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An effective uncertainty based framework for sustainable industrial product-service system transformation

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ABSTRACT

Industrial Product-Service Systems (IPS^2) can provide insights to enhance the environmental sustainability and lower environmental impact. However, its successful realisation for preventing the production of waste, while increasing efficiencies in the uses of energy and human capital remains a highly convoluted problem. This research article aims to address this issue by presenting an innovative uncertainty-based framework that can be used to assist in achieving increased sustainability within the context of IPS^2. The developed framework explains the drivers for decision-making and cost to enable sustainability improvements in transforming to industrial services. This is based on academic literature, and multiple case studies of seven industrial companies with over 30 h of semi-structured interviews. The validation of the framework through two case studies demonstrates that uncertainty management can enable resource efficiency and offer sustainable transformation to service provision.

1. Introduction

Sustainability involves maintaining change in a balanced manner, in which the exploitation of resources, investment plans, the technological development and institutional change all need to be in harmony, while meeting both current and future potential to meet human, organisational needs and aspirations (Global footprint, 2018). For many in the field, sustainability is defined through interconnecting considerations for environment, economic and social (EPA, 2018). However, the route to achieve it is not always clear. This is because the complexities and subjectivities, associated with socio technical systems that over time face changing requirements and dynamics, make it difficult to be universally accepted. A major challenge in this process is with managing uncertainties that affect our plans for achieving environmental, economic and social targets.

The context for this paper is unifying goods and equipment with industrial service or Industrial Product-Service Systems (IPS^2), a transformative process called *servitization* (Baines et al., 2009). This process offers firms and supply chains a number of advantages, including the ability to lock out competitors, lock in customers, and enhance differentiation levels (Colen and Lambrecht, 2012; Dachs et al., 2014). Such options are offered by product-centric businesses such as technology and manufacturing firms, which have traditionally focused on selling equipment and goods. However, how industrial firms approach this shift towards service-oriented strategies tends to vary, which are formalised through contracts. Some studies have observed that the pressures to attain competitive advantages often forces industrial firms to deliver high quality services for improved business performance, reduced cost, increased customer satisfaction and supplier profitability (Akkerman and Vos, 2003). Others have noted the importance of life-cycle oriented value-added services; that trigger new business streams, leading to prolonged equipment life, enhanced profits and predictable business volumes for manufacturing-based companies (Baines et al., 2010). Yet, the major target is always focused on achieving a sustainable competitive advantage (in an economic sense), something which has caused manufacturers to incorporate information intensive services to enhance the use of various innovative equipment and technologies (Youngdahl and Loomba,

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2000; Khan et al., 2014) The most visible outcome of this transformation is the changes to a company's offerings, as well as with the different options (e.g. an outcome-based service contract) that can be pursued to sell and deliver a product-service solution.

Uncertainty is considered as a driver of the challenges faced in transforming operations (Ng et al., 2009; Erkoyuncu et al., 2013; Hypko et al., 2010b). This is caused by variability in the environment, human error and/or human ambiguity (e.g. lack of knowledge) and could cause a negative, positive or neutral impact on the overall performance of an industrial project (Erkoyuncu et al., 2013). This in turn results in environmental impact with resource consumption. Managing uncertainty is especially relevant when considering the features of sustainability related to maintaining change. Although, contracts play a major role in how firms and supply chains operate, there is a gap in literature on the role of uncertainty management for realising the targets of servitization (including environmental impact) through industrial contracts (Erkoyuncu et al., 2013). This article addresses this gap with an emphasis on: can uncertainty management increase resource efficiency in order to aid sustainable industrial service transformation? There is a need to demonstrate the extent of changes that often place when attempting to minimise the consumption of resources within socio-technical systems. Therefore a rigorous, and fundamental transformation enabling uncertainty based framework is developed. The paper considers environmental impact that an industrial organisation makes in the form of (in)efficient use of resources including human, and materials usage. Accordingly, by increasing the efficiency, the unit cost for a spare is identical for different simulations and scenarios and therefore the reduction in terms of cost of spares immediately means that in terms of mass, and hence environmental benefits.

1.1. Contributions

The article focuses on IPS[2] that are delivered through performance -based contracts in large complex systems (e.g. aeronautics, aerospace, oil and gas, transportation industries). The authors have also noted a growing trend to adopt leasing type models, where the OEM owns the equipment (Hypko et al., 2010a).[1] As a result, various service contracting approaches are considered in order to develop a framework that can be used to calculate resource efficiency using different types of contracts including fixed price,[2] cost plus[3] and performance-based[4] contracts. Each of these approaches is designed to take on different levels of risk and uncertainty across the supply chain (Cuthbert et al., 2011). To summarise the key contributions at the outset, the article:

- Proposes a framework to assist the sustainable transformation to service oriented contracts by systematically incorporating uncertainty.
- Investigates uncertainty factors in the process of transformation to industrial service contracts. These factors tend to vary over product life-cycles and insights into potential sources of uncertainty have been shown to inform decisions to redesign supply chains, to retrofit an existing supply chain through the addition/deletion of products, to expand/shut-down production facilities, or to plan operations (Applequist et al., 2000).
- Reemphasises existing research on uncertainty management for industrial firms – that is predominantly studied in relation to manufacturing and product delivery processes (Mason-Jones and Towill, 1998; Van der Vorst and Beulens, 2002) – by considering how uncertainties are factored into industrial service contracts.
- Demonstrates the significant role uncertainty plays in achieving the targets set out in industrial service contracts and servization and the potential opportunity to reduce the environmental impact. This article also presents a framework to address uncertainty in a proactive manner.
- Demonstrates why uncertainty management, within the service transformation context, is important for achieving sustainability.

1.2. Towards sustained transformation

It is necessary to explain the essential ingredients required to better understand of how PSS can potentially lower the environmental impact during transformation. This is because some of these concepts often vary from business to business, leading to confusion and ambiguity within the community. This gives rise to the need to move towards formal discussion and investigation that can enable a common understanding within the subject area. To keep within the scope of this article, the authors have limited the discussion upon the following: how uncertainty management can aid in achieving sustained transformation for servitization. The remaining parts of this section explains in more detail the related concepts.

Servitization is considered as the strategic innovation of an organisation's capabilities and processes to shift from selling products to selling an integrated product and service offering that delivers value in use (Ulaga and Reinartz, 2011; Martinez et al., 2010). In the transformation process, the factoring of supply chain uncertainty into service contracts is an important activity for responding to new requirements for collaboration, technology, coordination, information sharing and so on (Bocken et al., 2014). Table 1, identifies some important differences between product and service supply networks. The key parameters that set the differences between the two types of networks include: nature of demand, required response time, delivery network, product portfolio, number of stock-keeping unit, reverse logistics, and performance metric (Ellram et al., 2004). Poorly prepared service contracts often lead to increased service delivery costs, reduced profits from service operations, and, in severe cases, major risks and losses to companies (Ng et al., 2009). Firms, therefore, need to factor uncertainty into the transformation of industrial service contracts.

Service contracts, as important bases for competition, contain promises to deliver service offering 'during the service period within a certain time limit' (Teunter and Fortuin, 1999) and contracts generally 'set the parameters for the management of performance' (Enquist et al., 2011). In industry, managers are increasingly aware of the limited amount of information that is available to firms for supporting the tendering process for industrial service contracts and that a service contract must reflect the interwoven and complex nature of decisions on service provision (Ng and Nudurupati, 2010; Erkoyuncu et al., 2011; Rojo et al., 2012). In view of this complexity, industrial practitioners often adopt attitudes that can be described as 'reluctant' when agreeing new contracts (Schwabe et al., 2015). However, the transformation

[1] In this case, a service contract formalises the responsibilities, the commitment across the supply chain and the perceived uncertainties Targets are often defined by the customer, however, with more performance oriented contracts, the prime contractor can also influence these targets.

[2] The fixed price contract puts the maximum risk and uncertainty on suppliers and there is the greatest incentive to reduce costs. This type of contract typically does not offer performance incentives.

[3] The cost plus contract offers an opportunity to share savings. This is the scenario where the risk and uncertainty is shared. Furthermore, it is the option that has the least level of incentive to reduce costs.

[4] The performance contract provides the greatest performance-oriented incentive whereby the focus is on achieving the specified targets with moderate risk on suppliers and moderate incentive to reduce costs.

Table 1
Comparison of traditional product-focused manufacturing and service-oriented supply chains (Ellram et al., 2004).

	Manufacturing supply chain	Service supply chain
Nature of demand	Predictable	Unpredictable, sporadic
Required response	Standard, can be scheduled	As soon as possible
Delivery network	Multiple networks	Single network
Product portfolio	Largely homogeneous	Always heterogeneous
Number of stock- keeping unit	Limited	15 to 20 times more
Reverse logistics	Doesn't handle	Handle s return, repair and disposal
Performance metric	Fill rate	Product availability

process is affected by the reluctance in agreeing new industrial service contracts, due to the growing liability of manufacturers for poor estimates of planned service scope and scale (Lay et al., 2009). Furthermore, as progress is made during service provision, supply chain and service exchanges can cause boundaries and upstream-downstream relationships between firms to become blurry or garbled (Ng et al., 2009). These problems can be further compounded if contractual agreements fail to correctly, completely and unambiguously define service roles and transformation activities (Hypko et al., 2010a).

