

Mapping a product-service-system delivering defence avionics availability



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ABSTRACT

Long-term support agreements such as availability-based contracts are often associated with the servitization of business models in such sectors as defence aerospace. In practice, there is no unambiguous way of linking availability and service outcomes from an operational perspective; rather, the focus tends to be placed almost exclusively on product-related metrics. To address this gap, this paper outlines a conceptual model of how advanced service outcomes should be delivered under an availability-based contract for defence avionics. The model is grounded on empirical evidence gathered through an in-depth case study in the UK defence sector. The research is one of the first attempts to shift the focus away from a notion of availability as a property designed into a piece of equipment, and to detect its emergence from the interactions between relevant socio-technical elements within the underpinning advanced service delivery system, or Product-Service-System (PSS), identified by analysis of empirical data. This research provides insights into where action should be taken within a PSS that would be difficult to obtain from the analysis of field reliability data alone. It also provides a conceptual model that can assist the formulation of scientific models based on quantitative data such as multi-echelon inventory systems for repairable items. While the transferability of the findings is limited by the specificity of the case, a detailed description is provided to facilitate comparison with other cases.

1. Introduction

Over the past decades defence industrial supply systems across Europe and US have changed from having a pyramid structure with discrete tiers to interdependent supplier networks. The forces driving this transformation include an increase in outsourcing and a decrease in the number of adversarial buyer-seller relationships adopted as part of governments' procurement processes; a reduction in manufacturing capability across the defence industry supply base; and the increasingly transnational nature of equipment development and production projects (Dowdall, 2004). Former upper tiers are now incentivised to take responsibility for how their products perform in the field rather than 'on the whiteboard'. For example, following the 2013 spending review the UK Ministry of Defence (MoD) shared with industry the challenge of reducing the cost of warship repair, maintenance and dockyard operations by signing innovative in-service support contracts worth £3.2Bn with BAE Systems and Babcock (MoD, 2015).

Availability-based contracts are incentivised contractual mechanisms that challenge an incumbent business model in such fields as

defence aerospace, where an asset (an aircraft, an aircraft engine, etc.) that fails to deliver its functionalities in the field is the source of additional streams of revenue through aftersales support (Caldwell and Settle, 2011). Examples include a recent £112 m extension of the availability-based in-service support contract for the UK Royal Air Force's (RAF) Eurofighter Typhoon fleet (BAE Systems, 2015), and a £420 m amendment to the Chinook through-life support contract to cover in-service support for the next five years while ensuring high levels of availability (MoD, 2015).

The concept of availability as an objectively observable indicator was originally developed in the field of reliability engineering and is implicitly adopted for the formulation and execution of availability-based contracts (Kashani Pour et al., 2016). For example, in outlining a business case for avionics prognostic health monitoring equipment Jazouli and Sandborn (2010) define availability as: "... the probability that a [technical] system will be able to function when called upon to do so." Although the specific analytical expression of availability may vary it is commonly understood that such features as reliability and maintainability are designed into individual technical systems and

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must act as the point of focus for the analysis. This analytical approach typically identifies causal links between availability growth and interventions in technical systems such as design reviews. While reviewing the design of a technical system may improve reliability under test-rig conditions it does not guarantee *per se* that the number of support interventions demanded on average by an item in the field will decrease. For example, extensive analysis of field reliability data obtained from a defence avionics case demonstrates that a multi-organisation logistic support system involved in the execution of an availability contract was facing, on average, a growing number of interventions per item despite an improved product design (Settanni et al., 2015). Evidence therefore suggests that the traditional view of availability as a property designed into a technical system should be complemented by an exploration of how the organisations that operate along the support chain contribute or fail to contribute to a diversity of capabilities to achieve the shared objective of maintaining a technical system in an operable and committable state (Hollick, 2009).

Shifting the focus away from purely technical systems, Baines and Lightfoot (2013) suggest that availability is a type of *advanced service*, and that the system of operations by which such a service is provided, called Product Service Systems (PSS), is as important as the service offering itself. This challenging view of availability as a service output of a PSS imposes a distinction between retrospectively computing an availability indicator which determines, based on its interpretation, whether contractually agreed levels of performance are delivered or not, and proactively providing an advanced service. Regardless of the service outcome it delivers, a PSS typically encompasses both technical and social elements (Morelli, 2002; Meier et al., 2010a). The technical elements of a PSS are regarded as a means to achieve ends rather than as the point of focus of the analysis (Settanni et al., 2014). In practice, investigating the system which delivers an innovative availability-based support solution rather than the asset being supported can be a challenge (Kapletia and Probert, 2010; Ng et al., 2011). The importance of achieving operational alignment across multiple organisations to successfully deliver under an availability-based contract may be disregarded even by the parties involved (Ng et al., 2013). Greater attention is paid to the design and theoretical refinement of contractual mechanisms (Selviaridis and Wynstra, 2015).

Following calls for more empirical research on PSS modelling (e.g. Cavalieri and Pezzotta, 2012), this paper assesses the performance of a PSS under an availability-based contract using a case based approach on a real-world industrial setting. It shows that it is a complex process requiring detailed exploration and analysis, which cannot be adequately captured by quantitative data alone. The analysis of a conjunction of causal mechanisms in the production of a given outcome is recognised in the organisation-orientated literature (e.g. Mills et al., 2013; Ng et al., 2011; Perrow, 1984). The novelty of the research presented in this paper lies in the identification through empirical evidence of causal conjunctures that complement product-related quantitative data and the visualization of this evidence through mapping techniques to support the underlying narrative of what the delivery of availability as an advanced service 'looks like' in a real-world case. These two activities taken together form an overall act of appreciation which qualifies as *conceptual modelling* (Sagasti and Mitroff, 1973; Becker et al., 2010). A conceptual model structures and delimits the areas of concern for the analyst with regards to a problem situation in a defensible way (Wilson, 2001). Although seldom made explicit and formalised, conceptual models deeply affect how scientific models are formulated, solved, implemented and validated (Sagasti and Mitroff, 1973). For example, the through-life costing methodology described by Settanni et al. (2014) explicitly requires a conceptual model of the PSS to derive a blueprint for the attribution of costs to multiple service outcomes. Hence, not only does a defensible conceptual model provide insights in its own right, but also it is a valuable premise for mathematical modelling. The conceptual model outlined in this paper is a complement, not an alternative to the

assessment of availability from quantitative data about technical systems, since it explores *how* the delivery of availability as an advanced service is realised in an industrial setting.

The following research questions are addressed:

- 1) *How* is availability delivered as an advanced service outcome under an availability-based contract in an actual industrial context?
- 2) Which aspects of the delivery of such an advanced service can be represented?

In order to provide focus in terms of an approach to investigate the outcomes of systems that are socio-technical in nature, preference is accorded to insights from the literature on accident investigation as well as on availability-based contracts and PSS modelling. Empirical evidence is gathered through an in-depth case study on avionics support under an availability-based contract in the UK defence sector. A conceptual model of the PSS of interest is then outlined through the analysis of the qualitative data obtained.

The rest of this paper is structured as follows. Section 2 summarises the literature on current approaches to investigate and represent PSS with a focus on the business model introduced by availability-based contracting. In Section 3 the research approach is presented and the case study setting is outlined. Findings from the case study are presented in Section 4, and their implications are discussed in Section 5. The paper closes highlighting limitations of the proposed approach and further work needed.

2. Literature overview

Availability-based contracts are specific forms of a broader category known as performance-based contracts (PBC). Providing a state-of-the-art in PBC research is outside the scope of this research, and is dealt with elsewhere (Selviaridis and Wynstra, 2015). Availability-based contracts are typically associated with the servitization of business models in sectors such as defence aerospace. For example, making reference to ATTAC (Availability Transformation: Tornado Aircraft Contract) a 'complex engineering service system' conveys the concept that value is created 'in-use' through the interaction of processes, people, technology and assets under availability based contracts (Ng et al., 2011).

From an operational perspective there is no unambiguous way of linking 'availability' and 'service outcome'. For example, in a servitized business model the cost of providing a service is often understood to be the expenditures incurred over the in-service phase of a durable product due to the occurrence of failure, as in traditional through-life costing models (Settanni et al., 2014). While some views on availability suggest a link with service outcomes they remain anchored in evidence gathered through product-related quantitative data only. Examples include Rijdsdijk (2013), who regards availability as a quality indicator which relates the performance of a product in fulfilling an intended purpose to its inherent ability to do so; Zio (2009), who introduces the concept of 'service availability' and highlights that availability is attained through the interaction of human, organisational and technical systems; and Houghton and Lea (2009), who report on the implementation of an availability-based contract for military vessels. Even works that conceptualise availability as an advanced service favour product-related metrics (e.g., Baines and Lightfoot, 2013).

Case study research on availability-based contracts has helped broaden the scope of the analysis beyond individual assets. However, such research is seldom concerned with outlining a formalised representation of a PSS that delivers availability as an advanced service. Mills et al. (2013) present a case study in defence aerospace and map the key actors involved in the execution of an availability contract through an Enterprise Image. Case studies are carried out in a similar context by Datta and Roy (2011) to outline a framework to support the implementation of an operations strategy, and by Kapletia

and Probert (2010) to map and characterise business solution models for customer support. Selviaridis and Norman (2015) present an empirical case study to examine PBC design, although the object of investigation is the provision of logistic services rather than availability.

