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Sophia Salas-Cordero, Rob Vingerhoeds, Claude Baron, Zolghadri Marc. Can Proactive Obsolescence Management and Innovation go hand in hand during the Conceptual Design Phase of Complex Systems?. 18th IFIP International Conference on Product Lifecycle Management (PLM), Jul 2021, Curitiba, Brazil. pp.40-54, <10.1007/978-3-030-94399-8_4>. <hal-03344919>

HAL Id: hal-03344919

<https://laas.hal.science/hal-03344919v1>

Submitted on 4 Sep 2023

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Can Proactive Obsolescence Management and Innovation go hand in hand during the Conceptual Design Phase of Complex Systems?

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Abstract. Innovation is a vital element in the dynamic world we live in, aiming at adding value to developing new systems. Obsolescence on the other hand comprehends the deterioration of the system or component capacity to operate when it is no longer suitable to fulfil the required function, even if it still operates and can be manufactured and supported. As innovative and obsolete products can be seen as opposites, the proactive management of obsolescence encompasses the principles of innovation. Obsolescence has so far been mainly addressed from a reactive point of view. Realizing the impact of the conceptual design phase on a system's life-cycle cost, this paper presents how a model-based system engineering approach, proactively assessing obsolescence risks, leverages with innovation considerations. In doing so, the paper builds on technology readiness levels (TRL) to identify critical components and innovation considerations. With clearly identified risks, designers can knowingly decide whether to improve a design, by making it robust and resilient, or to accept the risks and develop an obsolescence management plan. The paper is illustrated with an example from the automotive industry.

Keywords: Obsolescence, Innovation, Conceptual Design, Systems Engineering, Risk.

1 Introduction

Obsolescence is an issue that most likely all complex systems will experience at a certain point in their life cycle. It becomes a problem when obsolescence issues rise well before their planned retirement stage. The most common approach utilized to tackle obsolescence issues has been a reactive approach, which implies waiting for issues to appear instead of managing their risks. Such an approach often leaves little time for solving the situation and may therefore be expensive [1]. That is why this article proposes a proactive approach instead. For example, sustainment-dominated systems, those that require long-term support such as aircraft, ships, etc., have obsolescence

issues that represent a significant part of the life cycle costs [1]. As an illustration, obsolescence costs up to \$750 million per year to the US Navy [2]. Different drivers during the life cycle of a product come into play when looking into obsolescence. In the following paragraphs the main ones considered in this study are briefly introduced.

A large percentage of total product cost is decided during early design stages [3]. Knowing the impact of the conceptual design on the life-cycle cost, this paper intends to focus on metrics for obsolescence risk assessment that can be easily accessible during early stages of the design, such as: technology readiness levels, life cycle stages, and technology adoption life-cycle. The goal is to present an extension of the model-based systems engineering (MBSE) approach to proactively assess obsolescence risk presented in [4] by including innovation considerations.

For an organization, innovation plays a central role in creating value and sustaining competitive advantages [5]. It represents as well the core renewal process in any organization that does not want to risk its survival and growth prospects [6]. Innovation is a term used extensively, which has been defined over time differently in many fields. Innovation can be defined as “the multi-stage process whereby organizations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace” [5].

Striving to pursue a proactive management of obsolescence implies that precautionary measures should be taken to ensure the future functionality and sustainability of a system. Proactiveness allows to not wait for a sudden release of a product discontinuance notice (PDN) and just react to it, but to anticipate and have a plan. From a cost avoidance point of view, proactive approaches have proven to be very effective in comparison to reactive approaches [7].

DMSMS (Diminishing manufacturing sources and material shortages) is often used as synonym for obsolescence; nonetheless they have their subtle differences. As in [8], the current paper considers obsolescence to be concerned with suitability, meaning system architecture, functionality and performance, whilst DMSMS deals with the availability of a system/component/part. In obsolescence management, an important role is attributed to parts management. Parts management contributes to consider design aspects when choosing an optimal part during design. Its practice considers the application, standardization, technology (new and aging), system reliability, maintainability, supportability, and cost in designing or selecting parts and addressing availability, logistics support, DMSMS, life cycle cost, anticounterfeiting and legacy issues in supporting parts throughout the life of the systems [9].

The paper is structured as follows. Section 2 reviews the concept of obsolescence, technology life-cycle and adoption. Section 3 describes how innovation considerations can be included in the obsolescence risk analysis estimation methodology. Section 4 briefly presents the case study of obsolescence in an engine knock management system and introduces design structure matrices (DSM) as a way of representing the alternative architectures of the case study. Section 5 discusses the results obtained. In section 6 the paper concludes with a recompilation of the achieved goals and recommendations.

