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Conceptualising the impact of information asymmetry on through-life cost: case study of machine tools sector

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Abstract

Information asymmetry (IA) in terms of contextual variety and importance is one of the most challenging aspects of through-life costing in product-service systems (PSS). IA is an imbalance in the information, data and knowledge shared among the parties involved in a contractual agreement. In manufacturing systems under PSS, interaction and effective communication among several parties who are involved in a contractual agreement, rely on the continuity and accuracy of information and context. In such systems, contextual variety exhibits complexity and uncertainty in through-life costing and subsequently in PSS cost assessment. Although the economic aspect of PSS has been studied previously, the impact of IA on through-life cost and for different PSS solutions has not been detailed. Considering manufacturing value chains, this paper introduces a new concept of PSS-hierarchy to perform through-life costing in the presence of IA for various PSS solutions. Moreover, this paper proposes a generic life-cycle model for different PSS solutions to assess the total cost of ownership (TCO). The proposed model has been developed to support decisions on contract design in manufacturing systems. This study considers the manufacturer, service provider and customer perspectives to develop the TCO model using a machine tool manufacturing case study.

Keywords: Product-service system; Information asymmetry; Through-life costing; Total cost of ownership; Manufacturing systems; Uncertainty assessment

1. Introduction

Total Cost of Ownership (TCO) includes all direct and indirect costs associated with an asset over its entire lifecycle. In this context, an asset can be described as a product or a service that produces economic value for the owner. The direct cost of an asset, as examples, is a fee associated with the fabrication of a product or development

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of a service. Unlike indirect costs, direct costs are traceable; such as labour, material and logistics. In contrast, indirect costs are not completely related to a specific product or service and can benefit more than one contract. Such one-time expenses include the costs related with: new design or new equipment, renting, labour or customer trainings, labour and equipment insurances and administration costs. Moreover, total cost consists of fixed costs and variable costs. Generally, fixed costs are independent of the number of products or services. Variable costs are a function of the total number of products produced or services performed. In this context, through-life cost refers to the cost of an asset from the initial concept stage to the end-of-life stage [1,2].

In product-service systems (PSS), the lifetime ownership of products and services can play a key role in the estimation of through-life cost. In use-oriented and result-oriented PSS, since the ownership often remains with the service provider, the cost associated to the asset improvement (i.e. retrofitting or cost of change) is important and should be considered as an individual element in through-life cost breakdown structure. Improvement cost element is even more crucial for assets that go through multiple lifecycles before disposal. On the other hand, there are countless uncertainties around the characterisation of direct and indirect costs in different contracts. These uncertainties may arise from inequality, mislaid data and information shared among parties involved in a contractual agreement. This phenomenon is known as information asymmetry (IA). Despite the range of cost estimation approaches under uncertainty in literature, there is no unique way to classify through-life costs under IA as a source of uncertainty in cost estimation. To fill this research gap, the core contribution of this paper is to develop a framework to outline the TCO over the product lifetime for three types of PSS solutions in manufacturing systems and in presence of IA.

This paper is structured as follows: Section 2 discusses the literature review. A holistic view of LCC/TCO configuration for PSS is examined in Section 3, as well as an outline of the methodology implemented by the authors to develop the framework for cost evaluation in the presence of IA for PSS. Section 4 presents the case study adopted to develop the framework to estimate the TCO for manufacturing systems under PSS and give it a real-life context. Section 5 discusses the implementation of the framework and highlights the conclusions and the future work of this research.

2. Literature Review

2.1. Total cost of ownership for product-service systems

LCC represents TCO through an asset's entire lifetime [3]. Asset reliability and performance plays an important role to find the optimal estimation for TCO. The other element that has a significant effect on the optimal TCO is uncertainty. Therefore, a comprehensive through-life uncertainty analysis is vital to estimate the lowest long-term cost of ownership. Considering an asset as both a product and service, the TCO is composed of four main cost elements; acquisition, operation, improvement and end-of-life. Breaking down the TCO costs, the LCC cost drivers include: planning, design, creation, integration, operation and end-of-life. Integration costs consist of assembly, test and launch; operation costs consist of support & maintenance, utilisation and logistics; improvement costs and cost of change in design consist of investigation and solution; end-of-life costs include that of reuse, recycle or disposal [4].