Literature on the adjacent topic of PSS modelling is growing. Reviews have emphasised such aspects as information flows (Durugbo et al., 2011); design (Vasantha et al., 2011); mathematical modelling (Phumbua and Tjahjono, 2012); and conceptual modelling (Becker et al., 2010). Regardless of their specific application to PBC and availability-based contracts, a common oversight in PSS models is that they are rarely underpinned by empirical research, and adequately formalised to address the inherent ‘systems’ nature of a PSS (Cavaliere and Pezzotta, 2012). Models of a PSS in the context of availability-based contracts are not uncommon for design purposes. Works that outline primarily mathematical models emphasise product reliability metrics and costs, and use loosely formalised diagrammatic representations as conceptual models of the PSS (see e.g., Kyösti and Reed, 2015; Kimita et al., 2012). Meier et al. (2010b) model a PSS with emphasis placed on the IT infrastructure whereby a network of software agents is involved in delivering industrial machinery support under PBC. Although without reference to PBC Zhu et al. (2012) also model the IT infrastructure of a PSS applying a formalised conceptual modelling language, IDEF0, to a case in aerospace maintenance.

Few conceptual models of PSS are grounded on evidence gathered through case study research and none are primarily concerned with availability provision. Biege et al. (2012) adapt an existing business process mapping technique to derive an industrial service blueprint in a case study concerning a machine tool manufacturer seeking to expand its offering to services. Though they do not use a formalised representation technique, Lockett et al. (2011) explore how the relationships between companies that deliver a bundle of product and repair services change in moving from a traditional supply chain to a ‘PSS supply chain’. Non-formalised representation techniques are also used by Evans et al. (2007) in a multiple exploratory case studies to support the design of a PSS in the agri-food sector.

Finally, in the reviewed literature conceptual models, mathematical models and case studies are treated as ‘silos’ and rarely interact with each other. Exceptions could only be found outside the topic areas of interest for this research. For example Schulze et al. (2012) employ case study research to derive the relevant characteristics of a construction supply chain for use as a basis for an inter-organisational Activity-Based Costing (ABC) system. Hansen and Grunow (2015) use evidence from case study research to outline a mathematical model of the supply chain of a pharmaceutical product before it is launched.

3. Materials and methods

One may argue whether a PSS can be regarded as a tangible, indisputable object of analysis. Since the elements of a PSS are social and technical in nature even the formulation of the problem situation can be a challenge, and the term *system* more appropriately designates a way of thinking about the phenomenon of interest than some well-defined entity (Wilson, 2001). The need to obtain knowledge about an ill-defined situation brings the methodological questions to the fore (Flood and Carson, 1988), and subordinates the selection and application of methods to how such questions are answered (Harrington, 2005). In the following sub-sections methodology is dealt with first, then the industrial setting investigated is described, and the method used is introduced.

3.1. Methodology

Unlike works which adopt an exclusively mathematical approach to availability, mapping a product-service-system delivering availability as an advanced service presents the distinct challenge of how to shift the focus away from purely technical systems so that additional insights

which complement those provided by product-centric formulations of availability can be gathered. This task is challenging because different methodological stances may be taken in researching systems which include both social and technical elements. One such stance is to regard these systems as complex adaptive systems to be approached chiefly by quantitative data modelling. For example Sayama et al. (2013) model rescue operations as adaptive networks. Similarly, supply chains are theoretically construed as complex adaptive systems to be investigated by e.g., social network analysis (Carter et al., 2015). The emphasis is often placed on quantitative data modelling when the intent is to confirm a theory by seeking validation of the results obtained from a model with real-world quantitative data (Åsberg et al., 2011; Sagasti and Mitroff, 1973). Typically, studies are theory–confirming when they are concerned with availability as an objectively observable indicator causally linked to interventions carried out in a technical system, and is retrospectively computed from empirical quantitative data.

A different stance is taken in the field of system safety and accident investigation, where scholars are less inclined to try and understand systems which include social and technical elements solely through mathematical models and quantitative data (see e.g., Johansen and Rausand, 2014; Dekker, 2011). Experience from accident investigation suggests that the sequence of interactions between the elements of a socio-technical system may be unfamiliar, unplanned or unexpected, and hence neither visible nor immediately comprehensible to the analyst (Perrow, 1984; Hollnagel, 2012). The main methodological insight from accident investigation for the research presented in this paper is that the practice of outlining availability through cause-effect relationships analytically at the technical system level should be complemented by a richer picture. This picture should acknowledge that there may be multiple explanations spanning several levels of analysis over time for a particular outcome. The need to gain richer pictures by mapping the system of interest is evident in the investigations of large-scale multi-organisational systems that produced undesirable outcomes such as the shooting down of two U.S. Army helicopters by two U.S. Air Force fighter jets in 1994 (Snook, 2002), and the explosion of the Challenger Space Shuttle in 1986 (Vaughan, 1997). These works have demonstrated the need to bridge traditional analytical boundaries to investigate mechanisms which may be missed if focus is only placed on pinpointing cause-and-effect based on aspects such as the individual technical system. A more comprehensive view than one focused only on ‘easily observed’ adverse outcomes can be developed by moving away from individual technical systems and individual organisations, such that activities performed across organisations and the relationships between them are captured (Snook, 2002).

A descriptive case study approach is therefore deemed suitable to investigate a problematic situation in an existing industrial setting. Not only does it advance the collective process of knowledge accumulation (Flyvbjerg, 2006), but it also provides a fresh perspective on an already researched field (Eisenhardt, 1989), and an in-depth description of the interrelated processes and events that constitute the phenomenon of interest (Denscombe, 2010).

The research presented in this paper is exploratory and descriptive under conditions that could not be controlled by the researcher (Yin, 2009). Since the researchers were presented with facts and truths that can at best be described as perspectival, methods from the social sciences were deemed appropriate (Vermaas et al., 2011; Rosenblatt, 2002). Methods from the social sciences are also appropriate for the investigation of complex social and behavioural elements involved in operations and supply chain management (Boyer and Swink, 2008).

3.2. Case description

Fig. 1 depicts the industrial setting of interest for this research. It involves organisations which operate in the UK defence sector, anonymised for confidentiality reasons. A/C-Prov is a major aerospace

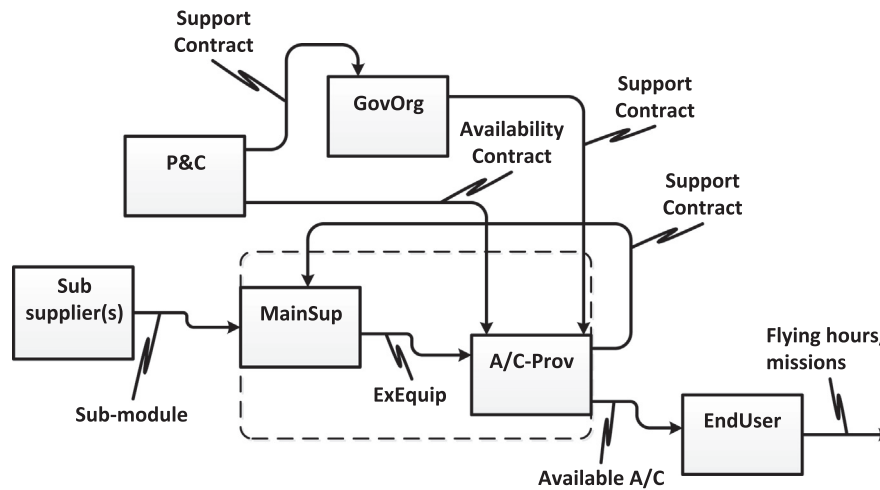


Fig. 1. Case setting; unit of analysis lies within the dashed box (see Section 3.3 for description of mapping technique).

Table 1
Quality criteria applied in this work (adapted from Lützhöft et al., 2010).

Criterion	Interpretation	What has been done to achieve criterion
Credibility	Conformity between data and researcher's reconstruction	Graphical representations are grounded in quotes. However, in-depth observation and extended engagement within the organisations was not possible.
Transferability	Thick description from which generalisation can be derived.	The case description and the structured graphical representations allow comparison of specific findings with other cases. However, generalisation and transfer of findings are outside the scope of this research.
Dependability	Transparency of research process.	The research process is fully documented, from questionnaire design, through to the pilot study to ascertain that the questionnaire was appropriate, up to the sampling process and the recording and transcription of each interview.
Confirmability	Data and findings are rooted in contexts and persons other than the researchers.	Graphical representations of the PSS were discussed with the interviewees to verify the researchers' interpretation. The conceptual model obtained from the analysis of qualitative data is rooted in the view of those involved in the functioning of the PSS investigated.

engineering company. MainSup is one of A/C-Prov's tier 1-suppliers providing, among other equipment, the exemplar avionics equipment of interest for this study, ExEquip, which is installed on a specific aircraft model by A/C-Prov. A/C-Prov acts as both manufacturer and whole-aircraft availability provider to the aircraft operator, EndUser. The contractual partner of A/C-Prov, however, is a fourth organisation, here called P & C, which acquires the aircraft and the means to support it e.g., spare parts.