2 Brief overview of Obsolescence

This paper addresses involuntary obsolescence, which refers to when neither the customer nor the manufacturer necessarily want to change the product or the system [10]. The so called built-in obsolescence or planned obsolescence [11] is out of the scope of this paper. The term of obsolescence as mentioned before goes beyond the availability of a component from its supplier [4] [12] [10]. This aspect concerning availability can be referred to as logistical obsolescence or DMSMS. In Table 1 the obsolescence categorization as proposed by [10] is listed. In the remainder we will address mainly functional improvement dominated obsolescence.

Table 1. Categorization and definition of involuntary obsolescence types according to [10].

Obsolescence type	Definition
Logistical	Loss of the ability to procure the parts, materials, manufacturing, or software necessary to manufacture and/or support a product.
Functional	The product or subsystem still operates as intended and can still be manufactured and supported, but the specific requirements for the product have changed; as a result, the product's current function, performance, or reliability (level of qualification) become obsolete.
Technological	More technologically advanced components have become available. This may mean that inventory still exists or can be obtained for older parts that are used to manufacture and support the product, but it becomes a technological obsolescence problem when suppliers of older parts no longer support them.
Functionality Improvement Dominated Obsolescence (FIDO)	Manufacturers cannot maintain market share unless they evolve their products in order to keep up with competition and customer expectations (manufacturers are forced to change their products by the market). Note that this differs from functional obsolescence in that for commercial products FIDO obsolescence is forced upon the manufacturers and functional obsolescence is forced upon the customers.

Systems engineering main objective is to design and develop a system that can be maintained effectively, safely, in the least amount of time, at the least cost, and with a minimum expenditure of support resources without adversely affecting the mission of that system [3]. In general companies approach obsolescence reactively, but this does not support cost avoidance [1] nor main systems engineering objectives.

This paper focuses on the use of proactive obsolescence management as part of obsolescence mitigation measures, taken to minimize the impact or likelihood of having an obsolescence problem [1]. As previously stated, parts management and therefore standardization are defining elements in an obsolescence management program. Parts management streamlines the selection of preferred or commonly used parts during systems design, whilst standardization abides by reducing the proliferation of part types used in systems design through the selection of standard or commonly used parts to

reduce design risks by using reliable and documented parts [9]. However, a granted preference to commonly used parts may unconsciously induce risks of obsolescence on a system and contradict innovation considerations.

Historically, in order to reduce costs and reduce development times, the use of commercial off-the-shelf components (COTS) has become more and more common as a design solution, but this may constitute a risk for parts obsolescence [13]. COTS components frequently need to be adapted in order to fulfill system requirements, which is a factor to take into consideration for upgrades. Whereas technology maturity is an important factor, product design adaptations do not always seem to be considered as a direct design risk for a system [14].

Obsolescence management activities should ensure that all the parts of a system can fulfil their requirements over their expected useful life [15] or if this cannot be ensured to provide the information regarding critical parts of a system allowing to prepare mitigation strategies. Most of the existing obsolescence management tools are focused on electronics [1][10] and do not evaluate the overall system design. The proposed method can be applied as part of a proactive obsolescence management approach for the complete system to help identify critical components.

As a combination of different obsolescence mitigation measures is generally used, a proactive, holistic approach is preferable, from the earliest design stages. The number of suppliers and manufacturers that are producing particular components (implementing a particular technology) need to be assessed, as well as their track record before including a component in the bill of materials (BOM) of the system. Double sourcing may be, for example, necessary to minimize the risk for those components [1].

Technology manufacturers regularly develop new versions of electronics, software and mechanical parts. Such rapid changes lead to technology outpacing systems with long life times, which therefore require support on legacy parts [13]. A supplier may favor high revenue over lower revenue parts, as well as lower risk production parts, and therewith end production of risky and/or low-revenue components. If a supplier goes out of business, the production of parts may be discontinued. In a worst-case scenario, new parts would need to be developed from zero in a limited time.

Several authors have pointed out how open architectures and standard interfaces could help minimize the impact of technology insertion and integration due to the obsolescence or technological evolution of a system [16][17][18][19]. However, for competitiveness reasons, proprietary solutions may be favored over open architectures, although it prevents designing for obsolescence avoidance.

To raise and maintain awareness of what subsystems/parts of the system represent a risk to not fulfill the expected requirements over the intended life cycle a MBSE approach from the early stages of design is necessary. Previous MBSE methods as in [20] depend mostly on the availability of subject matter experts for round tables. The current paper builds on quantifiable metrics, proposing to integrate and to have a holistic view of the different types of requirements and system elements, and to single out those parts identified as critical in the system architectures. As a first approach for obsolescence mitigation in the conceptual design stage, the risk metrics used in this paper takes into account technology readiness levels, interfaces within system's elements, technology adoption and product lifecycle stages.

3 Life Cycle Stages and Innovation

Obsolescence in this paper is meant to be addressed from the earliest design stages. ISO/IEC 15288 [21] identifies six life cycle generic stages (Fig. 1 top), interrelated with design activities as in [22] (Fig. 1 bottom). The concept stage has a Pre-Concept Exploratory Research Stage which often identifies enabling technologies. The concept stage overall identifies stakeholders' needs, explores concepts and proposes viable and feasible solutions. These studies include affordability assessment, environmental impact, failure modes, and hazard analysis[3]. This paper proposes to add at this stage an initial obsolescence assessment with the goal to minimize the system risk of not fulfilling the required functionalities or performances over its life cycle.

