calibrating the parameters for each particular platform.
- The strongest feature of this framework is it flexibility, because it can adapt to different levels of data availability and provide a cost estimate accordingly. On the other hand, the weakest feature of this framework is that it lacks for materials obsolescence forecasting, relying on expert judgement from the user.
- The variability on the estimates that may be associated with the high degree of subjectivity involved in the assessment done by the user, based on his experience, has been mitigated by clearly defining the concepts used in the framework, such as complexity and criticality.

- The experts agree that the terminology and concepts used in this framework are consistent, and the key cost drivers for materials obsolescence are considered.
- The main challenge in using this framework is that the user is required to have technical knowledge about materials and about the platform (e.g. commercial people cannot use it).

5.2 Ammunition Platform

A qualitative validation has been carried out with two experts on materials obsolescence for ammunition (D and E from Figure 4), and in the near future it is planned to apply the framework to three case studies in small, medium and large calibre in order to complete the quantitative assessment and validation. The experts agree that the terminology and concepts used in this framework are consistent, and the key cost drivers for materials obsolescence are considered. They also agree that the process/rationale of the framework is reasonable and it is appropriate to dispense with the obsolescence resolution profiles and the weight matrix used for air platforms because in the ammunition scenario, most of the parameters are correlated with the type of platform and type of material.

6. Conclusions

The literature review and interviews with experts show that no frameworks have been developed to estimate the cost of materials obsolescence hitherto, although they are required at the bidding process. A systematic framework has been developed and validated to address this issue. This novel framework is the first step to address the need to estimate the cost of materials obsolescence for availability contracts in the defence sector. A MS Excel-based tool (M-FORCE) has been developed for the representation and application of this framework. Some of the limitations of this framework are that it relies on experience rather than real data and also the user is required to have technical knowledge about materials and about the platform. However, the variability on the estimates that may be associated with the high degree of subjectivity involved in the assessment done by the user, based on his experience, has been mitigated by clearly defining the concepts used in the framework.

The scope for further research in the area of materials obsolescence is substantial, taking into account the lack of research existing in this area. There is a need for other tools to support materials obsolescence management, such as obsolescence monitoring tool (Analogous to those developed for EEE components). It is necessary to develop an algorithm able to forecast obsolescence issues in materials. Finally, further research is required to refine the cost metrics used in the M-FORCE, utilizing historical cost data from different projects.

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