While the study was conducted A/C-Prov was committed to a five-year fixed-price contractual agreement with P & C to provide agreed levels of aircraft availability. In parallel to the whole aircraft availability contract A/C-Prov was contractually tasked to ensure adequate stocks of spare parts for the aircraft's expected operational time. This contract, as shown in Fig. 1, is cascaded from P & C to A/C-Prov, MainSup and MainSup's sub-suppliers through organisations addressed aggregately here as GovOrg.

3.3. Methods

The choice of employable methods for data collection is constrained by the methodological stance taken as well as by the restrictions that the specific case imposes.

Direct observation of the activities undertaken to deliver available aircraft or repair instances of ExEquip was not granted to the researchers. Similar restrictions are not uncommon in research on defence industrial systems (Dowdall, 2004). Following Blessing and Chakrabarti (2009), semi-structured interviews were therefore selected as a suitable method to obtain a description of the PSS of interest (the unit of analysis) from the perspective of those involved in the execution of the availability-based contract (the units of measurement). Semi-structured interviews are often employed in contexts similar to the one investigated here (see e.g., Ng et al., 2013). In general, less structured

methods to gather knowledge from experts lead to a richer output (Cooke, 1994).

The chosen method has specific implications for the research. Given the methodological stance taken here, the evidence gathered through semi-structured interviews can be used to verify or calibrate a model of the PSS of interest, but not to prove or validate it (Woltjer, 2009). Hence, speaking of the defensibility of such a model (Wilson, 2001) is more appropriate than speaking of truthfulness (Lützhöft et al., 2010). Specific quality measures apply when research relies on qualitative data, namely: credibility, transferability, dependability and confirmability (Lützhöft et al., 2010). These criteria are consistent with the view that in case study research findings should be grounded in evidence and accompanied by information about the sample as well as on the procedures adopted for the collection and analysis of data (Eisenhardt, 1989).

As summarised in Table 1, each quality criterion has been addressed in this paper. However, some caveats are necessary. According to Johnstone et al. (2009) attempts to transfer findings from one setting to another can be deeply flawed. To provide sufficient context and details for insightful comparisons, this research aimed to provide a detailed description of the problem situation. Also, the interaction between the interviewee and the interviewer is context and time-specific (Payne, 1999), and hence inherently difficult to reproduce (Hargie and Tourish, 1999).

All the interviewees were employed by A/C-Prov or MainSup, and were identified through documentation provided by the companies e.g., process maps and organisational charts. The interviewees represent a cross section of functions and hierarchical positions including program director, analysts, contract managers, desk officers, support engineers and shop floor technicians. A different sampling strategy was adopted for each organisation. Snowball sampling (Denscombe, 2010) could effectively be employed in MainSup after identifying initial interview

partners. Within A/C-Prov the interviewees were selected according to the chain of communication required for delivering ExEquip from the interface with MainSup to the interface with EndUser. A total of 16 one-to-one interviews were conducted by one of the researchers. Although a questionnaire with open-ended questions was used as a reference, interviewees were allowed to elaborate on what they considered important. Most interviews took about one hour, their length ranging between 30 min and 2.5 h. All the interviewees signed a consent form which assured them their confidentiality.

During the interviews a structured graphical representation of the PSS of interest drafted by the researchers was used as supplementary material, as suggested by Hoffman et al. (1995); Snyder et al. (1992). There is no single best diagrammatic representation technique for a PSS (for an overview of techniques see e.g., Durugbo et al., 2011; Aguilar-Saven, 2004; Ma et al., 2002). Therefore, priority was accorded to the technique's flexibility and its ability to facilitate understanding, communication, and consensus between the interviewer and the interviewees on how the PSS works. IDEF0 (National Institute of Standards and Technology, 1993) was deemed a suitable choice as it is implementable using off-the-shelf software, unambiguous syntax-wise, and free from major weaknesses. The interviewees were allowed to modify the map if they so wished, to guarantee that the findings are rooted in the specific context and reflect the views of those involved in delivering avionics availability.

The interview recordings were transcribed, and coded using NVivo (Richards, 1999). The initial categories emphasised the identification of activities within the PSS and the relationships between them, in a fashion similar to the conceptualisation of system dynamics models (Luna-Reyes and Andersen, 2003) and conceptual models in Soft Systems Methodology (Ngai et al., 2012). Throughout the analysis new categories emerged, and categories were re-organised in more meaningful ways (Bryman, 2012). The final categories were obtained by deductive coding which captures themes that are specific to the maps as they were refined by adding activities and relationships, and inductive coding (Ryan and Bernard, 2000), which captures case-specific processes, links and emerging themes.

Direct quotations from the interviewees are used in the remainder of the paper. To fulfil the interviewer's responsibility for interviewee protection quotations are attributed to a role within an organisation (Payne, 1999).

4. Findings

Findings from the analysis of empirical data described in Section 3.3 are illustrated below. The focus is placed on the organisations involved initially, and then to functions that cut across the organisational boundaries. This approach reflects the convention suggested by Srari and Gregory (2008) of separately mapping supply network

configurations according to their network structure, which emphasises the organisational entities involved, and the flow of material and information, which brings the analysis closer to the operations.

4.1. Organisational perspective

Fig. 2 shows a reconstruction from interview data of the path followed by individual items of ExEquip as they are physically handled by the organisations involved in the execution of the availability-based contract—from EndUser to the suppliers of individual modules wrapped in ExEquip. The path follows a typical logistic operation (see e.g., Kiang, 1979): as failure occurs, ExEquip is removed from the aircraft and, if a spare item is available in stock, replaced and examined at an avionics workshop (AWS) to decide whether to ship it back to MainSup for repair. The aspects of the PSS that correspond to the classic logistic operation are the most prominent in MainSup's eyes: “We are very much a transactional sub-contractor providing repairs on a turn time” (MainSup Program Manager).

Inbound equipment at MainSup is booked into an IT system that “will record what was the fault that was found, was it confirming the customer fault, which [sub modules] were replaced? [We also] put a ‘ready for collection’ [mark on the IT system]. Also in the [IT] system we will forecast a delivery date”. In addition, “... we have to raise what we call compliance paperwork, which would be ITAR paperwork, check lists to say who the customer is, etc. ...” (MainSup Contract Manager). ITAR is the “International Traffic in Arms Regulations” to which ExEquip is subject (for an overview see e.g., Cook, 2010).

The main addition to a typical logistic scheme is that within the agreement in place between MainSup and A/C-Prov multiple routes may be used to process a repair request, each one associated with different procedures, resources and activities. The performance-based route warrants that MainSup observes a repair turnaround time (RTAT) which is less than or equal to a predetermined threshold. However, if MainSup is unable to replicate the suspected fault (No Fault Found—NFF) or suspects that the equipment has been mishandled by EndUser then an alternative route is used whereby performance in terms of RTAT is no longer contractually constrained: “So, when a defect report is raised, it will go back to the supplier, and then there's got to be a repair order raised, and a purchase order to say acceptance, to say it's going to cost you x thousand pounds to repair this unit. ‘Do you accept, do you not accept?’” (A/C-Prov Analyst) “... the purchase order then will go to our [contracts] department, checked through contracts ...” (MainSup Contract Manager).

Meeting the contractually-constrained RTAT may be complicated by the need to reach agreement with A/C-Prov and get additional information from either them or EndUser when a repair intervention is caused by suspect mishandling or NFF: “because we've got [that

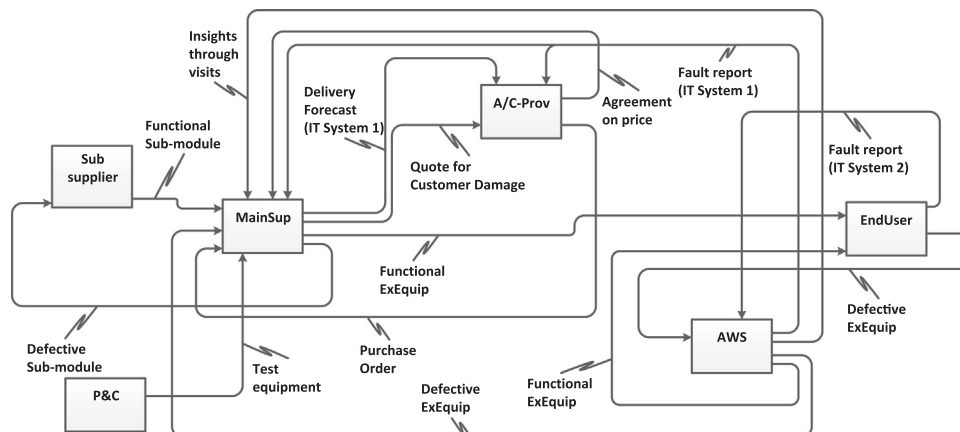


Fig. 2. Material and information flow between organisations involved in the Support Contract.