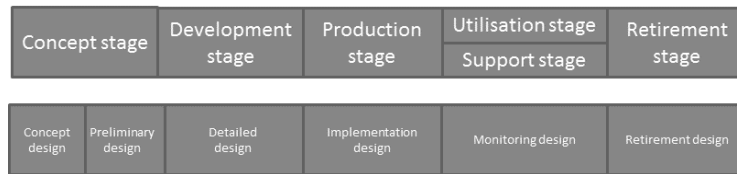


Fig. 1. Design activities per life cycle stage [22].

The mapping between standardized life cycle curve (Fig. 2) and technology adoption life cycle (TALC) as proposed in this study is shown in Table 2. A similar approach in [23] mapped the product life cycle phases to TALC. In the current paper a standardized life cycle curve was used. Standardized life cycle curve phases allow to position them in the planning of long-term product strategies [23], whereas TALC provides insight into market conditions by understanding the types of buying personalities [24].

Table 2. Adoption Life Cycle and buying personalities [23] [24]

Adoption LC phase	Also known as	Description	Standardized LC phase
Innovators	Technology enthusiasts	The first to commit to new technology.	Introduction
Early adopters	Visionaries	They are driven to embrace the new technology to gain a competitive advantage, accepting solutions that are not entirely complete and to commit required resources and effort to make the technology work.	Growth
Early majority	Pragmatists	Methodical and pragmatic in their approach to solving problems, they tend to buy from the market leader, as an efficiency measure and a safe purchase.	Maturity
Late majority	Conservatives	They aim for proven track records, but this information needs to be extremely thorough and proven to be reliable.	Decline
Laggards	Skeptics	They use established legacy systems until the option is no longer available.	Phase-out, Obsolescence

The standardized life cycle phases characterize sales, price and usage part modification [10]. The introduction phase tends to attract customers who value performance over price. Eventually a maturity phase could be reached due to incremental innovation processes, nevertheless after reaching this point the evolution during the maturity phase can be triggered only by radical innovation. Technological product performances move along an S-curve until technical limitations cause research effort, time and/or resource inefficiencies to result in diminishing returns [23].

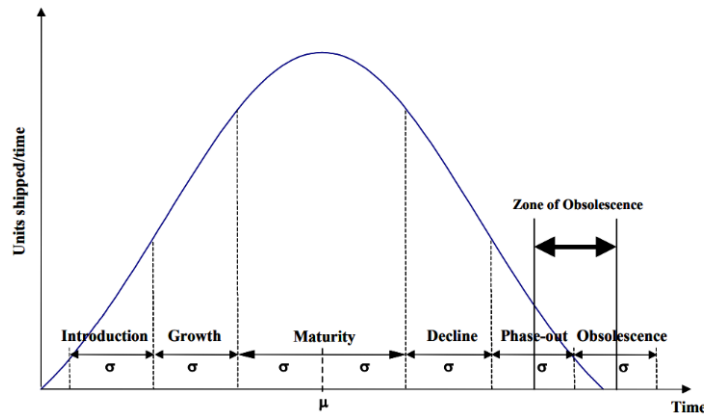


Fig. 2. Standardized life cycle curve [10]

4 Obsolescence Risk Assessment

Risks are uncertain events, that can be classified into opportunities (positive effects) or threats (negative effects)[25]. ISO 31000 on Risk management [26] expresses risk in terms of a combination of impact and likelihood, see equation 1.

$$\text{Risk} = \text{Likelihood} \times \text{Impact} \quad (1)$$

Risk estimation can be introduced into systems architecture considerations, for instance: for product development and technology integration programs. It is important to have objective estimations on the likelihood and the impact, as in [14] and [27], where TRLs were associated with likelihood and the impact with the number of interfaces. Building upon these objective measurement parameters, in this paper, it is proposed to include as well standardized life cycle phases jointly with technology readiness levels (TRLs) for the likelihood, and the number of interfaces within system elements for the impact.

NASA's TRLs offer a well-documented and widely used scale for measuring the degree of maturity in a given component according to [14]. TRLs can be determined with the help of a Technology Readiness Assessment [28] and are defined as standardized levels ranging from 1 to 9, their definitions are presented in Fig. 3. TRLs represent the aspects of integration and technology maturity, and the level of a product design adaptation. As such, TRLs can be perceived as a measurement of the degree of certainty

regarding the design, implementation and capabilities of a certain technology in a system. The more mature a system is, the less uncertainties there are on the design.