Recent growth of service roles in manufacturing companies has shifted the practice of industrial sectors from product-oriented to service-oriented. This is well known as servitisation. Moreover, the growth toward efficiency and innovation in such companies creates more integrated and subsequently complex manufacturing processes. The trend towards complex service-oriented manufacturing dissolves the distinction between product and service for manufacturers and customers. In this regard, a so-called hybrid product consists of an integrated combination of services and manufactured products [5]. This complication imposes manufacturers and decision makers to develop new policies and regulations to target hybrid products through their lifetime. Moreover, policies should target the efficiency, improvement and quality of services and be designed to enhance the competiveness of complex hybrid production systems; including hybrid manufacturing, service processes and ultimately hybrid products. According to the Central Intelligence Agency (CIA), The World Factbook, as of 2017 estimation, 63% of the world GDP comes from services on average. This figure is 80.4% for the UK economy [6]. This major proportion of services in GDP indicates the role of PSS implementation along economic activities in all sectors through product-service integration. In particular, for high value production sectors, PSS brought a number of new concepts in engineering and manufacturing such as: distributed manufacturing and additive manufacturing, digital twins, integrated vehicle health management, internet of services and industry 4.0 trend [7].

2.2. Information asymmetry

IA is an imbalance in the information, data and knowledge shared among the parties involved in a contractual agreement. It is precisely defined as a situation in which respective parties own different amounts and types of information over time about a project or contract [8]. For example, the amount of information possessed by an individual will affect their behaviour. If a person wants to purchase an asset, the seller can alter the price based on their knowledge about the condition of that asset [9]. This difference in ownership of information puts one or both parties in a disadvantageous or advantageous position, which usually results in economic variances. For instance, in a two-party servitisation agreement, one party may possess more information than the other, which generates the opportunity to make a deal to generate economic benefits for both parties [10].

IA exists since the starting point of two or more parties' collaboration and its influence may be negative or positive, depending on the contractual agreement and condition. Negative effects can generate economic losses based on a lack of trust among various stakeholders involved and, eventually, in termination of contracts. Current trends in manufacturing are moving towards providing advanced services along with products, leading to collaborations between many stakeholders (suppliers, original equipment manufacturers (OEM), third party finance providers, external subcontractors, etc.). The lack of common understanding of the information may be challenging for collaborative PSS projects involving multiple stakeholders. There is a difference between possessed information and knowledge generated from the information. There are two main scenarios that may lead from IA; adverse selection and moral hazard. These terms are explained by examples in the financial field. Within the finance domain, lenders are not completely aware of the credit worthiness of the borrowers before entering into a contractual agreement. The lack of more accurate and specific information is termed as adverse selection – a scenario that may occur before the deal – which leads to inefficiencies in service delivery [11]. On the other hand, having entered into a contractual agreement, stakeholders are misled by the changing behavior of one or more partners in order to avoid exposure to risk [12]. In the both IA categories, imperfect information causes an uncertainty in estimating the cost associated to the contract or the project.

3. A holistic view of LCC/TCO configuration for PSS

Business models in different sectors are mostly demand driven; suppliers are required to provide products based on exact specification from the customers. This determination may slow the innovation path in such businesses since the customer is responsible for innovate products and all the risk associated with the new design. Therefore, one of the main aspects to be considered in business models under PSS is value add for both the product or service provider and customer. There are two main strategies to tackle this problem; product-based and service-based. The product-based approach is applicable for businesses who provide the product but less of a service with that product. In such businesses, to move toward Servitisation of Products (SoP), focus is required on the design stage through the products' lifecycle and modifying the design to find the optimum solution or retain the competitiveness. For instance, the optimum design can be found by trade-off analysis between LCC and the lifetime of the product. Moreover, competitiveness can be retained by upgrading or re-designing the product based on to the market demand. A well-known and successful example of SoP movement is 'Power by the Hour' scheme at Rolls-Royce. The service-based approach is applicable for businesses who provide services more than products. In this case, to move toward Productisation of Service (PoS), a focus is required on the flexibility and wholeness of the service. A well-known example of PoS is the Uber Taxi service application. Considering value chain in any sector, the PoS and SoP movement strategies are both essential and vital. The integrated PSS approach composed of multiple PoS and SoP co-ordinations in different levels is referred to as the PSS-hierarchy in this research. Referring to servitisation over the product lifetime, the structure of TCO and LCC has been proposed by considering the 'Improvement' stage as an individual element in the cost structure as illustrated in Figure 1.