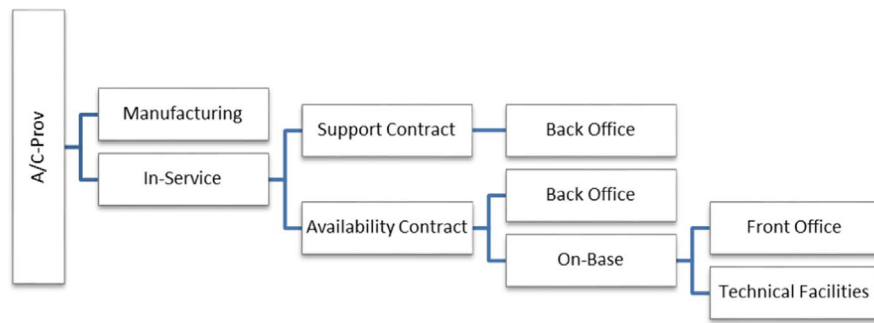


Fig. 3. A/C-Prov organisational segmentation.

number of] days. [The question is] are you going to get that information from the customer in time to make sure you can still achieve your metric?" (MainSup Contract Manager). Occasionally MainSup may "struggle to get the engagement on that [from A/C-Prov]" (MainSup Program Manager). In practice, repairs under the A/C-Prov Support Contract are processed as quickly as possible: "we're not going to be held up with documentation, [and a] purchase order, we don't even have to quote, if it's [covered by the Support Contract], it goes straight through [to the] repair" (MainSup Contract Manager).

Upon completion of the necessary administrative operations to channel ExEquip according to the appropriate contractual route the repair is carried out: "... the job then will appear on the workshop. So that's when all the contract stuff has been put in place and they are happy it can be worked on. [...] And [the team leader] is tasked with checking the work flow through the team and he knows when contract dates are coming up and all this. So he sees to distributing the work. So he will then say 'right, that number needs to be picked up' and then it will come on test and I or one of the others techs will pick it up and work on it." (MainSup Technician). When the workflow is completed "... a unit is repaired, so it comes out from the workshop with its own paperwork ... which would tell you exactly what they did with it, it'd also show you which parts have been used in that repair ..." (MainSup Contract Manager).

The management of ExEquip inventories poses a threat to the execution of the contract because the logistic support system is often confronted with unexpected demands for spare parts: "... in a nice simple world you have one [functional] asset out, another asset [that needs repair] in. But the reality of life is that you have one asset in, one asset out. Then suddenly you have three more assets in, 'oh, I haven't got sufficient spares to get the three more assets [that need repair] out.'" (A/C-Prov group leader). The situation might be further exacerbated by a lack of visibility of the location of ExEquip inventories at EndUser: "... how can you be AoG [Aircraft on Ground] for this piece of kit? We have only got [this number]. We know you have got [so and so many] on stock, where is the rest of this?", "we have no idea, we don't know" (MainSup Contract Manager).

Although not directly involved in the physical handling of the equipment described in Fig. 2, A/C-Prov is accountable for facilitating the overall process in view of the cost-effective delivery of availability as an advanced service: "... every time I need to send an item back to industry [...], that item will be shipped and picked up and it will go straight to [MainSup for repair] but it will be facilitated by [A/C-Prov]." "Then what you have is recognition that actually, could I improve or could I reduce the costs?" (A/C-Prov Analyst).

A/C-Prov's avionics workshop (AWS) is co-located with the customer to screen ExEquip as well as other equipment before it is sent to MainSup for repair. However, neither the Front Office nor the Technical Facilities co-located at the customer's airbase could be investigated due to access restrictions. Upstream, test equipment used at MainSup includes "a golden unit" of ExEquip which "is owned by [P & C]" (MainSup Technician). AWS also transfers the Fault Reports from EndUser's IT system into an IT system which A/C-Prov and

MainSup share access to (respectively, 'IT System 2' and 'IT System 1' in Fig. 2): "... the pilot will come in, he will input what he has seen, he will say 'here are my symptoms [...]' [and] that all goes into [IT System 2]. All the work that is done to recover that aircraft is in [IT System 2]." (MainSup Technician) What is subsequently recorded in IT System 1 is the outcome of inspection and testing at AWS: "then the bit he will put on [IT System 1] is [the unit] has failed test 1, 2, 3.'" (MainSup Technician). During such a transfer, loss of insight into the operating conditions in which the equipment has failed may occur, which has repercussions for how the repair of ExEquip is carried out by MainSup: "an accurate fault report would help", however, "we can do it without; we just run our own investigation" (MainSup Technician). In the presence of information loss duplication of tests already performed by AWS is probable, thus increasing the overall time and effort taken by troubleshooting activities. Occasionally, more detail or further explanation than what is included in a Fault Report is required by MainSup to carry out repair operations successfully: "[We] have got people [...] who regularly go to the [airbase] and they can ask these questions." (MainSup Technician). In Fig. 2 this is expressed according to IDEF0 syntax by representing 'Insights through visits' as a control arc (a condition that must be considered for the transformation of inputs into outputs to take place as depicted) from AWS to MainSup.

As anticipated in Section 3.2, A/C-Prov is both a manufacturer and an availability provider for the aircraft model of interest acquired by P & C and operated by EndUser. Such a dual role has a counterpart in the organisational distinction within A/C-Prov between 'In-Service support' and 'Manufacturing' (Fig. 3). The distinction is perceived as problematic, and was the subject of a restructuring program at the time of writing: "I have some good metrics that look 360 [degrees] at the product to say how it is performing. But because of the nature of [A/C-Prov], they would never have that data together on one bit of paper. I can say 'there is an issue here we are starting to see in service' we can build something into production to make it better going forward, that's quite a sophisticated conversation to have with [A/C-Prov]" (MainSup Program Director).

Fig. 3 shows that In-Service support is further subdivided by contract type, as Support Contract and Availability Contract. Support Contract looks upstream, defining relationships and performance metrics between A/C-Prov and MainSup. Availability Contract engages downstream directly with EndUser, also on-base to ensure that whole-aircraft availability is delivered by A/C-Prov. Organisational and contractual changes that occurred over time have increased the length of the communication and interaction chain between those within A/C-Prov dealing with EndUser and those dealing with MainSup. According to the latter: "the further we get from the customer the worse it is for the job" (A/C-Prov Desk Officer).

Although a distinct set of activities is carried out by Support Contract on individual aircraft subsystems such as ExEquip these activities contribute to whether whole-aircraft availability is eventually achieved or, by contrast, the aircraft is grounded. Hence, the underlying contracts are distinct but not separable, thus blurring the operational boundaries: "[The Availability Contract] looks at the total

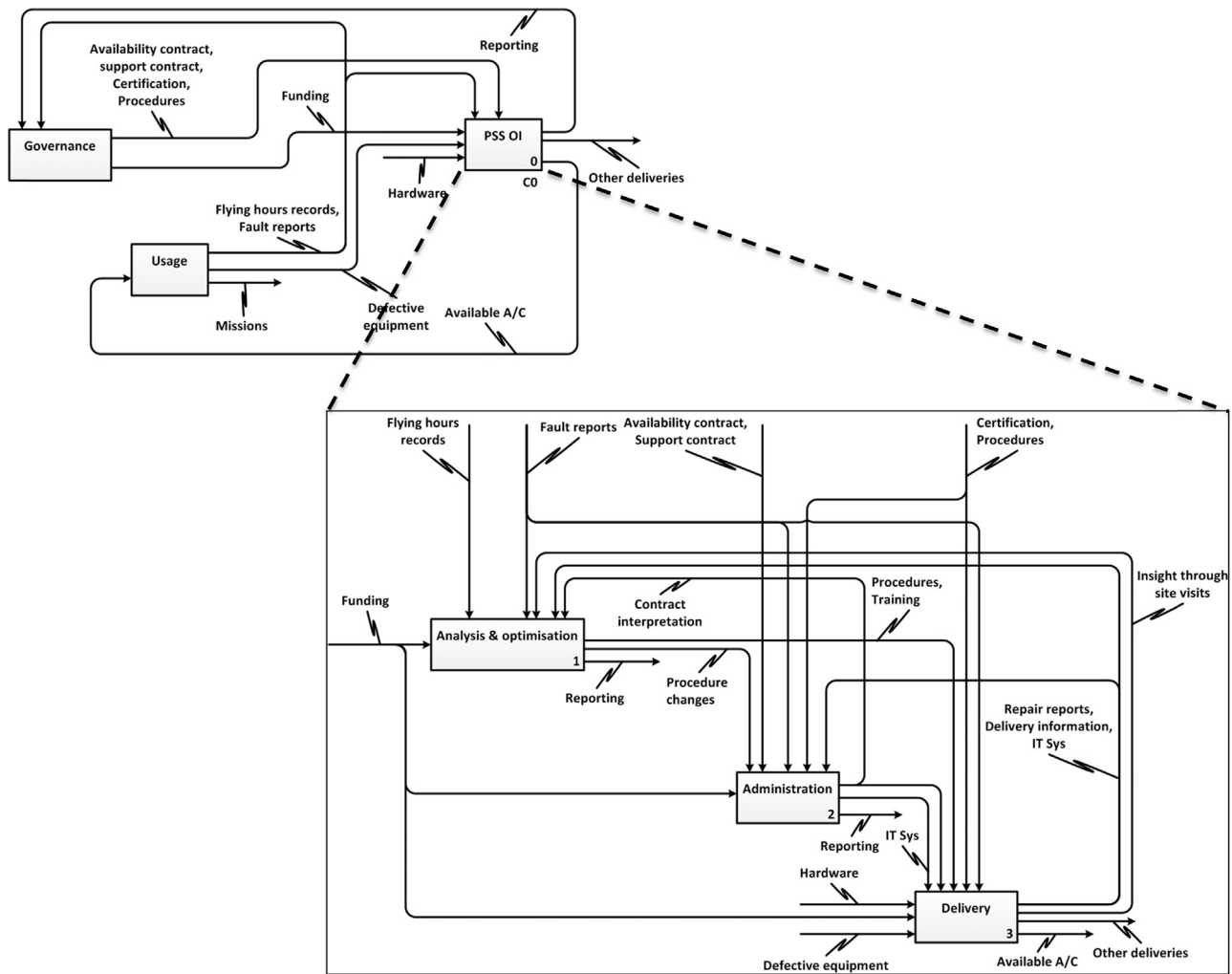


Fig. 4. Main functions constituting the PSS of interest (PSS OI) for aircraft availability provision, relationships are potential and are shown for exposition only.