TRL	Definition
TRL 1	Basic principles observed and reported.
TRL 2	Technology concept and/or application formulated.
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept.
TRL 4	Component and/or breadboard validation in laboratory environment.
TRL 5	Component and/or breadboard validation in relevant environment.
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space/target).
TRL 7	System prototype demonstration in a target/space environment.
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or flight/target).
TRL 9	Actual system "flight proven" through successful mission operations.

Fig. 3. TRLs definitions from NASA Systems Engineering Handbook [29].

System complexity often occurs at the interfaces between systems, sub-systems, and components/system elements [30]. The degree in which a change in the system will impact the system itself depends amongst others on the number of interfaces the system element has with other system elements. At the start of the conceptual design stage, a lot of system information is missing since a lot of design decisions have not yet been made. That is why as a first approach, first-degree undirected interfaces are considered to be adequate. Table 3 provides more information on the considered type of interfaces at this stage and the respective weights, an adaptation from the weights presented in [16]. Subsequently, when in the next life-cycle stages more information is available, the estimations can be adapted/refined to consider more certain and up-to-date information.

Table 3. Type of interfaces and respective weights

Interface type	Weight
Only physical / Only power / Only information	1
Physical + power / Physical + information / Power + information	2
Physical + Power + Information	3

To represent the interfaces, design structure matrices were chosen as a network modeling tool used to represent the elements comprising a system and their interactions, that highlights system's architecture or designed structure [31]. DSMs represented in NxN matrices map the interactions among the set of N elements of a system. They are particularly well-suited for applications in complex systems development and used more often in the area of engineering management [31]. In this paper, the convention used to represent the information on the DSM is inputs in rows (IR).

As mentioned in section 2, likelihood here depends on TRLs at the time of system design, as well as on the component life cycle stage (representation of the technology adoption life cycle stage). As an example, even if all components selected for a system under development would be at TRL 9, that does not automatically mean that all risks can be avoided, as such components themselves could already be in their decline life

cycle phase whilst the manufacturers are working on upgrades. Equation 2 is used to scale the parameters for the risk assessment. The desired scale for likelihood and impact is between 1 to 5 [27].

$$X_B = \frac{(n \times L_B - U_B) \times X_A + U_B \times L_A - n L_B \times U_A}{n \times (L_A - U_A)} \quad (2)$$

In equation 2, n is the number of factors that determine the parameter, $n=1,2,3\dots$, X_A is the input value in scale A , X_B is the output value in scale B , U_A and L_A are respectively the upper and lower limit of scale A , and U_B and L_B likewise for scale B . The number of interfaces that vary from 1 to given natural number are scaled using equation 2 to a scale of 1 to 5. As the likelihood metric derived from TRLs is inverse to the growth on TRL level, meaning the higher the TRL the less risk, the upper limit in scale A corresponds to 1 and the lower limit to 9, the boundaries of scale B are $L_B = 1$, $U_B = 5$ and $n=2$. If the X_A is a TRL 7, the obtained X_B using this equation is 1,4. To estimate the likelihood when it depends on several parameters equation 3 is used.

$$Likelihood = \sum_{i=1}^n (w_i \times X_{b_i}) \quad (3)$$

Here, n represents the quantity of total parameters impacting the likelihood, the same n as in equation 2, and X_B is the obtained scaled parameter from equation 2. For practical purposes, the proposed parameters used to calculate the likelihood are considered equally important hence w_1 and $w_2 = 1$.

5 Case Study

To illustrate the proposed approach a small case-study from the automotive sector is presented (see [4] for more information). The case-study concerns the knock detection functionality for gasoline engine management systems, an important functionality to detect an uncontrolled and unwanted self-ignition phenomenon so that corrective control actions can be made. Since the phenomenon is constituted of several resonances determined by cylinder geometry, signal treatments allow then to decide on the presence or not of knock, as well as its intensity. Looking at the engine knock management diagram (Fig. 4) presented in the notation of Object-Process Methodology [32], there are broadly four functions that can be identified:

- knock detection measurement (instrumentation),
- a knock signal pre-treatment (e.g. in smart ignition coils, before the signal goes via wiring to the engine management system),
- a knock signal treatment from hardware entry stage in the engine management system,
- a knock detection.

Different detection means can be envisaged: vibration detection, ionization current analysis, etc. In function of the actual sensing technique choice, a knock signal pre-treatment may be necessary or not, each option being designed on different technological bases, each having different benefits and disadvantages. Figure 4 presents a

diagram in which the components and functions of the system of interest can be found. From MBSE diagrams DSMs can be extracted automatically as proposed in [33].

For the hardware entry-stage different options can be thought of, such as a dedicated Integrated Circuit (IC), a general-purpose programmable IC, a signal treatment software solution in the main microprocessor, etc.