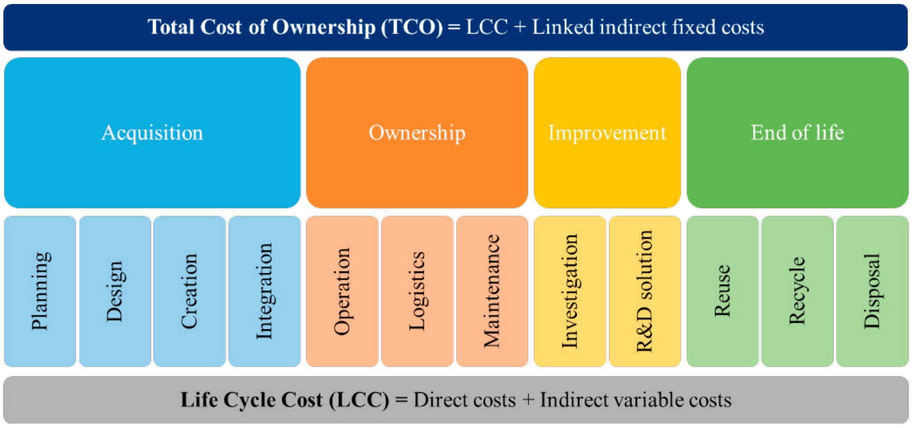


Figure 1. TCO and LCC cost elements for PSS

In PSS approach, the acquisition element of the TCO is known as direct procurement since it is associated with a product or service that is sold and offered by companies. Indirect procurement costs are not associated with a particular asset and stretch through the ownership phase including maintenance, operation, and logistics support costs. In the proposed LCC breakdown, a separate 'Improvement' phase has been added to the LCC structure as it is a key cost driver to find the optimal design and flexible service solutions as discussed earlier in this section.

4. Case study: Machine tool service provider

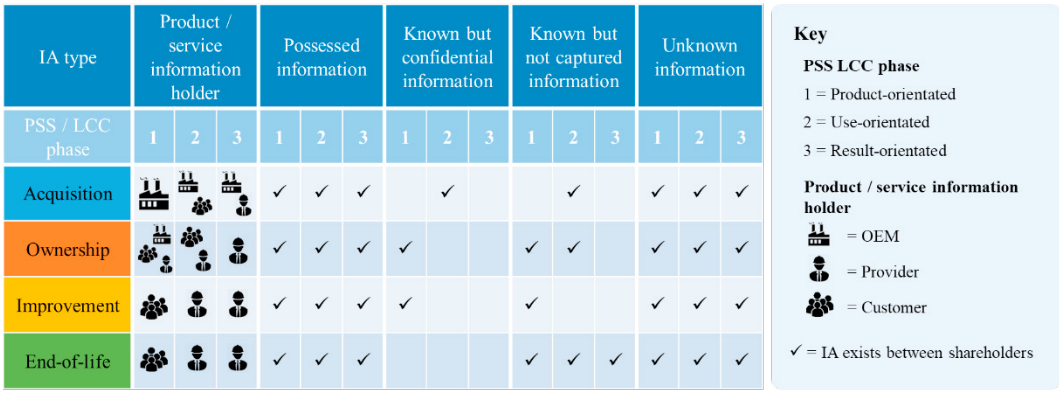
4.1. PSS for machine tool maintenance companies

To demonstrate the existence of IA in lifetime costing within a contract, a machine tool service-provider under a servitisation strategy is considered as a case study. Afterwards, qualitative research has been conducted to evaluate the influence of IA in LCC estimation. Concerning both environmental and economic aspects of machine tools, such assets go through a multi-loop lifecycle before disposal. Therefore, to maintain the sustainability, the machine must be operated with minimum environmental impact and maximum productivity and/or precision [13,14]. Increasing machine tool performance is therefore is at the forefront of the service-provider businesses. This is enabled through a number of activities along the operation phase such as breakdown responses, machine tool capability testing and optimising, machine relocations and installations, planned and un-planned maintenance, support and training and retrofits.