support solution but works it with [the Support Contract]. [The Support Contract] is not a part of [the Availability Contract]” (A/C-Prov Analyst). This vagueness leads to the paradoxical result that, “sometimes the [Support] contract gets in the way of providing availability” (A/C-Prov Desk Officer). With regards to data analytics, the described organisational divide is “where you lose a bit of knowledge” because the situation described by product-related data supplied to In-Service support may not overlap with the situation experienced by personnel close to the customer: “when you go [to the airbase] and you talk to the guys who are actually maintaining it, you get a completely different view of how it's operating in service, than you do from what's put on failure reports” (A/C-Prov Analyst). This incongruence may prevent an integrated view on equipment performance as it arises from failure reports.

4.2. Functional perspective

The organisation-centric network configuration map outlined in Fig. 2 is complemented by a map that focuses on service operations or ‘functions’, to use IDEF0 terminology, shown in Fig. 4. Unlike organisational units, functions could only be identified as the research progressed, and do not correspond to operations previously identified and mapped by the organisations involved.

Given the exploratory nature of the case study, Fig. 4 depicts the relevant functions in an aggregate and streamlined manner loosely applying IDEF0 for conceptual modelling.

Relationships within and across functions in terms of data and

documentation, personal interactions and physical handling of ExEquip are described in Table 2, where each cell corresponds to a directed arc in Fig. 4 linking the function listed row-wise to the function listed column-wise. Relationships between the functions that are included within the boundaries of this research are shown within the bold line in Table 2 and those outside the boundaries would require further investigation. The shaded cells in Table 2 represent links that would become apparent if the functions shown aggregately in Fig. 4 were progressively detailed using IDEF0 child diagrams or other diagrammatic techniques. For illustrative purposes, in Fig. 5 the Functional Resonance Analysis Method (FRAM) technique (Hollnagel, 2012) originally developed in the field of accident investigation is applied to provide a functional perspective on how ExEquip is made available to EndUser (see Section 4.1) with greater detail than in Fig. 4. A distinguishing feature of FRAM is its ability to facilitate the identification of the number and nature of connections for each element within the system of interest, thus highlighting which pre-conditions must be fulfilled for such an element to deliver its output.

In the specific case considered here it can be noted that regardless of how effective the repair is, failure to meet the RTAT ultimately depends on avoiding hold ups in the preconditions of ‘MainSup Shipping’, namely ‘compliance documentation’ and ‘release documentation’.

Each function identified in Fig. 4 is described below through the evidence that led to its identification.

Table 2
Relationships within and outside the PSS boundaries.

From \ To	Governance	PSS of interest			Usage	
		Analysis & optimisation	Administration	Delivery		
Governance		Funding;	Funding; Performance reviews; Price assessment; Priority requests	Certification; Procedures		
PSS of interest	Analysis & optimisation	Performance reports; Investigation reports;	Investigation reports;	Procedures; Conversation (personal, emails); Reliability reports;	Procedures; Training;	Recommendations; Procedures
	Administration	Performance reports; Invoices and quotations;	Contract interpretation; Conversation (personal, emails);	Contract interpretation; Purchase order; Conversation (personal, emails);	Contract interpretation; IT system (repair orders, part orders)	
	Delivery		IT system (Fault reports, repair reports, delivery dates); Conversation (personal, emails);	IT System (Fault reports, repair reports, delivery dates); stock levels	Repair records; Equipment (Sub-modules, Ex-Equip)	Available aircraft;
Usage		Flying hours (IT system)		Fault reports (IT system & form); Defective equipment	Discrepancy log book	

Note: Cells within thick borders capture what is included within the scope and boundaries of this research.

4.2.1. Usage

The Usage function represents available aircraft being deployed and operated by EndUser. From a functional perspective, ExEquip is not separated by the rest of the aircraft because whole-aircraft availability, to which available ExEquip contributes, is what enables the 'Usage' function to deliver its output of missions flown. The usage function

affects how other functions within the PSS boundaries work through its outputs of 'defective equipment' and 'failure reports'. For example, functioning equipment may be mistakenly removed from the aircraft or a fault report may be issued that provides little or no insight into the fault and the operating conditions in which it arose. Due to the restrictions already mentioned in Section 3, insights into the Usage function, could only be gathered indirectly through AWS, or informally during a visit the authors paid to the EndUser airbase.

4.2.2. Governance

The Governance function is fictitiously created as a residual category for activities that are not strictly speaking operational: "... I am not into the detail of the sort of things [they] are doing but I would run a regular review structure, so I have an oversight of [what they are] doing, what the key issues are, where the threats are and the opportunities are." (MainSup Program Director). These activities take place outside of the boundaries of this research but are capable of affecting the scope of the activities carried out within such boundaries, as well as the flow of information and knowledge within the PSS.

A prominent example of what the Governance function represents is the management of financial and performance-related aspects of the contractual mechanisms: "... ultimately, [GovOrg is] measuring industry and there are financial penalties ..." (A/C-Prov Desk Officer) "... or an [availability contract] type question it will come into [A/C-Prov]. Say, 'we have got an issue, here is some funding, here is a lot of questions, we like an answer within a certain number of days.'" (A/C-Prov Analyst). Contrary to what is commonly assumed, performance metrics related to the contract require interpretation, and hence their assessment is the topic of regular negotiations: "... then for example every six months or so you would have a meeting [with GovOrg, A/C-Prov and other organisations]. But that's more of a challenge meeting, a cost reduction challenge [...]. It's not part of operational business." (MainSup Program Director) "[...] without our input to [GovOrg] it would look like the suppliers are failing the contract in a lot of occasions. That is simply because the units that aren't covered by the

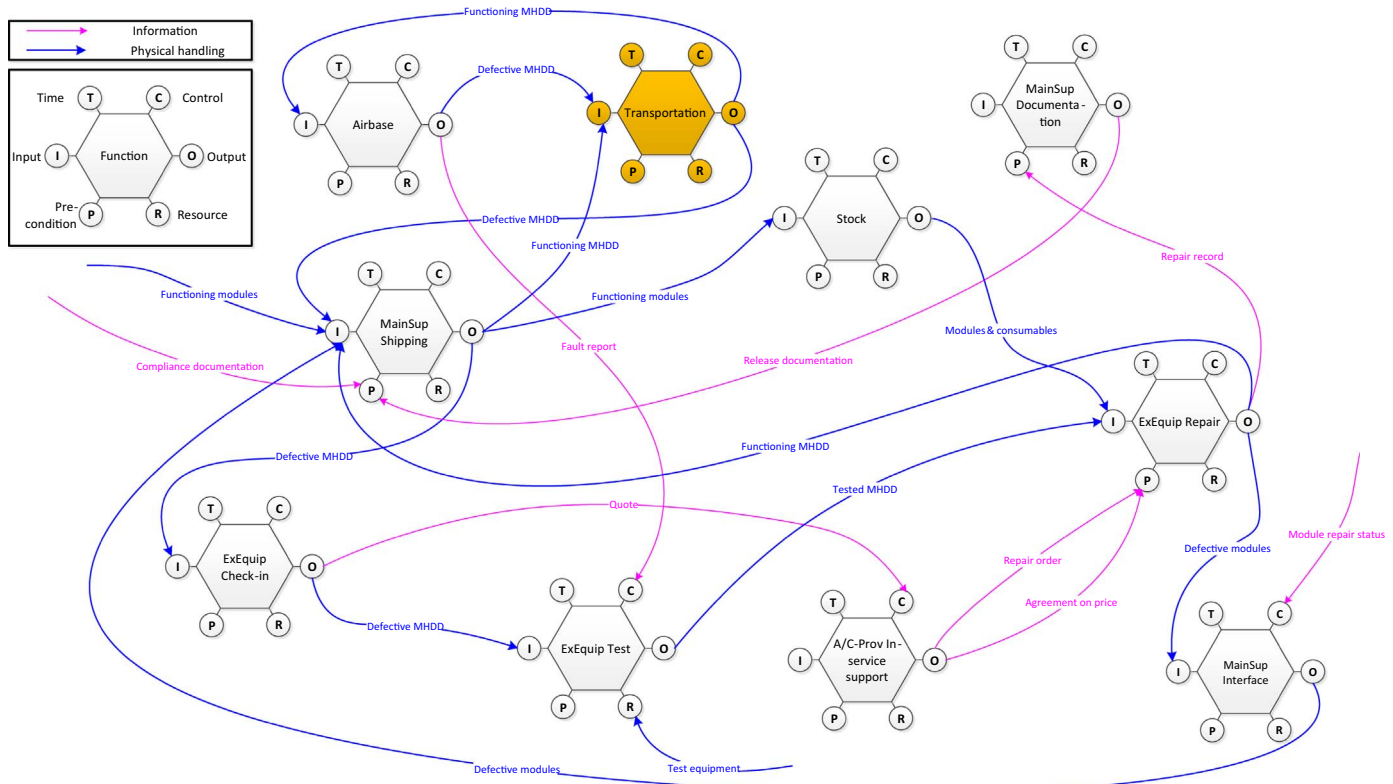


Fig. 5. Functional representation of ExEquip repair using FRAM. Transportation is presented in a different colour because its execution is outside the scope of this research.