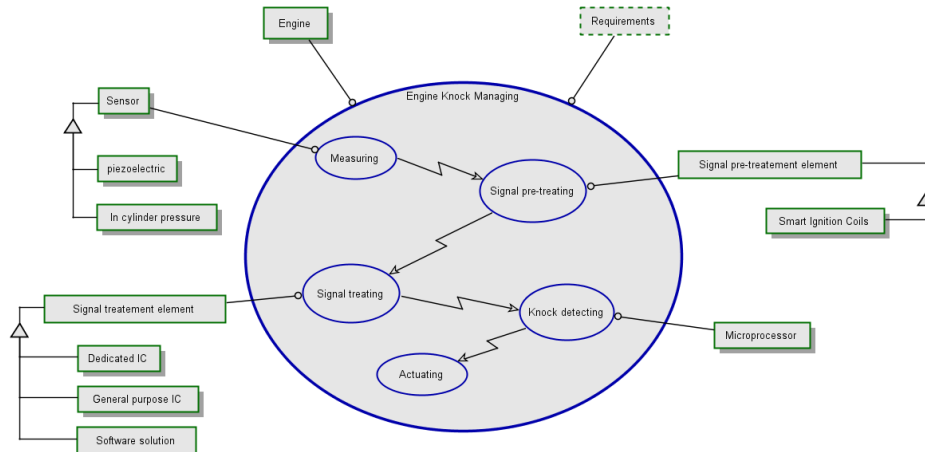


Fig. 4. Engine Knock management Object Process Diagram

In this case-study, the design of the knock detection functionality is explored. At the design stage of this functionality (mid 1990's), several system architectures were considered. The retained system architecture included a piezo-electric transducer for the measurement, no pre-treatment, a dedicated IC as hardware entry-stage and a regular software solution for the actual detection. The dedicated IC built on complex difficult to produce electronics was purchased from an external supplier. The IC supplier at some point decided to discontinue its production. As for this critical component no double sourcing was possible and as it was used in important volumes, an alternative solution needed to be developed within a very short amount of time. Could such a situation have been foreseen earlier in the systems life-cycle, maybe already during the design stage, allowing to take timely decisions?

Out of the many possible, four architectures were assessed, represented by the DSMs in the figures 5, 6, 7, 8 with the types of component interfaces (see Table 3) with respect to the study, i.e., calculating the impact of the component on obsolescence risk.

	Piezo-electric sensor	Microprocessor	SI engine	Dedicated IC
Piezo-electric sensor			1	1
Microprocessor				2
SI engine	1			
Dedicated IC	1	2		

Fig. 5. DSM Architecture A.

	Microprocessor	SI engine	Dedicated IC	Smart Ignition Coils	In cylinder pressure sensor
Microprocessor			2		
SI engine				1	1
Dedicated IC	2			1	
Smart Ignition Coils		1	1		1
In-cylinder pressure sensor		1		1	

Fig. 6. DSM Architecture B.

	Piezo-electric sensor	Microprocessor	SI engine	Software
Piezo-electric sensor		1	1	
Microprocessor	1			2
SI engine	1			
Software		2		

Fig. 7. DSM Architecture C.

	Microprocessor	SI engine	Smart Ignition Coils integrated with IC	In-cylinder pressure sensor
Microprocessor			2	
SI engine			1	1
Smart Ignition Coils integrated with IC	2	1		1
In-cylinder pressure sensor		1	1	

Fig. 8. DSM Architecture D.

6 Results and Discussion

The DSMs from the previous section provide information on the types of interfaces between components. Adding information on the lifecycle phase and TRL of each component (see Table 4) provides an obsolescence risk index. The risk input on the tables were obtained following these steps:

1. The life cycle phase, TRL and interface metric should be recalculated in the targeted range of 1 to 5 with equation 2.
2. The likelihood is calculated as the sum of the previously calculated risk input parameters with equation 3. The calculation of the impact could also be achieved through this equation in the case more parameters are being used to define it.
3. The risk can be assessed per component using equation 1.

Table 4. Impact versus likelihood per element Architecture A.

Component	Likelihood			Impact		Risk index
	Lifecycle phase	Risk Input	TRL	Risk input	N Connections	
Piezo-electric sensor	mature	1.6	7.0	1.4	2	9.0
Microprocessor	mature	1.6	8.0	1.2	2	8.4
SI engine	growth	1.3	8.0	1.2	1	2.5
Dedicated IC	growth	1.3	4.0	1.9	3	16.0

The DSM relations stated in each respective architecture (e.g. Fig. 5) are symmetrical. When more information is available at the initial phases of design, these relations could

become directed, and considering the inputs in row convention would facilitate more information to be represented in the DSM.