The business environment in many manufacturing sectors is changing and the focus is more on value-creation chains. They are, therefore, exploring product-service integrated models by extending service offerings throughout the life cycle of a product [15]. Moreover, Azarenko et al. [16] identified three core PSS pillars that can be applied within the machine tool industry; product, use and result-oriented services. Moving toward servitisation, in one extreme and under a product-oriented approach, the asset is sold to the customer. In this case, the actual usage is not relevant. The customer has full responsibility for the asset's performance. Maintenance activities from the service provider are always reactive – meaning they occur at the time of breakdown. However, in the other extreme under the result-oriented approach, the service-provider is now fully responsible for the asset. Performance monitoring is therefore vital to detect possible failures and deviation from schedules that may be caused to perform preventive maintenance. In between the two extremes lies the use-oriented approach. The product is often no longer sold but its 'useful life' is. In this case, the asset performance responsibility is dependent on the ownership of the asset. The service provider performs predictive maintenance and feedback to the customer on the asset utilisation.

4.2. Cost model development in presence of IA

As discussed earlier, IA exists throughout the product lifecycle when two or more parties possess a different type or amount of information. Moreover, IA occurs in a contract or project if information about products and services is not shared at all, not truthfully shared or if there is a risk associated with understanding the shared information. Different aspects of IA have been classified by Sceral, et al. [8] in two main categories: (i) any party could possess information and IA occurs due to the different understanding of the information owned; and (ii) any party lacks information and IA occurs due to the known but confidential information, known but not captured information and unknown information. This second category was split into three elements to expand on where IA may be identified. Based on an academic workshop, the matrix presented in Figure 2 identifies where IA exists between the relative shareholders over the three pillars of PSS (i.e. product, use and result-oriented) where information is possessed by the OEM, provider or customer for the four phases in LCC structure presented earlier in Figure 1. The existence of different IA categories between shareholders for the three pillars of PSS is summarised in Figure 2.



IA type	Possessed 1	Possessed 2	Possessed 3	Known but confidential 1	Known but confidential 2	Known but confidential 3	Known but not captured 1	Known but not captured 2	Known but not captured 3	Unknown 1	Unknown 2	Unknown 3
Acquisition	✓	✓	✓		✓			✓		✓	✓	✓
Ownership	✓	✓	✓	✓			✓	✓		✓	✓	✓
Improvement	✓	✓	✓	✓			✓			✓	✓	✓
End-of-life	✓	✓	✓				✓	✓	✓	✓	✓	✓

Figure 2. Illustration of types of IA between shareholders for three pillars of PSS

All shareholders that possess information throughout the product life-cycle can have a varying degree of understanding about that information. Therefore, IA as a result of possessed information is present in all phases for each PSS pillar. In the same way as possessed information, unknown information throughout the product life-cycle that is not apparent to any shareholder – the 'unknown unknowns' – result in IA in all four phases for each PSS LCC category and mostly due to lack of completeness of data and information. Known but confidential information for a product-oriented approach presents IA between the customer and provider in the ownership phase. This is mainly due to the failure rate anticipated by the customer which is not revealed as maintenance is done on a reactive basis. Likewise, the customer will not want to reveal information on how they might improve the product. In the acquisition phase for a use-oriented approach, there may be IA between the OEM and customer with regards to how the OEM may predict required maintenance (and therefore the cost of maintenance) for the product. IA due to known but not captured information for all three PSS pillars exists because of a lack of data accessibility. Moreover, IA occurs between the customer and provider in the product-oriented approach and between the OEM and provider in result-oriented approach due to inaccessible data owned by the customer and OEM in the respective approaches.

To evaluate the level of IA in each LCC phase and to compare its influence within the three pillars of PSS, a machine tool LCC calculation has been adopted from Enparantza et al. [4]. To the authors' knowledge, this study presented most relevant numerical data for this study. An example of the software analysis using a transfer machine case study resulted in three core parameters: acquisition, operation and maintenance costs. In this study, disposal costs were considered to be negligible compared to these main groups [4]. The percentage distributions and further elemental breakdown of these parameters are shown in Figure 3. According to the studied case, the qualitative outcome presented in Figure 2 has now focused on three LCC elements as summarised in Figure 4. Accordingly, the occurrence of each type of IA has been evaluated for the three LCC phases in each PSS pillar as summarised graphically in Figure 5.