Table 3
Summary of findings.

Synthesising claim	Supporting evidence	Section
The service provider's ability to achieve contractually agreed availability outcomes for a technical system is constrained by its dependency on other actors (system integrator, customer and end-user), which also inhibits engagement beyond the transactional provision of repair, thus generating tension	<ul style="list-style-type: none"> ● MainSup perceives itself as a <i>transactional</i> sub-contractor providing repairs on a turn time; ● Dependency on timely information inputs from, and level of engagement with A/C-Prov and EndUser with regards to issuing purchase and repair orders, assignment of repairs to the appropriate contractual route, investigation of NFF and mishandling occurrences; ● Dependency on P & C on testing in co-located facilities, information transfer across IT systems, decision on number of items to send for repair, and visibility of inventories; ● Need to overcome dependency by site visits at airbase from MainSup personnel. 	4.1
The variety of contracts and roles generates an organisational segmentation within the system integrator which is meant to facilitate the execution of these contracts. However, such segmentation may unnecessarily lengthen the communication chain, and prevent timely feedback from in-service operations into manufacturing.	<ul style="list-style-type: none"> ● The dual role of A/C-Prov as manufacturer and service provider is reflected in distinct organisational units presiding “In-service Support” and “Manufacturing” activities with little or no overlap ● Difficulty to inform A/C-Prov manufacturing process by sharing evidence produced by MainSup on technical systems’ behaviours in-service ● Longer interaction and communication chains resulting from organisational and contractual changes within A/C-Prov are believed to negatively impact the execution of the availability contract in practice ● ‘Support contracts’ for technical sub-systems and whole-aircraft ‘availability contract’ are not necessarily aligned, and sometimes support contracts ‘get in the way’ of providing aircraft availability ● Loss of knowledge by placing the focus on product-related data analytics generated from failure reports while overlooking accounts of the situation as experienced by personnel close to the customer. 	4.1
While availability is considered an ‘objective’ measure, in practice performance metrics related to and availability-based contract require interpretation, and hence their assessment is the topic of regular negotiations	<ul style="list-style-type: none"> ● Meetings between GovOrg, A/C-Prov and other organisations are more a cost reduction challenge and detached from the operational business ● A/C-Prov’s input to GovOrg is essential to avoid that suppliers appear to be failing the contract due to influence that items not covered by the contract and the external influences on the prioritisation of repairs may have on the RTAT. 	4.2
Both A/C-Prov and MainSup serving multiple customers under multiple contractual agreements, resources and activities are shared and <i>each service</i> outcome delivered cannot be understood in isolation from the others	<ul style="list-style-type: none"> ● Despite having a classic logistic operation as a common basis, within the agreement in place between MainSup and A/C-Prov multiple routes may be undertaken to process similar repair requests, each one associated with different procedures, resources and activities ● While the workshop activity can be fairly attributed to an item on a time-basis once the contractual route is established, the Administration functions take on responsibilities for multiple customers simultaneously so that allocating time to a specific contractual route is more difficult ● Multiple contractual routes and customer needs may interfere with each other as individual customers may require to reconsider prioritisations through GovOrg, or influence the route undertaken by an item with their ability or inability to provide timely information on NFFs and mishandling. 	4.1 4.2
Inventory management practice inspired by local optimisation may create tension upstream	MainSup perceived mismatch between the single-unit flow expected by MainSup and EndUser’s practice of returning batches of defective ExEquip generates unexpected demand for spare parts	4.1

contract generally have longer repair turnaround times.” (A/C-Prov Desk Officer).

Governance may also determine exceptions to how Administration and Delivery operate by altering the prioritisation of repairs upon requests from EndUser or other customers: “... *the only way to improve that [customer unit] is to put it in front of [another customer’s unit]. In that instance and if we can’t do that and the [customer is] desperate for it then there is a route where they will go into [GovOrg] and reference it and we will get the consent from them to move the units around. [...] So it wouldn’t satisfy the contract [for the other customer].*” (A/C-Prov Desk Officer) “... *nobody has requested this. This has been an internal decision, but it has affected our support level. But rightly or wrongly that’s a decision that someone else has made.*” (MainSup Desk Officer).

4.2.3. Delivery and administration

The Delivery and Administration functions operate within the PSS boundaries and are largely described by the findings in Section 4.1 and are therefore addressed aggregately here. These functions cover, respectively, equipment and spare parts handling (test, repair, packaging and documentation, and transport); and information flow processing (creation and release of purchase orders, quotes, performance reports, transfer of fault reports across IT systems, and regulation compliance checks e.g., ITAR). The residual output categories ‘other

deliveries’ in Fig. 4 denotes support services provided by the PSS concurrently with those falling under contractual agreement of interest for this study.

One aspect of Delivery and Administration that emerge more clearly at the function level than at the organisational level is the concurrency of multiple deliverables within the PSS of interest, and the challenges of time-based resource allocation between them: “*So when the guys are working on the job the clock is ticking so to speak. [...] So you know when things are being worked and when they are not.*” (MainSup project leader). By contrast, Administration functions take on responsibilities for multiple customers requiring repairs under multiple contractual routes: “*So, that’s not just [Aircraft 1], it’s [Aircraft 2], it’s [Aircraft 3], it’s [Aircraft 4], [Aircraft 5], everything. [...] My time is split up randomly throughout the day. [...] I can’t dedicate my day to something, because there will always be something else I need.*” (MainSup project leader).

4.2.4. Analysis & optimisation

This function steers the Delivery function on the basis of insights acquired through data gathering and analysis. In line with the concept of Supply Chain Analytics (e.g., Chae et al., 2014), Analysis & Optimisation includes IT-related elements for data gathering and analysis as well as data-driven practices across the multi-organisational enterprise: “... *collecting in-service data, looking at it, looking for*

trends ...” (MainSup Support Engineer) “... you stick it all in a spreadsheet, you do all your charts, you can start to see things, and you get a feel for your equipment, because maybe [...] two or three occurrences of a single fault on your equipment may be nothing, but two or three occurrences on another person's equipment may be a massive issue, depending on the level of failures in general ...” (A/C-Prov Analyst). However, this function involves rather heterogeneous groups which “are kind of a bit different in that they are a bit more on doing their own type of thing.” (A/C-Prov Analyst). The analysis of data translates into action-taking through communication at the interface between organisations: “... will have a meeting with the [team leaders] and they'll sit down and say 'these are the issues we're seeing from the suppliers, you're damaging screws, you're doing this, you're doing that'. And then what the [team leaders] do is they go back to their [personnel] and say: 'right, it's been told that this is getting done'. Not casting any blame or anything, just say 'we need to be wary when we're tightening screws up or cleaning screens or [...] scratching them'. Silly little things like that. It's all just trying to look after the small things so that the big things don't happen really.” (MainSup Support Engineer).

5. Discussion

The findings, synthesised in Table 3, demonstrate that delivering advanced service outcomes within an availability based contract involves the contribution of a range of capabilities from different organisations in addition to features that may be designed into a piece of equipment.

A defensible representation of the underpinning delivery system, a PSS, is provided through the use of evidence gathered from a real industrial setting and the use of mapping techniques such as IDEFO and FRAM that emphasise it is a ‘system’ which is not exclusively technical in nature. The conceptual model created provides insights that expand and complement those commonly obtained by analysing product-related quantitative data. To use an example from an adjacent case, with reference to a defence avionics availability contract Settanni et al. (2015) demonstrate by analysis of field reliability data that excessive pressure is exerted on the resources of a multi-organisation logistic support system despite product design improvements. However, within that study the researchers are unable to shed light on why this happens, and where in the system action should be taken.

The answer to the first research question outlined in Section 1 (“How is availability delivered as an advanced service outcome under an availability based contract in an actual industrial context?”) is that despite contractually agreed goals and the willingness to work together towards achieving those goals, the relationship tensions between MainSup and A/C-Prov play an important role in how the organisations involved interact in practice.