For Architecture A the interfaces found in the DSM are the following: the dedicated IC with a total of 3 interfaces, the piezo-electric sensor and microprocessor with each 2 interfaces, and the actual engine with 1 interface. Rescaling the number of interfaces to a range from 1 to 5 allows to calculate the risk input. As an example of impact calculation an X_A equal to 3 can be found as the number of interfaces in the initial scale: $U_A=3, L_A=1$, and the desired scale: $U_B=5, L_B=1$ when this information is substituted in equation 2 the impact (X_B) in the desired scale is equal to 5. The likelihood depends on two parameters: technology readiness level and life cycle phase (in equation 2, $n=2$). For instance, a TRL of 7 in a scale from 1 to 9 (scale A) needs to be recalculated in the scale from 1 to 5 as a risk input calculation. Which would mean that $X_A=7, U_A=1, L_A=9$, and $U_B=5, L_B=1$. Substituting the values of these parameters in equation 2 the value for X_B is obtained and equals to 1.4. The risk input coming from the Lifecycle phase would be similar but with $U_A=6$ and $L_A=1$. Afterwards, the resulting likelihood is calculated with the help of equation 3.

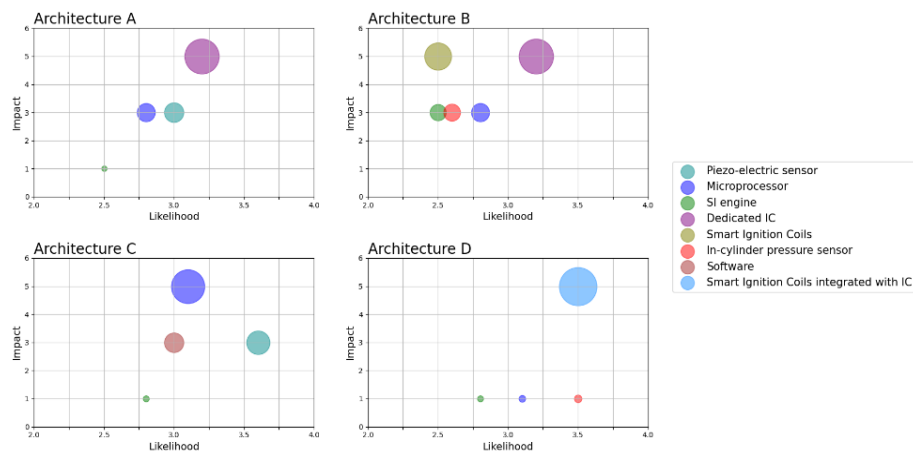


Fig. 9. Impact versus likelihood per element per architecture

In Fig. 9 the size of the bubble of the chart represents the magnitude of obsolescence risk index. In the case of architectures A and B, the dedicated IC emerges as a critical component, with the highest likelihood and impact. The dedicated IC TRL was low at the time of developing the solution, since was not yet qualified for automotive applications. A component designed for an environment different to the one in which was originally qualified would have a TRL of 4. An assumption that the TRL could be 9 in such cases is not correct due to the fact that the component was never validated in the new relevant environment.

System elements need to be carefully selected in order for a system not to become obsolete before it is even deployed. A component of TRL 9 could be entering its decline

life cycle phase whilst its manufacturer due to changes in the demand and the market is working on its upgrade. Assessing the trade-offs to select components is needed to take into account that the time and effort spent improving a technology from TRL 6 to TRL9, could be more rewarding than just choosing a TRL9 technology that might enter soon its decline phase. Nonetheless, parts management may be inducing risks of obsolescence on a system by streamlining the selection of preferred or commonly used parts during systems design. Granting this sort of preference may not be a path to added value creation, and contradicts any preference for a company to be an early technology adopter. The fact that any organization would give preference to commonly used parts just because they seem like the “safe option”, constitutes also an obsolescence risk and a risk of subsistence and growth prospects of the same organization.

System parts, components can be defined as the constituents of systems; the system characteristics, performances and functionalities depend on its constituents and their interactions, it is imperative to select them properly. The opportunity of accompanying technology incremental innovation (small improvements in product functionalities) is granted when it is decided to be part of the early phases of the technology adoption life cycle. This is the time period when a certain technology is still flexible and can be adapted to specific requirements. Once the technology reaches its mature phase this possibility decreases and opens the door to an eventual radical innovation (break-through in product functionalities); when this occurs, the previous technology starts phasing out and at the end becomes obsolete. This process is known as the technology/marketing s-curve phenomena and is indirectly considered in this study with the mapping between technology adoption life cycle phases and the standardized life cycle phases.

For the first two architectures not only did the dedicated IC had the largest magnitude of the obsolescence risk index, but this component also only counted with one supplier, which is an additional risk to consider. When designing a system, it is necessary to make sure that components included in the BOM can be provided by multiple suppliers to minimize the number of critical components [1], or to document and monitor properly this risk. From this point of view, using a dedicated IC seems not to be the best option.

Architecture C as seen in Fig. 9 seems to be a more balanced solution, it could have been a better option from an obsolescence point of view, but at the time of developing the system due to technology constraints it would have not been economically viable. When observing Architecture D, it would be valid to question whether an initial investment to further develop the technology behind the smart ignition coils integrated with IC would provide a resulting architecture with the least magnitude of obsolescence risk index. A very important trade-off when designing a system: the effort to further develop a technology versus the return of investment. Had these considerations been taken at the early stages of design of this system as an obsolescence mitigation measure at least a monitoring of the state and obsolescence drivers of the system could have been put in place.