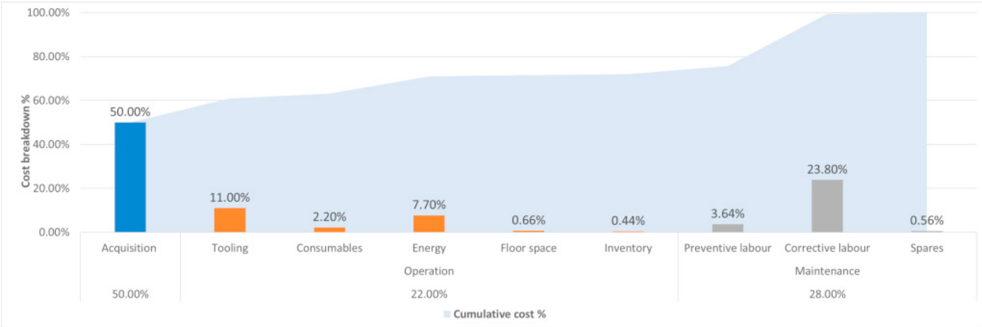


Figure 3: Predefined cost breakdown structure based on the cost model case study [4]

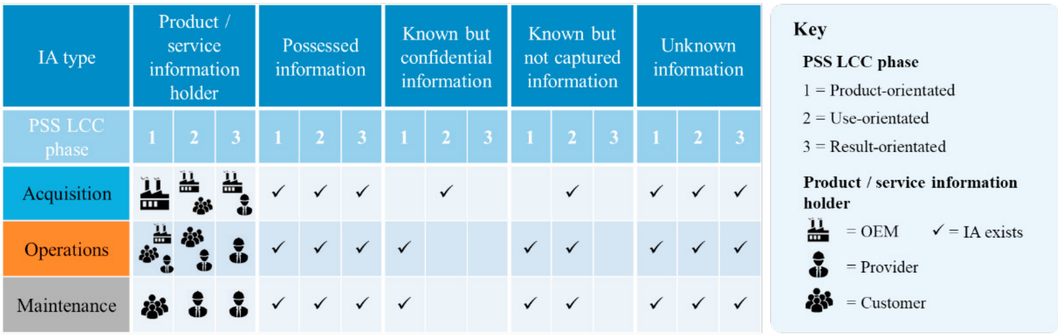


Figure 4: Illustration of types of IA between shareholders based on the cost model case study

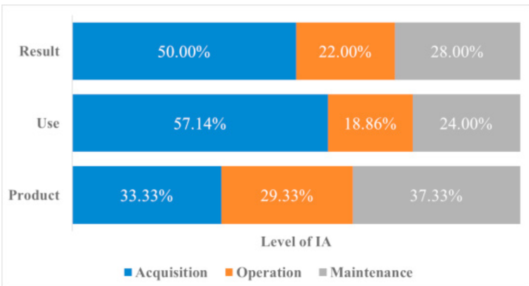


Figure 5. Occurrence of IA at each life-cycle phase for three PSS pillars based on the cost model case study

4.3. Developed LCC/TCO framework

Following the results presented in Figure 5 and the estimated cost breakdown structure example (Figure 3), the level of IA was evaluated for each cost driver and with regards to the three pillars of PSS. The probability of IA is presented in a table inside Figure 6 as a percentage. This was calculated based on the multiplication rule in probability theory – i.e. for two independent events A and B, $P(A \text{ and } B) = P(A) \times P(B)$. The combined probability was calculated for each PSS pillar and presented for each cost driver in Figure 6. Furthermore, the proposed LCC breakdown structure, a conceptual framework for the three pillars of PSS was developed. This framework identifies the core phases in the product life-cycle and which shareholder (provider, customer or OEM) has responsibility for each stage in the life-cycle. At this point, the level of IA that exists between shareholders for the three pillars has been demonstrated for acquisition, operation and maintenance cost elements. The level of IA between shareholders is categorized as high (>20%), medium (20% - 12%) and low (<12%). The range in each category is assigned based on the table of data in Figure 6. It is worth noting that the level of IA between each shareholder from possessed information is assumed as low (see Figure 7).