The variety of contracts and roles generates an organisational segmentation within A/C-Prov which affects the relationship with MainSup, especially in terms of communication and line of visibility of downstream operations. In turn, MainSup is dependent on A/C-Prov, EndUser and the P & C, and perceives its relationship with them as largely *transactional*, much like a sub-contractor providing repairs on a turn time. This constrains its ability to meet a contractually agreed RTAT and inhibits further engagement with A/C-Prov.

The answer to the second research question (“Which aspects of the delivery of such an advanced service can be represented?”) is that avionics availability is not an output that can be unambiguously attributed to a single organisation or to a function. Rather, it is an emergent property of the PSS as a whole, determined by the dependencies between its elements. In particular, the interpretation of avionics availability itself depends on the perspective taken by a specific organisation, group, or even individual. For example, MainSup delivers ‘available ExEquip’ when it declares a repaired unit “ready for collection”, and the agreed RTAT is met. In A/C-Prov there is

no dedicated metric for avionics availability, although ExEquip availability may determine whether an aircraft is grounded or in a fit state for EndUser to fly.

The importance of mapping key organisations involved in a PSS should not be neglected. In line with such works as Mills et al. (2013), the research provides findings about the organisational aspects of delivering under an availability contract, and recognises that the complexities associated with such delivery in an actual industrial setting limit the researchers’ ability to describe what constitutes the PSS of interest.

As Maull et al. (2013) point out, some service outcomes may be concurrently delivered. The research findings underline that both A/C-Prov and MainSup serve multiple customers under multiple contractual agreements, and that *each service* outcome delivered cannot be understood in isolation due to shared resources and activities.

The presence of tensions between MainSup and A/C-Prov indicates that integration of manufacturer and service roles in A/C-Prov is a challenge despite the shared goal and mutual willingness to work together, confirming a recurrent theme in the literature (see e.g., Johnstone et al., 2009). The same can be said with regards to tier-1 suppliers’ frustration resulting from the inability of manufacturing companies to engage more with them as they become service providers (see e.g., Lockett et al., 2011; Martinez et al., 2010).

Although without reference to equipment support services, it has been pointed out that a lack of understanding of the supplier’s production process may hamper joint efforts for cost reduction (Romano and Formentini, 2012). The findings show that the organisational fragmentation within A/C-Prov appears to impair their ability to gain a more holistic view of equipment performance, and hence to effectively implement improvement measures.

Often, the importance of the multi-organisational dimension of advanced service delivery is emphasised through the concept of ‘enterprise’ (Kapletia and Probert, 2010; Ng et al., 2011). A commonality of purpose and the presence of organisational interdependencies play a central role in the concept of enterprise (Mills et al., 2013). The research findings highlight that, in practice, the contract may be ‘in the way’ of delivering the service outcome, and that meeting upstream availability metrics (e.g., RTAT) does not necessarily imply that the downstream availability metrics are met (e.g. Aircraft on Ground). Thus a ‘true’ *commonality of purpose* is not at the core of the contractual agreement in place between A/C-Prov and MainSup, and that the relationship between them reflects more a supply chain providing logistic support rather than an enterprise. However, interdependencies between MainSup, A/C-Prov and EndUser emerge in practice because value is co-created through a timely flow of information from EndUser which enables MainSup to meet its contractual performance, as well as the ability of A/C-Prov to engage with MainSup to share expertise and knowledge to improve the handling of ExEquip in the field. A mismatch between practice and contract is highlighted by the finding that the contractual agreement per se does not imply successful delivery of availability as an advanced service outcome. This confirms the view that to base the relationships between organisations only on contractual agreement may not be appropriate in situations that require flexibility and quick response to changes (Pilbeam et al., 2012).

A controversial aspect is whether aiming for local optimisation creates tension at the system level (Dekker, 2011). The findings suggest that some practices may promote local optimisation while creating service capacity issues. As observed in Section 4.1 mismatch between the single-unit flow expected by MainSup and EndUser’s practice of returning batches of defective ExEquip generates unexpected demand for spare parts. While a detailed investigation of how the returning decisions are made at EndUser was not possible (as discussed in section 3), the practice of returning more than one instance might suggest the employment of typical computational outcomes from inventory replenishment models – a supposedly ‘optimal’ order size

(see e.g. Shapiro, 2007). This kind of optimisation carried out on the basis of estimated cost and demand parameters from the perspective of only one supply chain actor (e.g. EndUser) has practical repercussions on upstream actors' operations (e.g., MainSup), which are typically disregarded. However, other works conclude that the relationship between supply chain operational alignment and contractual performance is not significant (Ng et al., 2013).

The conceptual model outlined raises awareness of the critical role that relationships and contractual agreements play in how equipment support operations are managed in practice rather than 'on the white board'. The representation of an existing PSS using empirical qualitative data can be particularly helpful as a tool to understand and manage relationships in a situation where a System-of-Systems Integrator is contractually obliged to work with their competitors, as is currently the case for most defence industrial supply systems across Europe and the US (Dowdall, 2004).

6. Conclusion

This paper outlines a conceptual model grounded in empirical evidence that represents how advanced service outcomes are delivered under an availability-based contract for defence avionics. The focus is shifted away from a notion of availability as a property designed into a piece of equipment, and directed toward the Product-Service-System (PSS) which underpins the delivery of those service outcomes necessary for the execution of the contract. Evidence is gathered through an in-depth case in the UK defence sector to address the questions: "How is availability delivered as an advanced service outcome under an availability based contract in an actual industrial context?" and "Which aspects of the delivery of such an advanced service can be represented?"

From the outset both researchers and interviewees could identify organisational entities, such as departments and groups, within the industrial context investigated. However, only through the research process could the PSS of interest be represented. The PSS has organisational facets that are known and established, but also functional facets which are shaped by practice and are more difficult to represent. In addition to mapping the organisations involved in the execution of the contract investigated here, top-level aggregated functions were identified and represented. The juxtaposition of organisational and functional views in the research shows that an outcome orientation within an availability contract is achieved in practice through interactions between functions identified across the organisations involved.

Some of the findings might sound counterintuitive. For example, despite the presence of agreed contractual goals and the willingness to work together towards their achievement a variety of contracts and roles between the aircraft system integrator and the avionic sub-system provider create tangible tensions. Sometimes support contracts for technical sub-systems are perceived to 'get in the way' of providing whole-aircraft availability, highlighting the need to complement contractually established and supposedly objective performance metrics with insight into how availability is delivered in practice. Also, 'avionics availability' is not a service output that can be directly attributed to a specific function or organisation; rather, it should be regarded as an emergent property of a PSS.

However, it is precisely such counterintuitive evidence that justifies the need to complement the analysis of contractual metrics and product-related data with empirical evidence about how availability is delivered in practice: if availability is interpreted as an advanced service outcome it can be neither understood nor actively influenced without analysing the socio-technical system that delivers it.

While generalisations are beyond the scope of this paper the authors' experience with industry suggests that other organisations in adjacent fields may also place excessive emphasis on those performance indicators and practices which most directly and exclusively

relate to a technical system. The findings presented in this paper suggest that activities which are less immediately related to a technical system and hence traditionally outside the scope of most quantitative availability models become prominent when investigating the extended enterprise's ability to successfully provide advanced service outcomes.

As anticipated in the methodology section, this research has obvious limitations. One such limitation is the inherently limited transferability of the findings, which are restricted to the specific case considered, and reflect conditions which held while the study was carried out. Nevertheless, a detailed description is provided in order to facilitate comparison between cases. Similarities between the findings of this research and those from other works were highlighted in the discussion, demonstrating that aspects of the context investigated are transferrable to other settings. Another limitation is that rigour in the application of diagrammatic techniques such as IDEFO and FRAM was sacrificed to provide flexibility and to capture context-specific elements whilst maintaining a concise representation. Finally, important elements of the PSS of interest exist outside the system boundaries of the case study shown in this paper. However, the process of how to address availability as an advanced service is valuable to show, even if only aggregately. The work captures those elements which may determine the ability or inability of a PSS to deliver its service outcomes beyond the 'classic' logistic operation underlying most mathematical models of availability. It is important to emphasise that these elements are largely non-technical in nature.

Further research should expand the scope of the analysis and integrate in a more systemic way the use of qualitative and quantitative data for the representation and modelling of a PSS. The conceptual model outline in this study is not meant to be a "stand-alone" contribution; it provides a blueprint to assist the formulation of scientific models based on quantitative data e.g., a multi-echelon inventory system for repairable items, as well as insights into where action should be taken within a PSS that would otherwise be difficult to obtain from analysis of field reliability data alone.