7 Conclusions and Recommendations

This paper proposes an MBSE analysis method that can be used since the early design stages to raise and maintain awareness of what subsystems/parts of the system represent a bigger risk to not fulfill the expected requirements over the intended life cycle, and thus should be considered as critical from an obsolescence point of view.

The presented method is accessible and feasible to implement. Nevertheless, it complements but does not preclude the system's engineer and program manager's role to determine which trade-offs are considered acceptable in order to ensure the development of a system. Technology Readiness Levels (TRLs) and component life cycle stages were used to rate the likelihood, the latter representing the technology adoption life cycle as a representative of innovation considerations for design. While the number of interfaces represents the complexity and therefore the potential impact of the risk on the whole system. The likelihood and impact of the risk were objectively rated, for which this approach provides a good option to objectively obtain an evaluation of the risk a component might bring when developing a system.

This paper as well presents the application of the obsolescence assessment method on a real-life case study, and illustrates how knowing a priori the risk that the dedicated IC represented, the need for an obsolescence management plan could have been foreseen. If monitoring had been initiated at this phase as an obsolescence mitigation measure, obsolescence issues could have been addressed proactively and strategically.

During the early stages of design, alternative system architectures and the results of technology maturation studies are reviewed. The technology maturation process can help identify requirements and development routes that are not feasible. Avoiding the use of high-risk obsolescent critical components can prevent from unnecessary unplanned expenses due to redesign and rework further down the life cycle. Nevertheless, if the constraints imposed on the system design do not allow for an optimal architecture definition from an obsolescence point of view, after the assessment is completed what can be done is to monitor closely the obsolescence risk of the critical components.

In order to evaluate the impact of this obsolescence risk assessment from the early design stages, it is recommended to measure the achieved cost avoidance through the life cycle of systems. Part of the envisioned future work entails including more than just undirected first-degree interfaces to explore how that affects the results if it does. DSMs were chosen as the modeling tool taking into account the possibility to expand the proposed approach in the future to consider not only undirected and first-degree dependencies, which could be possible when more system information is available.

References

- [1] F. J. Romero Rojo, R. Roy, and E. Shehab, "Obsolescence management for long-life contracts: State of the art and future trends," *Int. J. Adv. Manuf. Technol.*, vol. 49, no. 9–12, pp. 1235–1250, Aug. 2010, doi: 10.1007/s00170-009-2471-3.
- [2] C. Adams, "Getting a Handle on COTS Obsolescence - Avionics." <https://www.aviationtoday.com/2005/05/01/getting-a-handle-on-cots-obsolence/>

(accessed Jan. 15, 2020).

- [3] D. D. Walden, G. J. Roedler, K. Forsberg, R. D. Hamelin, and T. M. Shortell, *Systems Engineering Handbook : a guide for system life cycle processes and activities*, 4. edition. New York: NY John Wiley & Sons, 2015.
- [4] S. Salas Cordero, R. Vingerhoeds, M. Zolghadri, and C. Baron, “Addressing Obsolescence from Day One in the Conceptual Phase of Complex Systems as a Design Constraint,” *IFIP Adv. Inf. Commun. Technol.*, vol. 594, pp. 369–383, Jul. 2020, doi: 10.1007/978-3-030-62807-9_30.
- [5] A. Baregheh, J. Rowley, and S. Sambrook, “Towards a multidisciplinary definition of innovation,” *Manag. Decis.*, vol. 47, no. 8, pp. 1323–1339, Sep. 2009, doi: 10.1108/00251740910984578.
- [6] J. Bessant, R. Lamming, H. Noke, and W. Phillips, “Managing innovation beyond the steady state,” *Technovation*, vol. 25, no. 12, pp. 1366–1376, Dec. 2005, doi: 10.1016/j.technovation.2005.04.007.
- [7] Defense Standardization Program Office, *SD-22 Diminishing Manufacturing Sources and Material Shortages: A Guidebook of Best Practices for implementing a Robust DMSMS Management Program*. VA, USA: DoD approved for public release, 2021.
- [8] A. Soltan, S.-A. Addouche, M. Zolghadri, M. Barkallah, and M. Haddar, “Obsolescence paths through the value chain,” *Procedia Manuf.*, 2018, doi: 10.1016/j.promfg.2018.10.169.
- [9] Defense Standardization Program Office, *SD-19 Parts Management Guide*. VA, USA: DoD approved for public release, 2013.
- [10] B. Bartels, U. Ermel, M. Pecht, and P. Sandborn, *Strategies to the Prediction, Mitigation and Management of Product Obsolescence*, vol. 87. John Wiley & Sons, 2012.
- [11] B. London, *Ending the depression through planned obsolescence*. New York, 1932.
- [12] T. Dowling, “Planning For Change With A Holistic View Of The System,” 2001. Accessed: Mar. 11, 2020. [Online]. Available: www.dsdm.org.
- [13] R. A. Lebron, R. Rossi, and W. Foor, “Risk-Based COTS Systems Engineering Assessment Model: A Systems Engineering Management Tool and Assessment Methodology to Cope with the Risk of Commercial Off-the-Shelf (COTS) Technology Insertion During the System Life Cycle,” *RTO SCI Symp. Strateg. to Mitigate Obs. Def. Syst. Using Commer. Components*, 2000.
- [14] T. ; Garg, S. ; Eppinger, N. ; Joglekar, and A. Olechowski, “Using TRLS and System Architecture to Estimate Technology Integration Risk,” in *Product, Services and Systems Design*, vol. 3, pp. 301–310, Accessed: Mar. 28, 2019. [Online]. Available: <http://mitsloan.mit.edu/shared/ods/documents/?DocumentID=4124>.
- [15] International Electrotechnical Commission, Ed., *IEC 62402 International Standard*, 2nd Edition. La Plaine Saint-Denis: AFNOR — French Standard Institute, 2019.
- [16] J. E. Devereaux, “Obsolescence: A Systems Engineering And Management Approach For Complex Systems,” 2010. Accessed: Feb. 10, 2020. [Online]. Available: <https://dspace.mit.edu/handle/1721.1/59233>.
- [17] B. Michael Ostrovsky *et al.*, “Stability in Supply Chain Networks,” doi: 10.1257/aer.98.3.897.
- [18] D. Young, “New Approaches to Processor Lifecycle Management,” *RTO SCI Symp. Strateg. to Mitigate Obs. Def. Syst. Commer. Components*, 2000.