Uncertainty management is central to how firms implement industrial service contracts (Erkoyuncu et al., 2013; Hypko et al., 2010b; Ng and Nudurupati, 2010). This is because supply chains that deliver industrial services are traditionally plagued by uncertainty (Davis, 1993) that poses "decision making situations in the supply chain in which the decision maker does not know what to decide as they are indistinct about the objectives; lacks information about (or understanding of) the supply chain or its environment; lacks information processing capabilities; is unable to accurately predict the impact of possible control actions on supply chain behaviour; or, lacks effective control actions (non-controllability)" (Seuring and Müller, 2008; Van der Vorst and Beulens, 2002). With this in mind researchers have studied and drawn parallels between effective uncertainty management for decision making situations and themes such as self-managed teams (de Jong et al., 2001), service quality expectations due to cultural differences (Donthu and Yoo, 1998; Reimann et al., 2008) and industrial service delivery (Erkoyuncu et al., 2013; Durugbo and Riedel, 2013; Colen and Lambrecht, 2012). Uncertainty among service teams and B2B customers, poses evaluation challenges to establish contractual compliance, and is reduced and avoided through frequent communication among partners to establish and maintain 'tolerance zones' (de Jong et al., 2001; Reimann et al., 2008). A tolerance zone is the minimal level of service acceptable to the customers (adequate service) and the level the customer believes the service should be and can be (desired service). Beyond this zone, customers feel frustrated and innately decrease their loyalty and confidence in firms and supply chains. This tolerance zone is dynamic and has an impact on the level of environmental impact that an organisation has. This study is scoped based on the transformation of IPS^2 literature. Accordingly, it considers uncertainty management for service contracts as a significant means to determining the value of servitization (which influences the environmental consequence), as demonstrated in Fig. 1.

Value is at the centre of the servitization process. Traditionally, manufacturing products were based on efficiency and the creation of economies of scale, value in industrial services can offer new opportunities for innovation, flexibility, differentiation, individualisation and variety (Johnstone et al., 2009; Bowen et al., 1990). Market trends suggest that these new opportunities are increasingly significant factors for commercialisation (e.g. Brohman et al., 2009; Töllner et al., 2011) and sustaining business-to-business relationships (Ryals and Humphries, 2007). Furthermore, envisioned

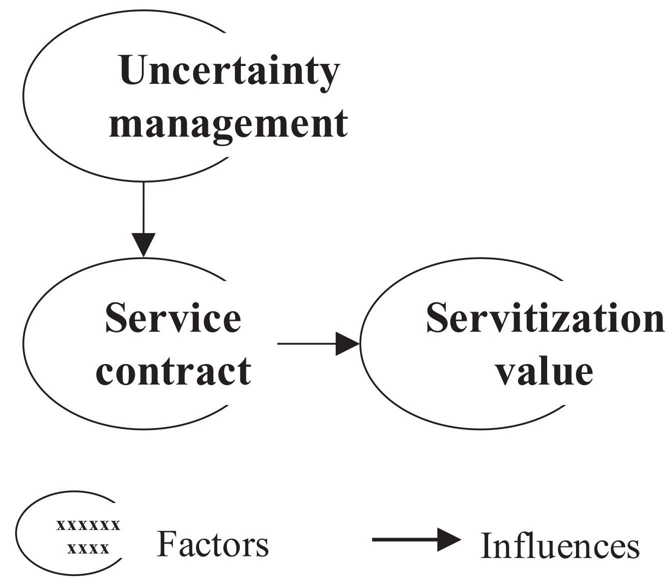

Fig. 1. Research scope.

in the 'New Business for Old Europe', the value of servitization in creating new business opportunities that are environmentally conscious has been touted as a useful avenue for strengthening the position of European companies in value chains thereby making them competitive in relation to low-cost economies such as China (Tukker and Tischner, 2006).

Value from servitization is manifested in the 'win-win-win' (for the manufacturer, customer and environment/government) of service networks (see for instance Baines et al., 2009; Durugbo and Riedel, 2013; Dachs et al., 2014). For suppliers, such as third-party logistics (3 PL) providers, Original design manufacturers (ODMs) and Original equipment manufacturers (OEMs), a win is reflected in profitable service operations that applies lean responses to customer service requirements and realises steady cash flows. The customer on the other hand, benefits from an assortment of systems for service delivery with lower service costs. For the State, environment and society, stems from functional and sustainable consumption/production in which firms design and market results or functions to customers. While the increasing importance of transforming to service offerings is widely acknowledged in academe and industry, existing studies of servitization are limited in their emphasis on uncertainty management in industrial service contracts in terms of evaluating sustainability. In view of the increasing significance on servitization for future production and economies (Baines et al., 2009), the current state of the literature necessitates studies to shed light on uncertainty management for industrial services.

There are numerous value output, however, a growing area of importance is the operational availability of assets. Accordingly, this paper uses the Equipment Available Days (EADs) percentage during a certain planning period, as a measure of availability.

2. Research methodology

The adopted research method; covers the choice of the qualitative research, population and sampling, data collection methods, data analysis, and the data validation. Fig. 2 summarises the research method, whereby an iterative cycle was followed across the project phases including 'Project definition', 'Data collection', 'Data analysis' and 'Validation'.

2.1. Why qualitative research?

To address the research question, the qualitative multiple-case study research method (Eisenhardt, 1989) was applied in an exploratory study involving 7 companies and 21 participants that provide industrial services. This was selected because there was a need to collect primary data due to a lack of published literature in the field.

2.2. Choice of the case study methodology

A case-based research was favoured for two main reasons. Firstly, the study was driven by an initial assessment of the literature which indicated limited insights into uncertainty management for transformation of industrial service contracts and to understand the sustainability implications. This steered the research towards a multi-case approach that was exploratory in nature (Marshall and Rossman, 1999). Thus, uncertainty management for industrial service contracts was viewed as a promising area of research and case studies were used to explore the 'what's' and 'how's' of management approaches that contribute to the management of uncertainty for industrial service contracts (corresponding to the vertical arrow from uncertainty management transformation to service contracts in Fig. 1). Secondly, in comparison to surveys, the qualitative case study research methodology offers a more viable avenue to studying information-rich cases (Yin, 2009). This feature in particular made case studies desirable for shedding light on the uncertainties of transformation that become apparent or prominent during the preparation of service contracts. The study therefore makes use of an exploratory approach that generalises at a level of theory as opposed to statistical representativeness or significance.

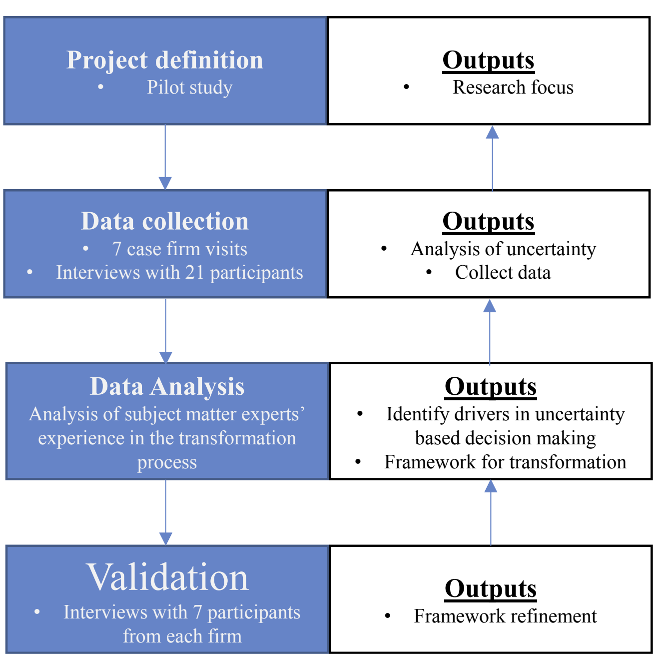

Fig. 2. The adopted research methodology.

2.3. Population and sampling

For this research, participants were purposefully sampled, as is often the case for qualitative studies (Miles and Huberman, 1994), and collected data from seven multinational firms that provide industrial services, as shown in Table 2. The case firms included major employers of industrial service personnel (Avionic Systems, Space Design, Enterprise Services, Aerodynamic Manufacturing, Aeronautic Hardware and Technology Specialists) and a unique case of experts in uncertainty management for decision-making and forecasting of industrial services (Cost Software). Attention was particularly paid to value propositions gained from transformation that are manifested in specific payment plans for pay—on—order, pay—on—availability, and pay—on—capacity levels of service systems (Tukker and Tischner, 2006; Meier et al., 2010). One main servitization strategy adopted by the case firms is: *contracting for availability* (pay—on—order to pay—on—availability) where service providers are paid according to the period of time that assets are made available. This contracting approach is influenced by price, lifespan, geographical and temporal variations for life-cycle inventories and an understanding of the underpinning variations have been viewed by practitioners as important for creating solution-oriented partnerships (e.g. Krucken and Meroni, 2006; Durugbo and Riedel, 2013). Industrial ecologists also consider these variations as crucial to making service-related decisions on energy use and carbon emissions (Williams et al., 2009; Deng et al., 2011).

2.4. Data collection methods

The pilot phase helped with testing and refining questions and further evaluating the scope of the research. The data collection phase involved an iterative process which involved collecting data and sharing the results with the participants for verification purposes. Using questions based on the research model in Fig. 1, semi-structured interviews were conducted with 21 different personnel involved in uncertainty management for industrial service contracts at the case firms in durations ranging from 1 to 4 h *via* face-to-face and telephone conversations at the request of interviewees. In this process, none of the case firms allowed the interviews to be recorded, which resulted in note taking during interviews. The notes taken from the interviews were sent to the participants to verify the collected data. The questions used in the semi-structured interviews were categorised into three key areas in line with the research question:

- Theme 1: What are the uncertainties that are faced in the IPS^2?
- Theme 2: How are uncertainties managed in IPS^2?
- Theme 3: What are the links between uncertainty and sustainability (economic, environment and social) attained from servitization?