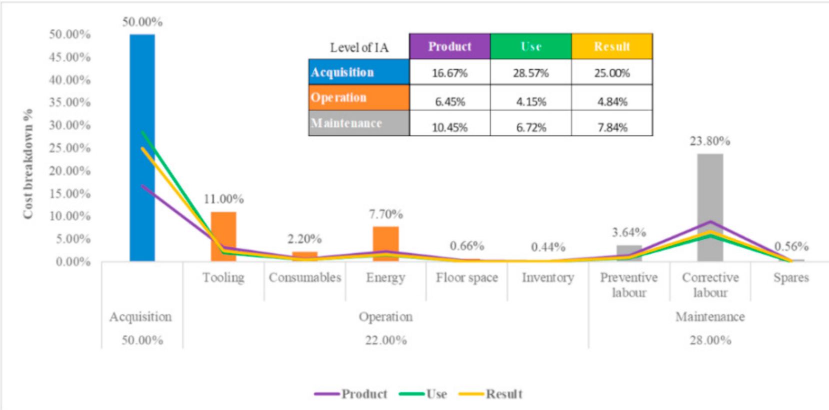


Figure 6: Level of IA for each cost driver in three pillars off PSS based on the cost model case study

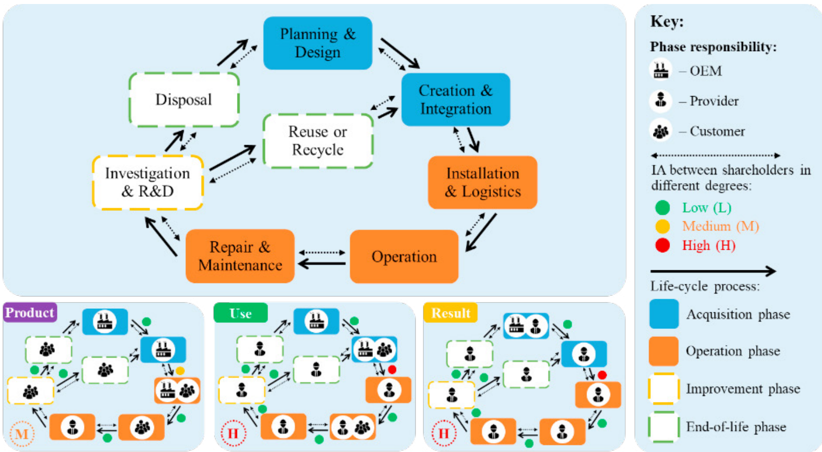


Figure 7: A framework to assess the level of IA at each lifecycle phase for three pillars of PSS for the case study

5. Discussion and conclusions

The case study examined in this paper demonstrated the occurrence and level of IA throughout the asset lifecycle in the context of PSS. The proposed framework highlighted the importance of considering IA in TCO and the significance of IA as an uncertainty in PSS. The results illustrate that the occurrence of IA in the acquisition phase for a use-oriented service is relatively high. In contrast, IA has a low incidence on the ownership phase of the same service. For a product-oriented service, IA has an approximately even probability of existence throughout the three phases examined. Comparing use-oriented and result-oriented services to the product-oriented service, the frequency of IA in the ownership phase is relatively low. This could be due to the ownership of the product or service being retained by the provider. Following the combined probability calculation, the level of IA at the ownership phase for a result-oriented is relatively low. However, the level of IA is higher at acquisition for the latter two PSS pillars due to the higher proportion of LCC for this phase.

Integrated configurations of product and service are increasingly implemented to fulfil customer needs and to offer more efficient and customised designs in PSS. The optimal solution is therefore core for businesses under PSS, as well as maintaining a level of competitiveness. This causes an increase to the linked costs associated with retrofitting, new design and management. This increase is more significant for products that go through multiple lifecycles before disposal – such as machine tools. It is therefore vital to consider an improvement stage as an individual cost element in the LCC cost structure as proposed in this paper. Furthermore, IA has not been fully studied as a source of uncertainty to evaluate the LCC for manufacturing sectors with PSS configuration. In this regard, the qualitative research in this paper demonstrated the important connection between IA and for cost estimation in PSS. Moreover, it is highlighted that the impact of IA should not be ignored in LCC evaluation. However, the academic literature provided very little guidance on the effective approach for such problems. The qualitative research thereby focused on acquisition, operation and maintenance costs at this stage. Further work will focus on comprehensive research to identify IA for all LCC cost elements in the PSS configuration and assess the impact of IA in through-life costing.

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