- [19] M. Buratti, D. Del Brusco, and A. Difesa, “The Obsolescence Management Based on a ‘Pro-Active’ Approach in Conjunction with a ‘Pre-Planned’ Technology Insertion Route,” *RTO SC Symp. Strateg. to Mitigate Obs. Def. Syst. Using Commer. Components*, 2020.
- [20] M. Zolghadri, R. Vingerhoeds, C. Baron, and S. Salas, “Analysing the Impacts of System Obsolescence based on System Architecture Models RE MODELS,” in *Proceedings of the TMCE 2020 Symposium*, May 2020, vol. 2020, pp. 11–15, Accessed: Apr. 27, 2021. [Online]. Available: <https://bit.ly/2IUT2RA>.
- [21] ISO/IEC/IEEE, “15288:2015 - Systems and Software Engineering – System Life Cycle Processes,” 2015.
- [22] F. Brazier, P. van Langen, S. Lukosch, and R. Vingerhoeds, “Design, Engineering and Governance of Complex Systems,” *Proj. People – Mastering Success.*, pp. 34–59, 2018.
- [23] A. Orcik, Z. Tekic, and Z. Anisic, “Customer Co-Creation throughout the Product Life Cycle,” *Int. J. Ind. Eng. Manag.*, vol. 4, no. 1, pp. 43–49, 2013, Accessed: Oct. 17, 2020. [Online]. Available: www.iim.ftn.uns.ac.rs/ijiem_journal.php.
- [24] Wohlers Associates INC, “Rapid Prototyping & Tooling State of the Industry,” 2002. Accessed: Mar. 23, 2020. [Online]. Available: <http://wohlersassociates.com/talc2.pdf>.
- [25] Project Management Institute, *A guide to the Project Management Body of Knowledge (PMBOK guide)*, 6th ed. Newton Square, PA: Project Management Institute, 2017.
- [26] ISO, “31000:2018 Risk management,” 2018.
- [27] I. H. Arroyo and C. Fortin, “Technological and Complexity Risk Analysis For Set Based Design Evaluation,” in *2018 IEEE International Systems Engineering Symposium (ISSE)*, Oct. 2018, pp. 1–5, doi: 10.1109/SysEng.2018.8544382.
- [28] GAO-16-410G, “Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects,” 2016. Accessed: Jun. 18, 2021. [Online]. Available: <https://www.gao.gov/assets/gao-16-410g.pdf>.
- [29] NASA, *NASA Systems Engineering Handbook*, SP-2016-6105 Rev2. 12th Media Services, 2017.
- [30] P. J. Clarkson, C. Simons, and C. Eckert, “Predicting Change Propagation in Complex Design,” *J. Mech. Des.*, vol. 126, no. 5, p. 788, Sep. 2004, doi: 10.1115/1.1765117.
- [31] S. D. Eppinger and T. R. Browning, *Design structure matrix methods and applications*. MIT Press, 2012.
- [32] D. Dori, *Object-Process Methodology: A Holistic System Paradigm*. Springer, 2002.
- [33] W. Pons, S. Salas Cordero, and R. Vingerhoeds, “Design Structure Matrix Generation from open-source MBSE tools,” no. Manuscript submitted for publication under revision, 2021.