Overall, the study composed of 7 case firms that involved over 30 h of semi-structured interviews and workshops. In adopting a semi-structured approach, an attempt was made to strike a balance between structured and unstructured interviews with a view to offering opportunities for interviewees to elaborate and clarify responses where necessary.

Table 2
Overview of case firms.

Case firm[a]	Overview	Size of company	Interviewees (and working experiences)	Interview duration	Industrial services considered for case study
Enterprise Services	Major contract manufacturer interested in acquiring and delivering cost effective (available- and capable) industrial services to end-users	Large (>10,000)	• Through life analysis (33 years) [b] • Programme manager (25 years) • Assistant project manager (22 years) • Project manager (4 years)	2 h with each participant	Outsourcing and data management
Aerodynamic Manufacturing	Original equipment manufacturer with availability and capability contracts for aircraft control systems	Large (>10,000)	• Project manager (25 years) • Cost estimator (31 years) • Reliability engineer (8 years) [b] • Risk specialist (34 years) • Project manager (25 years)	1 workshop (4 h with all listed participants)	Maintenance, spares, data management, and training systems
Aeronautic Hardware	Original design manufacturer that offers subsystem capabilities for aircrafts	Large (>10,000)	• Whole Life Cycle/ Integrated Logistics Support Engineer (5 years) [b]	1 h meeting	Maintenance and testing services.
Technology Specialists	Original equipment manufacturer with availability contracts for aircraft communication and security systems, and capability contracts for design services	Large (>10,000)	• Research director (25 years) [b]	1 h meeting	Consultancy, data management, asset management, training, and testing services.
Cost Software	Design house that models aerospace service cost for clients	Medium (<250)	• Software specialist (20 years) [b]	1 h meeting	Cost estimation, bid preparation and process analysis
Avionic Systems	Original equipment manufacturer with long-term availability contracts for aircraft components to commercial, security and military customers	Large (>10,000)	• Principal reliability specialist (20 years) • Integrated logistics support manager (12 years) [b] • Supportability engineer (18 years) • Systems engineer (26 years) • Risk specialist (18 years) • Project manager (22 years)	1 workshop with all participants (4 h) and follow interviews 1 h with each participant	Maintenance, spares, and radar services
Space Design	Original equipment manufacturer that focuses on availability contracts of aircraft subsystems for civil and defence customers	Large (>10,000)	• Project manager (6 years) • Integrated Logistics Support Manager (30 years) [b] • Design engineer (16 years)	1 workshop (3 h) with all listed participants and 3 sets of 1 h meetings with the project manager	Field services, spares, equipment overhaul, repairs, data management, equipment leasing, and inventory management services

[a] Pseudonyms are used to maintain anonymity and confidentiality of case firms.
[b] Pseudonyms are used for those that were involved in the validation phase.

2.5. Data analysis

Responses taken from the interviews were analysed in line with the research question. To do this, thematic analysis was applied to decipher and interpret common and unique themes from the interview notes (Aronson, 1994; Holloway, 1997; Boyatzis, 1998). As part of this process, notes were iteratively reviewed and meticulously searched through for patterns that would enable themes to naturally emerge from the interview note data. Key concepts from the notes were subject to critical analysis by the authors of this article to determine important (and interesting) themes. The research is therefore positioned within an interpretive epistemology to make sense of uncertainty management for industrial service contracts.

Apart from playing major roles in industrial service projects and supply chains, all sampled firms had dedicated resources – teams, managers and/or software – for analysing, monitoring and controlling service provision phases and costs. The main goal, in line with the research agenda, was to understand how these firms managed uncertainties of servitization that become apparent or prominent during the preparation and delivery of service contracts. Additional emphasis was placed on how case firms factored uncertainty into sustainable delivery of industrial service contracts and identify what sustainable delivery meant.

2.6. Validation methods

Two types of validation was performed. One involved quantitative analysis of the outputs from the framework, embedded in an MS Excel toolkit. This used representative data from 2 defence related case studies for labour and spares resources consumed on servitization projects. The second form of validation of the transformation framework (and the associated data collection methods) was done by 7 industry engineers/managers who deal with uncertainty issues, as highlighted in Table 2. All experts were working in outcome based contracts, and have a combined experience of over 130 years. These participants had also taken part in the pre-data collection phase of this project. In the validation phase feedback was elicited to refine the framework for transformation of industrial services, and the list of uncertainties in IPS^2.

3. Research findings: uncertainties in transformation of IPS^2

The study aims to understand whether uncertainty management can enable sustainable transformation of IPS^2. Here sustainable transformation refers to the economic and environmental impact whilst transforming to a service oriented business model.

3.1. Understanding uncertainties in IPS^2

It was found that the supportability and maintainability and particularly reliability of engineering systems play an important role in the decision-making processes for transforming firms (as aligned with Guajardo et al., 2012). This means that the type of equipment/technology has a direct role in the experienced uncertainty through the reliability, maintainability, and supportability requirements set on the solution provider. The uncertainty in these areas results in varying levels of sustainable transformation across servitized solutions. It was also realised that these factors are often driven by regular reviews of servitization data notions of ownership. System in the context of this paper includes aircrafts, engines, control systems, fuselage and so on. Firms within the sample are posed with service operation quandaries that often require partners to refer back to pre-defined industrial service contracts for access to some initial data. As a rule, internal reviews of contract bids are also undertaken to assess how decisions on the use of service delivery funds are or have been made. Although, access to pre-existing contracts and structured review processes were in place to develop and enhance contract preparation, managers of uncertainty within the case firms generally agreed that actions prescribed within pre-existing contracts or through the use of existing management tools only applied in contractual decisions if they corresponded with their ‘gut feeling’ on how proposed service contracts would contribute to system reliability, maintainability a supportability.

The analysis of data indicates that to apply transformation, company decisions tend to be reviewed and repositioned towards using industrial services to maintain system reliability, maintainability and supportability for customised and innovative system solutions. This in turn influences how sustainable a product-service system is. Guided by these main challenges, case study participant, Cost Software, developed modules in its software packages to model various confidence levels and intervals in the availability and capability of planned industrial services. For case study participants, Enterprise Services, Aerodynamic Manufacturing, Aeronautic Hardware and Technology Specialists, system reliability shaped how firms built service contracts and performance metrics that assure operational hours. The reliability, maintainability and supportability of these systems was also influenced by uncertainties of life-cycle management, industrial problems connected to high-priority client needs (such as aircraft availability and fight hours) and the nature of client/partner B2B contact for industrial service delivery. It also became apparent that the ability to maintain and leverage B2B relationships stipulated in contracts was viewed by firms as a key strategy for competitiveness through their supply chains. Participants observed that, to gain an appreciation of transformation, there is a need to consider and to understand a firm's strategy for maintaining system reliability, maintainability and supportability. Also B2B relationships were referred to grow in importance in particular with regards to approaches that enabled firms to factor uncertainties into industrial service contracts.

It was also found that companies do factor supply chain uncertainty into transforming industrial service contracts and that this factoring is managed through the use of breakdown structures and cost estimates. When considered in a regimented manner these analyses help to make more profitable decisions in preparation of bidding proposals, the generation of price quotes, outsourcing decisions, and selection of an appropriate design alternative and more (in line with). Within the life cycle, operational and support costs have been considered to constitute the most significant portion (in line with). The importance of service contract costing strategies was also a key theme encountered during the data analysis. A growing area of interest was noted in regards to the sustainability of the transformation process. Based on these findings, Table 3 presents the types of uncertainties that were identified across the case studies within the servitized context and presents challenges caused by the shifting responsibilities with transformation.

The significance of uncertainty is in relation to measuring the confidence in meeting targets in: the cost and profitability of delivering industrial product-services, sustained existence of the supply chain and the affordability for the customer. It is recognised that each of these elements can affect the environmental impact. The unique nature of uncertainties in servitization is associated to the shift in the responsibilities of manufacturers or solution providers that puts more emphasis on the data, information and knowledge availability about the equipment/technology reliability over time. The uncertainty in IPS^2 primarily affects the cost, availability and planning the maintenance interventions. The role of uncertainty in IPS^2 is important to understand as they are often are captured through a triangular distribution. The likely actual cost or availability varies from the original estimate and impacts the profitability and the environmental impact of the solution provider.

What is unique with IPS^2 is that it is prone to more dynamic uncertainty originating from multiple sources; particularly from the reliability of equipment/technology. The dynamic uncertainty refers to the variability over time that can come from any of the uncertainties. The dynamic uncertainties also can show interrelated and correlated behaviour that increases the complexity of achieving targets of transformation. As a result industrial product-service firms are faced with a bigger challenge to avoid under or over estimating the cost and/or availability targets. The targets in an IPS^2, are typically to maximise availability and minimise cost and uncertainty. Although, uncertainty could also result in better than expected outcomes, the feedback from the case studies was that the aspiration is commonly to reduce uncertainty. This was considered to be linked to the confidence in delivering the cost and availability targets. This in turn may affect the pricing strategy where a suitable amount of contingency will need to be considered (as in line with Rapaccini, 2015).

4. Uncertainty based framework for sustainable IPS^2 transformation

Within this research, three areas of uncertainty management for industrial services have been studied: challenges for forecasting costs and performance within service contracts, link between uncertainty and resource consumption and adverse uncertainty

Table 3
Types of uncertainty for industrial services.

Case firm	Existing uncertainties	Transformational uncertainties	Key types of uncertainties
Enterprise Services	• Lack of data and through-life performance of products • Affordability of projects	• Left shift in service prediction • Shift in contractual culture	• Whole life cost estimate • Pricing and affordability • Defining appropriate performance levels • Suitability of contract type to equipment and phase in life • Supply chain integration
Aerodynamic Manufacturing	• Enhanced competition • Meeting reliability, maintainability, supportability targets	• Left shift in service prediction • Shift in contractual culture • Increased service responsibility	• Meeting reliability targets • Whole life cycle cost estimation • Lines of maintenance • Equipment utilisation, • Training requirements • Repair turnaround time, • No-fault found rate
Aeronautic Hardware	• Enhanced competition • Meeting reliability, maintainability, supportability targets	• Shift in source of revenue • Cultural shift to deliver service	• Pricing, flying hours • Obsolescence, • Failure rate, • Supply chain integration, • Risk contingency
Technology Specialists	• Enhanced competition	• Left shift in service prediction • Shift in value proposition • Cultural shift to deliver service	• Supply chain integration, • Cost of incentives, • Stock out costs, • Equipment use pattern,
Cost Software	• Enhanced competition	• Shift in value proposition	• Duration of contracts, complexity of projects
Avionic Systems	• Enhanced competition • Meeting reliability, maintainability, supportability targets	• Shift in source of revenue • Left shift in service prediction • Increased service responsibility	• Pattern of equipment usage, • Equipment utilisation, • Failure rate, • Supply chain integration, • Repair turnaround time, • No-fault found,
Space Design	• Enhanced competition • Meeting reliability, maintainability, supportability targets	• Shift in source of revenue • Left shift in service prediction • Shift in contractual culture • Increased service responsibility	• Obsolescence, • Failure rate, • Whole life cost estimate, • Supply chain integration, • Repair turnaround time, • Transport cost,

management attitudes confronted by firms. The findings from these areas reflect the significance of models and tools for supporting uncertainty management but also stress the importance of uncertainty specialists for supporting in-house and external bidding teams. The challenges of forecasting costs also reflect a range of *life-cycle*, *quality, information*, *culture,* and *value* uncertainty peculiar to industrial services. These sources of uncertainty have been summarised in Table 4.

The findings of this study have some useful managerial implications. It identifies costing strategy and system reliability as central to the uncertainty management of industrial contracts for servitization. These factors, as depicted in the strategic framework in Fig. 3, are associated with attitudes that need to be positively and negatively factored into decision making and forecasting processes. A focus on system reliability stimulates an attention to confidence levels/intervals and system obsolescence/models during the tendering process – positively impacting on contractual decision-making processes. In the case firms, software packages (Cost Software) and performance metrics (Enterprise Services, Aerodynamic Manufacturing, Aeronautic Hardware and Technology Specialists) can be developed to assess confidence levels a priori and to establish 'confidence in cost'.

A positive impact on contractual decision-making is also at the heart of an emphasis on costing strategy that drives industrial firms to develop strategic roles/teams and cost databases/estimates. The use of these strategic components, especially with regards to elucidating cost driver and levers, make the identified strategic components an attractive prospect within case firms for strategising industrial service costing. On the other hand, decision-making reluctance and over- and under-estimations are challenges identified within the study that impact negatively on contractual decisions. Both challenges, as suggested by case firm participants, stem from combined foci of system reliability and costing strategy. Contractual decision making for "effective" servitization can result in better environmental consequences.

In all, the findings of the study suggest that due to the interwoven and complex nature of service decisions, the value derived from transformation not only stems from affordable and profitable customer solutions but also on the combined foci of system reliability and costing strategy. These considerations also play an important role in the preparation and use of contracts to servitize. The study also highlights the importance of early deliberations on the nature of obsolescence for technologies and systems that are central to service provisioning. Costing in relation to service contracts also underscores the importance of clarifying uncertainties associated with different service-based costs such as prime costs vs. derived costs from the case findings. Distinctions can also be made with regards to uncertainties of aspects such as cost timing (daily vs. weekly vs. annually) or phase costs (design vs. delivery). These distinctions have implications on whole life cycle costs, which the British Standard Institute, BS5760, has been considered to be the cumulative costs of a product over its life cycle. Many definitions of life cycle costs have been developed, while differences between ideas have emerged associated to the scope. In particular, difficulties have arisen in defining the life of a product. Largely, the life cycle is referred to encompass all stages between conceptual design and disposal, where the very end of the life cycle is also included (Boussabaine and Kirkham, 2004). Estimating whole life cycle costs

Table 4
Sources of uncertainty for industrial services.

Source	Description	Main motivation	Example of indicators from case firms	Practical implication for delivering industrial services
Life-cycle	Variability in stages that mark the life span for enabling and enhancing the use of core products and technologies	Increasing popularity of a plethora of methods targeted at creating segments that capture whole life cycles costs.	• Obsolescence and legacy equipment support • Hardware and software obsolescence • Whole life-cycle management • Equipment management and costs • Aircraft technology and component obsolescence	• Emphasis on through-life and disposal phases for customer solutions. • Manufacturing that is closely knit to service elements
Quality	Inconsistency in actual and perceived levels of reliability	Pressures for servitization and industrial support that delivers reliable functionality, as opposed to product-oriented ownership, in durations typically over 30 year.	• Lines of maintenance • Pattern of equipment usage • Equipment modularity and reuse • Equipment utilisation and management • Aircraft and subsystem failure rate • New avionic systems	• Redefinition and transfer of risks to service providing firm • Understanding and developing designs that reflect high quality services
System (Information and Service)	Unpredictability in the behaviour and structures of systems for managing services and information.	Producers have found themselves offering packages that fulfil customer needs using delivery systems	• Information system failure rate and security • System integration • Service system definitions	• Changing role and responsibility for planned and unplanned service activities • Increased role of information for conducting up-to-date equipment health assessments
Culture	Volatility in the corporate culture and identity of service providing firm	Industrial firms have found themselves ever more cautious of the actual and promised reliability of products	• Training/ retention of service teams • Structure of operations and projects • Changes in organisational culture • Contract timing • Changing end-user needs	• Forming long term relationships (with a win-win emphasis) in parallel with equipment life cycle
Value	Fuzziness of value propositions due to evolving client needs and scope of projects/operations	'Hidden' benefits in provided service function and element.	• Affordability for clients • Profitability for service providers	• Focus on delivering functions that consumer's value, gain better positions in markets

requires a continuous process of forecasting, recording and managing costs throughout the life of equipment with the specific aim of optimising its value. Furthermore, cost or work breakdown structure aid in developing the costing process in a structured manner.

The findings also indicate that obsolescence acts as a key driver for uncertainty management by “product-centric businesses” for services. This is in contrast with demand and supply for manufacturing and product delivery processes (Mason-Jones and Towill, 1998; Van der Vorst and Beulens, 2002). Planning wise, considerations for obsolescence is needed to enhance cost estimates within service contract bids. As mentioned earlier, obsolescence is closely linked to technology uncertainty (Ragatz et al., 2002) and this connection has implications for levels of

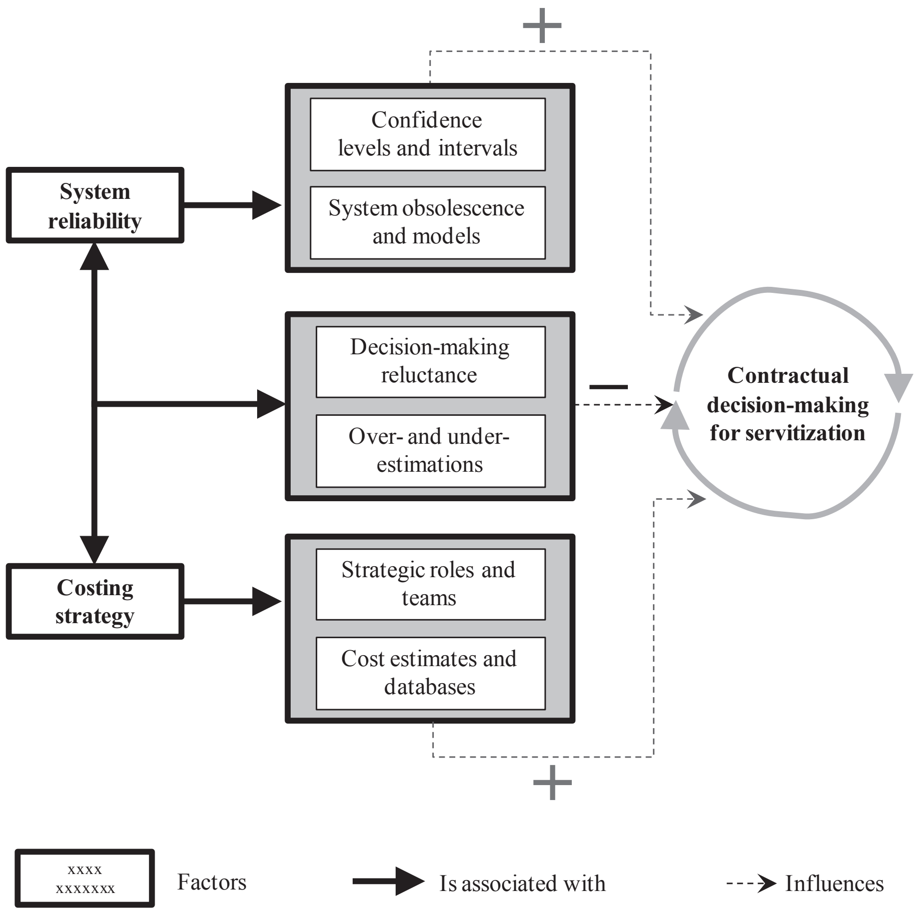

Fig. 3. Strategic framework of uncertainties in sustainably transforming to IPS.[2].

investment in the core technology. Other implications of the study for managers (in view of the importance of 'gut feelings') include factoring obsolescence into service team recruitment/retention strategies, and holistic views of the different life-cycle, quality, information, culture, and value sources of uncertainty for industrial services.

4.1. Formalising the framework

An MSc Excel based software tool was developed that utilises the presented framework. The context for applying the framework is the transformation to availability based complex engineering service solutions. The framework allows to evaluate how managing uncertainty can assist in enhancing resource (e.g. people, spares) efficiency whilst achieving cost and EADS%. The framework is structured in six steps:

Step 1: Insert the lever (e.g. people, spares) cost at different thresholds (input).

This step covers collecting cost related data (e.g. historical or future estimates) that feeds in to the analysis in the framework. The data is collected for different thresholds (e.g. budget, contractual limits). The cost level is estimated based on the labour related resource consumption (e.g. 10 h of effort with a rate of £15). An example input set for Steps 1–3 is demonstrated in Table 5.

Step 2: EADS % value for different thresholds (input).

EADS% captures how many days the equipment will be available for use. The EADs agreed and the maintenance planning must be evaluated in order to accomplish these target days. The term "EADs at risk" is used to define the risk of not obtaining the predetermined EADs. The more money is spent on maintenance, the more chance that the EADs will be achieved or the lower the risk of not obtaining the required EADs. However, an optimum balance between money invested and EADs is needed according to the usage requirements of each type of equipment. Accordingly, as the investment increases, the EADS at risk level decreases as the likelihood of achieving the performance target is more achievable. This step covers collecting EADS% related data (e.g. historical or future estimates) that feeds in to the analysis in the framework. The data is collected for different thresholds (e.g. budget, contractual limits).

Step 3: Insert the target cost figure (input).

This involves an input for the selected cost level that meets the affordability limits and other factors such as labour resource availability of a project.

Step 4: Evaluate the outcome in EADS % at risk (output).

The developed toolkit determines the optimum level of EADS% at risk for the given cost level. This gives the opportunity to compare the EADS% achieved vs the potential EADS% that could be achieved. This then can assist in realising if resources have been wasted in delivering services. The figure below is provided as an example, where by for the planned cost of £148,000, the optimum EADS% is 76%. This is calculated based on the level of benefit in the change from one cost investment to another against the level of EADS % gained. The optimisation considers the return on one unit of investment for each EADS%. Table 6 demonstrates an example EADS % at risk output.

Step 5: Develop values for the Monte Carlo simulation (output).

The uncertainty level is represented through developing a three point estimate. For this the toolkit, determines, the best and worst

Table 5
Example input requirements for the uncertainty management toolkit (Steps 1–3).

Thresholds for levers	Step 1: Insert the lever cost at different thresholds	Step 2: EADS % value for different thresholds	Step 3: Insert the target cost figure
Threshold	COST in £'000	EADS %	PLANNED COST
1	6.000	1.00	5.900
2	5.800	2.00	
3	5.500	3.00	
4	5.200	4.00	
5	5.100	4.20	
6	4.800	6.40	
7	4.400	7.00	
8	4.000	7.80	
9	3.500	9.00	
10	2.000	12.00	

case scenarios for cost and the unit return of availability. Accordingly, as the unit of return diminishes, the toolkit considers that point to determine the minimum cost level. Using the input values used in Figure x, the three point estimate output is calculated as demonstrated in Table 7.

Step 6: Quantify cost and EADS% at risk (output).

This step focuses on measuring the uncertainty level in the estimated cost and EADS % at risk level. This output is important to demonstrate how managing the uncertainty level affects the resource consumption (which is measured through the cost estimation) and the output achieved in the EADS % at risk level. In Fig. 4 an example output is provided to demonstrate how the percentile value captures the confidence in the cost and EADS % values. It also enables to calculate whether improved uncertainty management offers benefits in cost and availability in terms of better returns and higher confidence in achieving targets.

4.2. Case study

This section presents the analysis of two data sets provided by the Ministry of Defence (MoD) UK, for the systems used in land and air domains. These datasets were representative from real-life projects due to sensitivities with sharing the actual data. The first data focused on the resource consumption related to people within a land based systems' maintenance. The second data set focused on the resource consumption in terms of spare parts usage within an aid domain related vehicle. The analysis presented in the following sub-sections is structured to demonstrate how uncertainty management in both case studies had an impact on the cost, EADS% and the confidence in delivering the projects.

4.2.1. Case study 1. people

The case study focused on representing the resource consumption related to people through the cost estimate using a land based systems' maintenance. First, the results for the scenario where there was no uncertainty management in the project will be presented. Thereafter the focus will shift to the case where uncertainty management was applied. The input for these scenarios is based on a unique example with MoD, which involved a change in management in the case study and the impact of uncertainty management was measured using the presented framework. In order to clarify, uncertainty management was considered to include: any type of investments to increase knowhow in maintenance or spares management, intentional increase/decrease in resources consumption (e.g. additional spares or people), or buffer allowed for using facilities or tools.

Table 7
Example values developed for Monte Carlo Simulation.

	VALUES FOR THE MONTE CARLO SIMULATION		
	Max	ML	Suggested Min
COST in £'000	6.000	5.900	5.800
EADS %	1.00	1.50	2.00

4.2.1.1. Scenario 1. before uncertainty management. This scenario focused on data collected from a project with no explicit uncertainty management strategy. In this case a very reactive approach was taken to the maintenance requirements, which meant there were in some cases overtime expenses for people. Fig. 5 shows the input data for cost, EADS% and the planned cost level that was determined based on the budget that was available. Accordingly, for the investment of £78,500 k, the EADS % at risk was 4.38%. Furthermore, the figure also illustrates the three point estimates for cost and EADS % at risk.

Table 6
Example output for EADS % at risk (e.g. 1.5%).

Thresholds for levers	Step 1: Insert the lever cost at different thresholds	Step 2: EADS % value for different thresholds	Step 3: Insert the target cost figure	Step 4. Evaluate the outcome in EADS %
Threshold	COST in £'000	EADS %	PLANNED COST	EADS % EQUIVALENT of the planned cost
1	6.000	1.00	5.900	1.50
2	5.800	2.00		
3	5.500	3.00		
4	5.200	4.00		
5	5.100	4.20		
6	4.800	6.40		
7	4.400	7.00		
8	4.000	7.80		
9	3.500	9.00		
10	2.000	12.00		

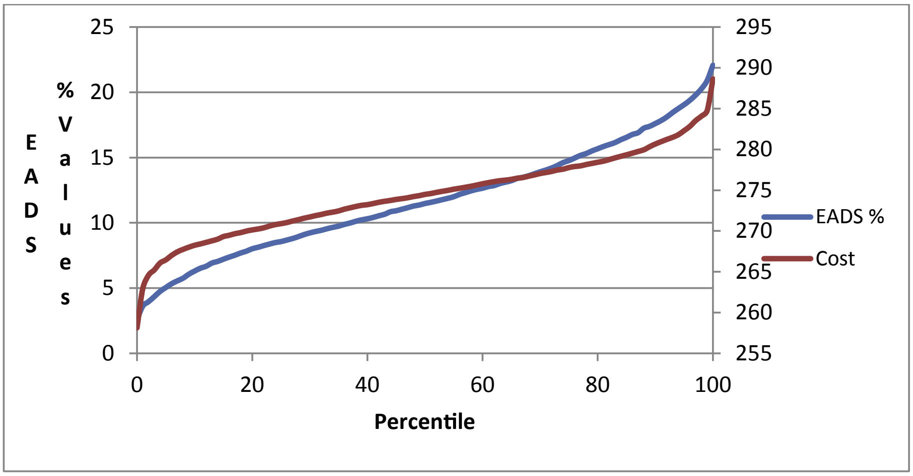

Fig. 4. Uncertainty confidence output in cost and EADS % at risk value.

4.2.1.2. Scenario 2: after uncertainty management. Scenario 2 focused on the case where the organisation actually made explicit plans to manage uncertainty. The organisation identified that the main drivers of uncertainty were related to: dynamic failure behaviour, varying time it takes to get people to an equipment that has failed and varying skill levels of people affecting the turnaround time. Accordingly, as a response the uncertainty management strategy related to people included putting in place the following strategies:

- Further training to the maintenance staff to have a broader level of skills to deliver the maintenance
- Created a new team of two people that predicts when and where failures may happen and to plan for maintenance requirements in terms of people availability
- Investment in navigation technology to reduce the uncertainty in traffic etc to travel to the point of interest for maintenance

The results presented as follows includes the cost investment made in uncertainty management as an aggregation to the people costs. Fig. 6 presents an overview of the Scenario 2 input and output.

4.2.1.3. Comparison of scenarios. The comparison between Scenario 1 and 2 demonstrates that the overall cost and EADS% at risk levels improved with better uncertainty management. Accordingly, when you consider the return of EADS % level for the current state for costs in Scenario 1 and 2 4.78%–1.75% for the same cost level of £78,500 k. This is a significant improvement and offers increased confidence in delivering targets and a better return on investment for the resource consumption level. Fig. 7 shows an overview of the comparison of the scenarios.

4.2.1.4. Case study 1: detailed evaluation of the impact of uncertainty on cost and EADS % (step 6 in toolkit). This step focused on evaluating the uncertainty in cost and EADS % at risk, as represented as

Thresholds for levers	Step 1: Insert the lever cost at different thresholds	Step 2: EADS % value for different thresholds	Step 3: Insert the target cost figure	Step 4. Evaluate the outcome in EADS %	Step 5. EVALUATE THE BENEFIT OF CHANGE
Threshold	COST in £'000	EADS %	PLANNED COST	EADS % EQUIVALENT of the planned cost	BENEFIT RATIO
1	80.000	2.50			25.00%
2	78.000	5.00			11.54%
3	76.000	6.50			26.67%
4	75.500	7.50			71.43%
5	75.300	8.75			90.28%
6	75.000	12.00	78.500	4.38	1.25%
7	55.000	16.00			3.70%
8	52.000	18.00			4.55%
9	48.000	22.00			1.92%
10	40.000	26.00			
	VALUES FOR THE MONTE CARLO SIMULATION			Planned cost - change in benefit ratio by moving 1 unit	0.50
	Max	ML	Suggested Min		
COST in £'000	80.000	78.500	78.000		
EADS %	2.50	4.38	5.00		

Fig. 5. Overview data for Case Study 1 and Scenario 1.

Name of Lever: People: Level 1

Thresholds for levers	Step 1: Insert the lever cost at different thresholds	Step 2: EADS % value for different thresholds	Step 3: Insert the target cost figure	Step 4. Evaluate the outcome in EADS %	Step 5. EVALUATE THE BENEFIT OF CHANGE
Threshold	COST in £'000	EADS %	PLANNED COST	EADS % EQUIVALENT of the planned cost	BENEFIT RATIO
1	80.000	1.00	78.500	1.75	14.29%
2	75.000	3.50			13.89%
3	72.000	6.00			7.14%
4	70.000	7.00			11.11%
5	68.000	9.00			3.62%
6	62.000	11.50			3.33%
7	55.000	15.00			2.08%
8	47.000	18.00			2.04%
9	40.000	21.00			3.13%
10	36.000	24.00			
	VALUES FOR THE MONTE CARLO SIMULATION			Planned cost - change in benefit ratio by moving 1 unit	0.50
	Max	ML	Suggested Min		
COST in £'000	80.000	78.500	75.000		
EADS %	1.00	1.75	3.50		

Fig. 6. Overview data for Case Study 1 and Scenario 2 (Steps 1–5 in framework).

percentile, using the Monte Carlo simulation. The results are divided for Scenario 1 and 2.

4.2.1.5. Scenario 1. before uncertainty management. Fig. 8 illustrates the confidence in achieving cost (vertical right hand side) and EADS % (vertical left hand side). As an example at 60 percentile, the cost is estimated to be £78.900 k and the EADS % at risk at 4.03%. The figure at 80 percentile, the cost is estimated as £79.220 k and EADS

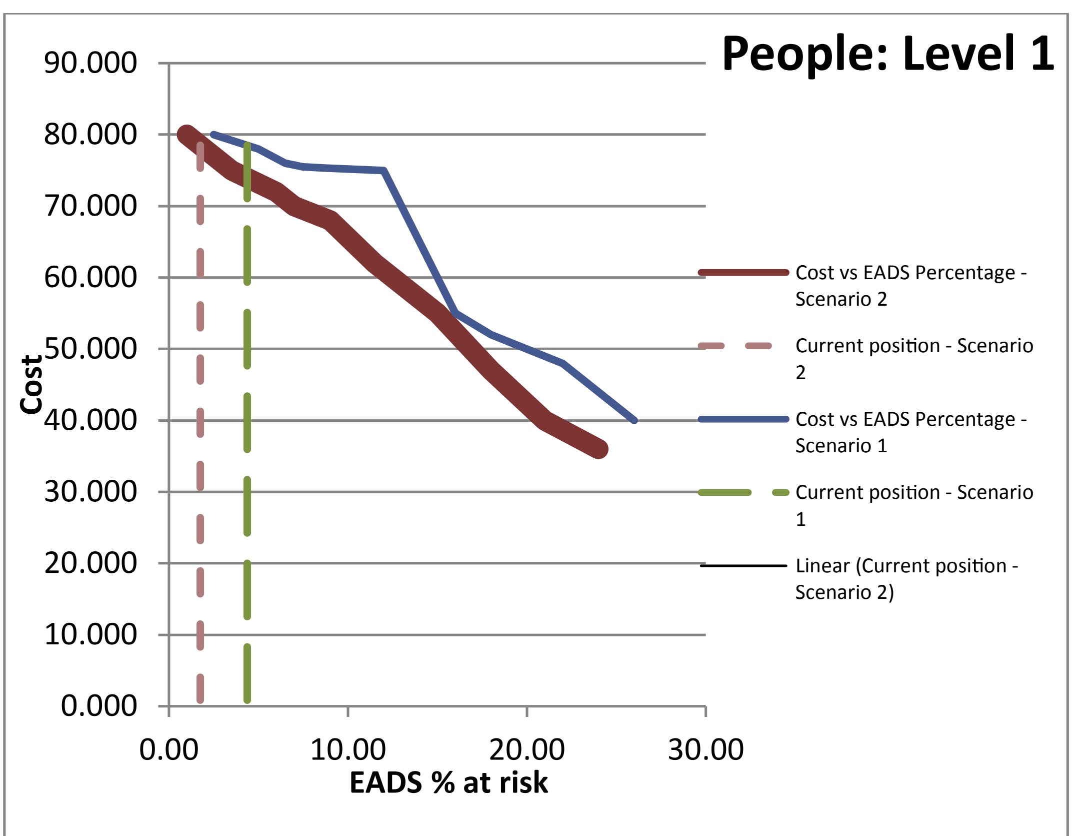

Fig. 7. Comparison of Scenario 1 and 2 outputs (Step 5 in framework).

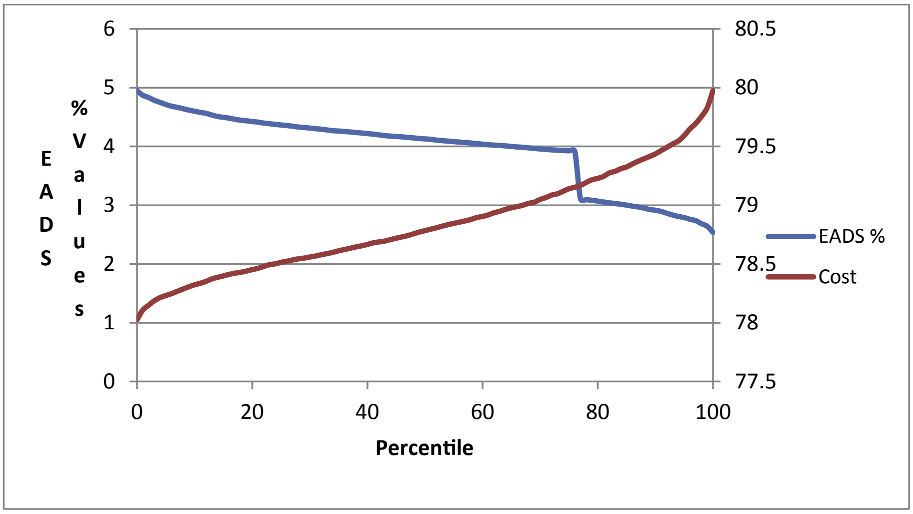

Fig. 8. Case Study 1: Confidence in estimates for Cost and EADS % at risk for Scenario 1 (before uncertainty management implemented).

% at risk at 3.06%.

4.2.1.6. Scenario 2. after uncertainty management. Scenario 2 focused on the case where an uncertainty management strategy was implemented, as described above. The results demonstrate that the confidence at 60 percentile for cost is £78,230 k and the EADS % at risk is 2.30%. At the 80 percentile level the cost figure £78,800 k and the EADS % at risk is 1.91%. These results shows that, compared to Scenario 1 at the same level of confidence, the implementation of uncertainty management has resulted in a reduction in cost (less people resources used) and an improvement in the performance outcome with the EADS % at risk figure (higher likelihood of equipment availability). Further detailed results for Case Study 2 are shown in Fig. 9.

4.2.2. Case study 2: spares

Case study 2 focused on the spares consumption within an air domain related vehicle. The focus was on costs of spares for break system per annum. Accordingly similar to case study 1, the same structure to present results are followed in this section.

4.2.2.1. Scenario 1. before uncertainty management. This scenario focused on data collected from a project with no explicit uncertainty management strategy. In this case a very reactive approach was taken to the spares requirements, which meant there were in some cases a need to buy parts very expensively due to the urgent need for the break system. Fig. 10, shows the input data for cost, EADS% and the planned cost level that was determined based on the budget that was available. Accordingly, for the investment of £33,000 k, the EADS % at risk was 0.93%. Furthermore, the figure also illustrates the three point estimates for cost and EADS % at risk.

4.2.2.2. Scenario 2. after uncertainty management. Scenario 2 involved implementing a number of uncertainty management strategies for spares requirements. In the case organisation, the current challenges related to spares included:

- Lack of up to date information about spare parts availability
- Lack of prediction of equipment reliability and spares requirements over time
- Lack of engagement with suppliers about collecting information for obsolescence

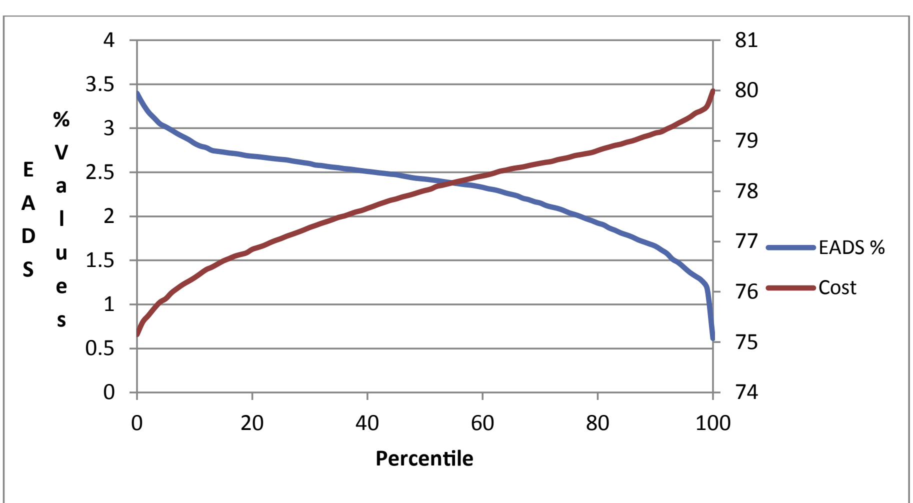

Fig. 9. Case Study 1: Confidence in estimates for Cost and EADS % at risk for Scenario 2 (after uncertainty management implemented).

Name of lever: Spares: Level 1

Thresholds for levers	Step 1: Insert the lever cost at different thresholds	Step 2: EADS % value for different thresholds	Step 3: Insert the target cost figure	Step 4. Evaluate the outcome in EADS %	Step 5. EVALUATE THE BENEFIT OF
Threshold	COST in £'000	EADS %	PLANNED COST	EADS EQUIVALENT of the planned cost	BENEFIT RATIO
1	34.000	0.75	33.000	0.93	15.91%
2	32.000	1.10			5.36%
3	28.000	1.40			5.56%
4	24.000	1.80			14.00%
5	22.000	2.50			37.50%
6	21.000	4.00			33.33%
7	20.000	6.00			12.50%
8	18.000	8.00			11.67%
9	14.000	15.00			10.53%
10	12.000	19.00			

	VALUES FOR THE MONTE CARLO SIMULATION			Planned cost - change in benefit ratio by moving 1 unit	0.00
	Max	ML	Suggested Min		
COST in £'000	34.000	33.000	32.000		
EADS %	0.75	0.93	1.10		

Fig. 10. Overview of data for Case Study 2 and Scenario 1.

Accordingly, an overview of the uncertainty management strategies included:

- Investment in software to have better reporting of spares usage and storage
- Recruited an obsolescence management lead
- Training for people involved in spares procurement

Fig. 11 presents an overview of the data Steps 1–5 in the presented toolkit for Scenario 2 for Case Study 2.

4.2.2.3. Comparison of results. The comparison of results between Scenario 1 and 2 for Case Study 2 is presented in Fig. 12. It can be observed that with Scenario 2 there is an improvement with the Cost vs EADS % at risk level. It can also be observed that in Scenario 2 for the same cost level the EADS % level is lower, which demonstrates a higher level of likelihood of achieving the performance targets.

4.2.2.4. Case study 2: detailed evaluation of the impact of uncertainty on cost and EADS % (step 6 in toolkit). This step applied the Monte Carlo simulation. The results are divided for Scenario 1 and 2.

Scenario 1

Fig. 13illustrates the confidence in achieving cost (vertical right hand side) and EADS % (vertical left hand side). As an example at 60 percentile, the cost is estimated to be £33,104 k and the EADS % at risk at 0.96%. The figure at 80 percentile, the cost is estimated as £33,370 k and EADS % at risk at 0.86% (see Fig. 13).

Name of lever: Spares: Level

Thresholds for levers	Step 1: Insert the lever cost at different thresholds	Step 2: EADS % value for different thresholds	Step 3: Insert the target cost figure	Step 4. Evaluate the outcome in EADS %	Step 5. EVALUATE THE BENEFIT OF
Threshold	COST in £'000	EADS %	PLANNED COST	EADS EQUIVALENT of the planned cost	BENEFIT RATIO
1	34.000	0.50	33.000	0.55	6.25%
2	28.000	0.80			11.11%
3	27.000	0.90			8.33%
4	24.000	1.20			16.67%
5	22.000	1.80			35.71%
6	21.000	2.80			39.13%
7	20.000	4.60			19.33%
8	18.000	7.50			9.11%
9	14.000	11.80			4.66%
10	10.000	14.50			

	VALUES FOR THE MONTE CARLO SIMULATION			Planned cost - change in benefit ratio by moving 1 unit	0.00
	Max	ML	Suggested Min		
COST in £'000	34.000	33.000	27.000		
EADS %	0.50	0.55	0.90		

Fig. 11. Overview of data for Case Study 2 and Scenario 2.

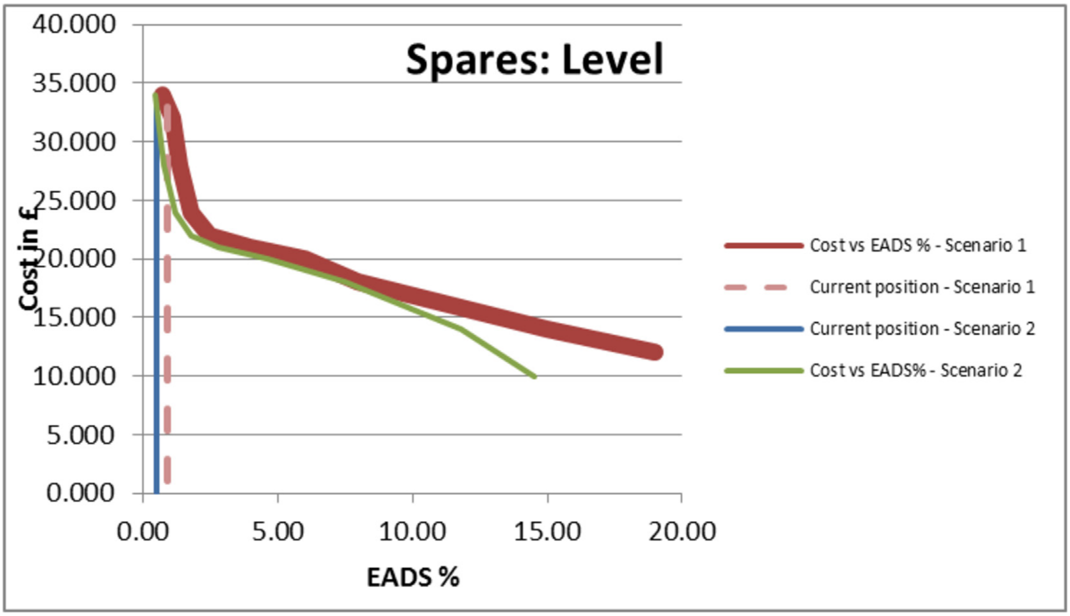

Fig. 12. Comparison of results for Case Study 2 for Scenario 1 and 2.

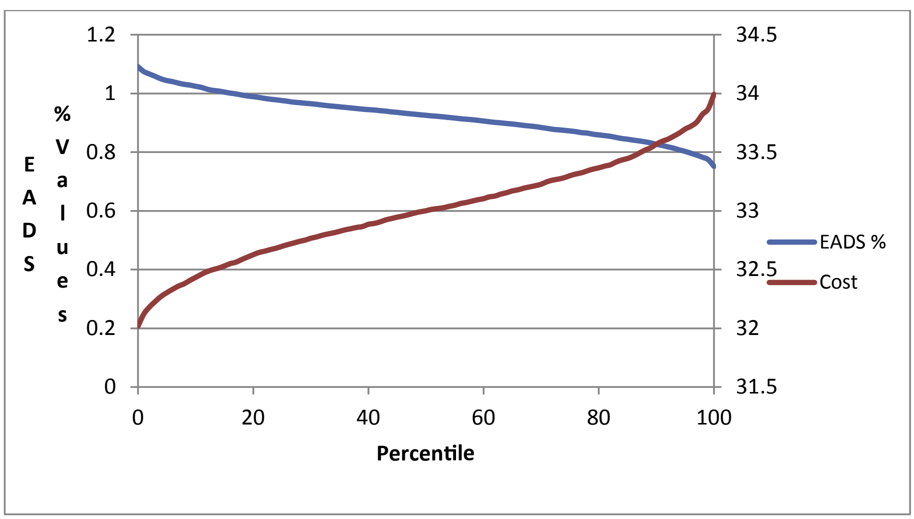

Fig. 13. Case Study 2: Confidence in estimates for Cost and EADS % at risk for Scenario 1 (before uncertainty management implemented).

Scenario 2

Scenario 2 focused on the case where an uncertainty management strategy was implemented, as described above. Fig. 14 demonstrates the results that the confidence at 60 percentile for cost is £32,078 k and the EADS % at risk is 0.61%. At the 80 percentile level the cost figure £32,806 k and the EADS % at risk is 0.56%. Similar to Case Study 1, the results shows that, compared to Scenario 1 at the same level of confidence, the implementation of uncertainty management has resulted in a reduction in cost (less people resources used) and an improvement in the performance outcome with the EADS % at risk figure (higher likelihood of equipment availability).

Both case studies demonstrated that the sustainability of service transformation can benefit from uncertainty management. Particularly, reliability and cost came out as key drivers in the transformation process and these would benefit from uncertainty management.

4.3. Qualitative validation feedback

The methodology behind the validation of the proposed framework was described in Section 3 (under 'Validations methods'). Accordingly through interviews with seven industry experts it was possible to review and update the research findings. A summary of the results from the validation is provided below:

- framework for transformation of industrial services: various factors such as (e.g. environmental conditions were considered to be part of the system reliability concept) were removed on the basis that they are already covered at the higher level. Additionally, it was highlighted that more emphasis needs to be put on the contractual approach undertaken and how that influences the sustainability.
- the list of uncertainties in IPS[2]: most importantly, the concepts of 'culture' and 'value' were added. From the perspective of

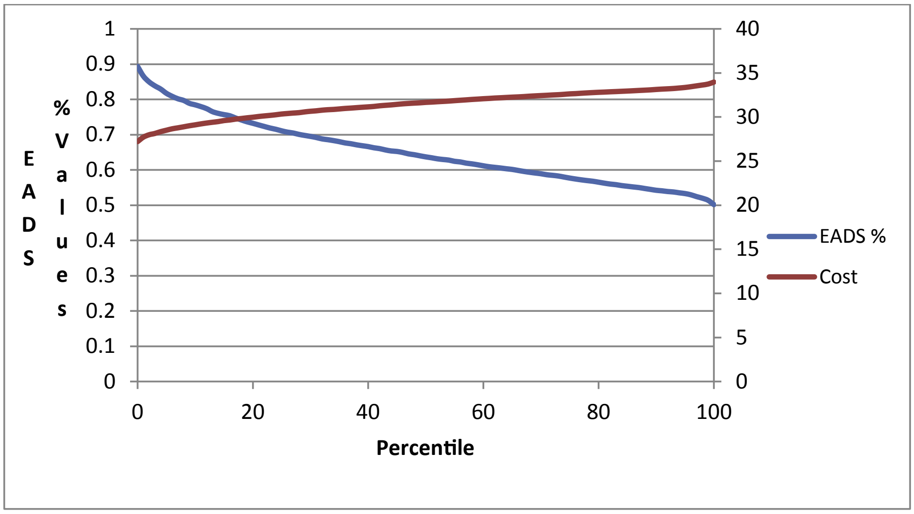

Fig. 14. Case Study 2: Confidence in estimates for Cost and EADS % at risk for Scenario 2 (after uncertainty management implemented).

culture it was possible to capture the role of organisations and individuals in creating and measuring uncertainty. In terms of 'value' it became apparent that the term value has different meanings to the customer and the solution provider. In particular the uncertainty associated to the evolving solutions that the customer requires was captured as an addition to the list of uncertainties.

- the toolkit offers an effective approach to estimate the value of investing in uncertainty management and for evaluating its benefits.

5. Discussion

Literature (e.g. Youngdahl and Loomba, 2000; Sääksvuori and Immonen, 2008) suggests that more and more manufacturers are shifting their focus from selling goods and equipment to transform processes that deliver customers solutions. The evidence also indicates that the sustainable success of these solutions is influenced by arrangements and foci that are life-cycle oriented, high quality and information intensive. This makes service contracts vital to decision making for sustainable industrial servitization under uncertainty. Thus, this study sought to answer the question: Can industrial firms sustainably servitize and how can they realise this? Driven by the research programme and findings presented in the previous sections, this section now discusses the research's theoretical contributions and managerial implications.

An important factor that triggers a change in the uncertainties is the enhanced future emphasis in service oriented contracts. The uncertainties for the OEM are exacerbated with the need to look-ahead over a long duration of time. In such contexts, uncertainty is even more so driven by both lack of information and poor timeliness of its availability. The transformation process promotes the need to look ahead much earlier than the traditional context of selling spares. Furthermore, the shift in value co-creation over the long term due to supply network engagement and dynamic equipment behaviour creates additional challenges in transformation. As a results, the support solution is often more uncertain than provision of a product centric solution, which leads to challenges with managing resource efficiency, and sustainability.

The article makes four useful contributions. First, the article identifies that uncertainty management can be a major factor in the tendering and use of service contracts to realise servitization for industrial firms. This was further demonstrated through two case studies. Although the significance of contracts for servitization and challenges of limited information to support tendering processes has been highlighted in the extant literature (e.g. Ng et al., 2009; Erkoyuncu et al., 2011), there is a need for insights into mechanisms for factoring uncertainty management into service contract. Along these lines, this research focused on the tendering of contracts for servitization, and grounded on literature, identified the value derived from transformation as the culmination of uncertainty management for service contracts.

The second useful contribution of the paper is the identification of equipment reliability and cost as key determinants for how service contracts are used to realise servitization. In the case studies that led to the development of the framework, service reliability is reflected in suggestions that the 'gut feelings' domain experts is prioritised even though work breakdown structures and cost estimates play a major role and how servitization data is intrinsically presented. Costing strategy on the other hand, was captured in the research through different perspectives that attempt to capture a holistic view of service costs. Examples of strategies for realising this holistic view include roles and teams for generating cost estimates, obsolescence management strategies, closely working with clients, and the use of systematically generated documents.

Using insight from the case firms, the article makes a third contribution with regards to identifying service contract problems that cause uncertainties of industrial firms to surface or become more apparent. As suggested in the extant literature, uncertainty poses a quandary for firms – causing forecasts and decisions to be made with difficulty (Applequist et al., 2000; Datta and Roy, 2011). With this in mind, the goal of most studies have been to categorise uncertainty sources and to develop mathematical optimisation models and pure modelling tools to aid managers in predicting and making strategic choices (e.g. Applequist et al., 2000; Niranjan and Weaver, 2011).

The article makes an important fourth contribution by demonstrating how uncertainty management can help to increase resource efficiency, which can enable the sustainable transformation to services. The developed framework was implemented on two case studies from the defence sector, which focused on resources (including people and spares usage). The results show that by managing uncertainty, there can be three areas of improvement: 1) cost improvement, 2) performance improvement (e.g. availability and reliability increase), and 3) improved confidence in achieving targets. By improving the way resources are used, the performance and cost can also be improved and there can be environmental benefits with less material (i.e. mass) and energy usage.

6. Conclusions and future work

There is a knowledge gap regarding the bridging and successfully realising sustainable organisational transformations and innovations. As a result, there is a lack of frameworks and tools that can be used to enable project managers, practitioners and strategic designers in designing and managing the process of sustainable PSS. The research presented in this article aimed at addressing this problem and, in particular, attempts to discuss issue on: how a servitization transition framework can be designed and managed to achieved sustainable PSS?

This paper takes the perspective that uncertainty management, can contribute to the sustainable transformation to services. To tackle sources of uncertainty within product and manufacturing, product-centric businesses within industrial service supply chains and networks need to strategise contracts for servitization. This is to sustain the life-cycle, quality, information, culture, and value uncertainties of solution-oriented partnerships that cooperatively discover, design and deliver services, and reliability-driven value propositions. Frameworks are hence required for managing the transition paths to progressively develop, foster and promote transformations. In this context, this article offers insights from a sociotechnical experiment using a multi-case study into how industrial service providers use industrial service contracts to sustain and manage uncertainties of servitization; that become apparent (or prominent) during the preparation of service contracts. The work highlighted has furthered knowledge in the following:

- This study identified that organisations do factor uncertainty into sustainable industrial service contracts. This is managed through the use of breakdown structures and cost estimates.
- Case firms used breakdown structures and cost estimates to initially build service contract bids and to subsequently act as reference points for making decisions on the use of service delivery funds. The bidding process for industrial services offers limited amount of time to make in-depth analysis of the uncertainties that influence whole life cycle and through-life cost drivers. Moreover, gaps can occur between uncertainty management for *system reliability* and the consideration of uncertainty in service cost estimation that drives *costing strategy.*
- A need for integrating these two concepts has been identified specifically for the bid phase and factors for contractual decision-making to realise servitization are recognisable. However, subjectivity is present throughout the cost uncertainty management process (e.g. uncertainty identification, prioritisation and mitigation). This can create ambiguity with the analysis, and with a lack of data management strategies in place, it can cause inefficiencies in firms. Insights from the multi-case study also suggest a need for cultural shifts towards long term collaborative relationships across the service supply networks with joint targets.
- The paper also identified that uncertainty management can improve on resource efficiency (e.g. labour and spares usage) and increase the confidence in achieving performance targets. This can offer an important shift towards understanding the dynamic nature of attaining sustainability given the influence of uncertain factors.

Sustainable transformation is causing changes in perceptions towards uncertainty and in prioritising areas that need to be managed. This is mainly associated to the changing and dynamic end-user needs, affordability of clients and the contract duration that promotes long term performance-oriented targets. Such changes are highly promoting new approaches to the design of hardware (e.g. equipment modularity and reuse) and software (e.g. due to obsolescence issues), whole life-cycle management and equipment utilisation and management. Challenges experienced with the predictability of cost for service contracts are also becoming more prominent largely due to the dynamic nature of service provision. This is associated to the changing nature of the customer requirements particularly at the early stages (e.g. performance targets, service system definitions). Furthermore, this creates challenges with estimating the lines of maintenance, structure of operations and projects, and in turn in determining the profitability for service providers.

There is an expectation that the delivery of service-based solutions is to grow over the coming future. This further enhances the need for better handling uncertainty in the in-service phase for sustainable transformation of outcome-based contracts. For future research, initially a link between uncertainty, system reliability, costing strategies and delivering value needs to be formed. Furthermore, there is need for research and tools that demonstrate the application of methodologies to manage cost uncertainty. Also, for future research, there is a need to address the sustainable transformation issues faced in organisational culture that stem from servitization. This will be facilitated by developing a willingness to adhere to the customer specified performance requirements, by reducing adverse uncertainty management attitudes.

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