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References

- Aguilar-Saven, R.S., 2004. Business process modelling. review and framework. *Int. J. Prod. Econ.* 90 (2), 129–149.
- Åsberg, R., Hummerdal, D., Dekker, S., 2011. There are no qualitative methods – nor quantitative for that matter. The misleading rhetoric of the qualitative-quantitative argument. *Theor. Issues Ergon. Sci.* 12 (5), 408–415.
- BAE Systems, 2015. £112M Typhoon support contract extension sustains 650 jobs [online]. Available at: (<http://www.baesystems.com/en-uk/article/pound112m-typhoon-support-contract-extension-sustains-650-jobs>) (accessed November 2015).
- Baines, T., Lightfoot, H., 2013. *Made to Serve*. Wiley, Chichester.
- Becker, J., Beverungen, D.F., Knackstedt, R., 2010. The challenge of conceptual modeling for product–service systems: status-quo and perspectives for reference models and modeling languages. *Inf. Syst. e-Bus. Manag.* 8 (1), 33–66.
- Biege, S., Lay, G., Buschak, D., 2012. Mapping service processes in manufacturing companies: industrial service blueprinting. *Int. J. Oper. Prod. Manag.* 32 (8), 932–957.
- Blessing, L.T.M., Chakrabarti, A., 2009. *DRM, a Design Research Methodology*. Springer, Heidelberg.
- Boyer, K.K., Swink, M.L., 2008. Empirical Elephants. Why multiple methods are essential to quality research in operations and supply chain management. *J. Oper. Manag.* 26 (3), 338–344.
- Bryman, A., 2012. *Social Research Methods* 4th ed.. Oxford University Press, Oxford.
- Caldwell, N.D., Settle, V., 2011. Incentives and contracting for availability: procuring complex performance. In: Ng, I.C.L., Parry, G.C., Wild, P., McFarlane, D., Tasker, P. (Eds.), *Complex engineering service systems: Concepts and research*. Springer, Berlin, 147–160.
- Carter, C.R., Rogers, D.S., Choi, T.Y., 2015. Toward the theory of the supply chain. *J. Supply Chain Manag.* 51 (2), 89–97.
- Cavalieri, S., Pezzotta, G., 2012. *Product–Service Systems Engineering*. State of the art

- and research challenges. *Comput. Ind.* 63 (4), 278–288.
- Chae, B., Olson, D., Sheu, C., 2014. The impact of supply chain analytics on operational performance: a resource-based view. *Int. J. Prod. Res.* 52 (16), 4695–4710.
- Cook, K.L.B., 2010. *The ITAR and You. What You Need to Know about the International Traffic in Arms Regulations*, Proceedings of the IEEE Aerospace Conference, 6–13 March 2010, Big Sky, MT, USA.
- Cooke, N.J., 1994. Varieties of knowledge elicitation techniques. *Int. J. Hum.-Comput. Stud.* 41 (6), 801–849.
- Datta, P.P., Roy, R., 2011. Operations strategy for the effective delivery of integrated industrial product-service offerings: two exploratory defence industry case studies. *Int. J. Oper. Prod. Manag.* 31 (5), 579–603.
- Denscombe, M., 2010. *The Good Research Guide: for Small-scale Social Research Projects* 4th ed. McGraw-Hill/Open University Press, Maidenhead.
- Dekker, S., 2011. Drift into failure: from hunting broken components to understanding complex systems. Ashgate, Farnham.
- Dowdall, P., 2004. Chains, networks and shifting paradigms: the UK defence industry supply system. *Def. Peace Econ.* 15 (6), 535–550.
- Durugbo, C., Tiwari, A., Alcock, J.R., 2011. A review of information flow diagrammatic models for product-service systems. *Int. J. Adv. Manuf. Technol.* 52 (9–12), 1193–1208.
- Eisenhardt, K.M., 1989. Building theories from case study Research. *Acad. Manag. Rev.* 14 (4), 532–550.
- Evans, S., Partidário, P.J., Lambert, J., 2007. Industrialization as a key element of sustainable product-service solutions. *Int. J. Prod. Res.* 45 (18–19), 4225–4246.
- Flood, R.L., Carson, E.R., 1988. *Dealing with complexity: an introduction to the theory and application of systems science*. Plenum Press, New York.
- Flyvbjerg, B., 2006. Five Misunderstandings About Case-Study Research. *Qual. Inq.* 12 (2), 219–245.
- Hansen, K.R.N., Grunow, M., 2015. Planning operations before market launch for balancing time-to-market and risks in pharmaceutical supply chains. *Int. J. Prod. Econ.* 161, 129–139.
- Hargie, O., Tourish, D., 1999. The Psychology of Interpersonal Skill. In: Memon, A., Bull, R. (Eds.), *Handbook of the psychology of interviewing*. Wiley, Chichester, 71–87.
- Harrington, A. (Ed.), 2005. *Modern social theory: an introduction*. Oxford University Press, Oxford.
- Hoffman, R.R., Shadbolt, N.R., Burton, A.M., Klein, G., 1995. Eliciting Knowledge from Experts. *A Methodological Analysis. Organ. Behav. Hum. Decis. Process.* 62 (2), 129–158.
- Hollick, L.J., 2009. Achieving shared accountability for operational availability attainment. Proceedings of the Annual Reliability and Maintainability Symposium, Fort Worth, Texas, USA, 26–29 January 2009.
- Hollnagel, E., 2012. FRAM, the functional resonance analysis method: modelling complex socio-technical systems. Ashgate, Farnham.
- Houghton, D., Lea, G., 2009. Managing and supporting ship availability. *Maint. Asset Manag.* 24 (2), 36–44.
- Jazouli, T., Sandborn, P., 2010. A Design for Availability Approach for Use with PHM. Proceedings of the Annual Conference of the Prognostics and Health Management Society, Portland, Oregon, 10–16 October 2010.
- Johansen, I.L., Rausand, M., 2014. Defining complexity for risk assessment of sociotechnical systems: A conceptual framework. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, vol. 228 no. 3, pp. 272–290.
- Johnstone, S., Dainty, A., Wilkinson, A., 2009. Integrating products and services through life. An aerospace experience. *Int. J. Oper. Prod. Manag.* 29 (5), 520–538.
- Kapletia, D., Probert, D., 2010. Migrating from products to solutions. An exploration of system support in the UK defence industry. *Ind. Mark. Manag.* 39 (4), 582–592.
- Kashani Pour, A.R., Sandborn, P., Cui, Q., 2016. Review of Quantitative Methods for Designing Availability-Based Contracts. *J. Cost. Anal. Parametr.* 9 (1), 69–91.
- Kiang, T., The development and implementation of Life Cycle Cost methodology, In AGARD (Advisory Group for Aerospace Research and Development), *Methodology for control of Life Cycle Costs for avionic systems*, 1979, AGARD/NATO, Neuilly-sur-Seine CEDEX, France, pp. 3.1–3.25
- Kimita, K., Tateyama, T., Shimomura, Y., 2012. Process Simulation Method for Product-Service Systems Design. *Procedia CIRP* 3, 489–494.
- Kyösti, P., Reed, S., 2015. Prediction of service support costs for functional products. *Simul. Model. Pract. Theory* 59, 52–70.
- Lockett, H., Johnson, M., Evans, S., Bastl, M., 2011. Product Service Systems and supply network relationships. An exploratory case study. *J. Manuf. Technol. Manag.* 22 (3), 293–313.
- Luna-Reyes, L.F., Andersen, D.L., 2003. Collecting and analyzing qualitative data for system dynamics. methods and models. *Syst. Dyn. Rev.* 19 (4), 271–296.
- Lützhöft, M., Nyce, J.M., Petersen, E.S., 2010. Epistemology in ethnography. assessing the quality of knowledge in human factors research. *Theor. Issues Ergon. Sci.* 11 (6), 532–545.
- Ma, Q., Tseng, M.M., Yen, B., 2002. A generic model and design representation technique of service products. *Technovation* 22 (1), 15–39.
- Martinez, V., Bastl, M., Kingston, J., Evans, S., 2010. Challenges in transforming manufacturing organisations into product-service providers. *J. Manuf. Technol. Manag.* 21 (4), 449–469.
- Mauil, R., Smart, A., Liang, L., 2013. A process model of product service supply chains. *Prod. Plan. Control* 25 (13–14), 1–16.
- Meier, H., Roy, R., Seliger, G., 2010a. Industrial Product-Service Systems—IPS2. *CIRP Ann. - Manuf. Technol.* 59 (2), 607–627.
- Meier, H., Uhlmann, E., Krug, C., Völker, O., Geisert, C., Stelzer, C., 2010b. Dynamic IPS2 networks and operations based on software agents. *CIRP J. Manuf. Sci. Technol.* 3 (2), 165–173.
- Mills, J., Purchase, V.C., Parry, G., 2013. Enterprise imaging. representing complex multi-organizational service enterprises. *Int. J. Oper. Prod. Manag.* 33 (2), 159–180.
- (MoD) Ministry of Defence, 2015. *Annual Report and Accounts* [online]. Available at: <https://www.gov.uk/government/publications/ministry-of-defence-annual-report-and-accounts-2014-to-2015> (accessed November 2015).
- Morelli, N., 2002. Designing Product/Service Systems. *A Methodological Exploration. Des. Issues* 18 (3), 3–17.
- National Institute of Standards and Technology, 1993. *Integration definition for function modeling (IDEFO)* [online]. Available at: (<http://www.idef.com/wp-content/uploads/2016/02/idefo.pdf>) (accessed November 2015).
- Ng, I.C.L., Ding, D.X., Yip, N., 2013. Outcome-based contracts as new business model. The role of partnership and value-driven relational assets. *Ind. Mark. Manag.* 42 (5), 730–743.
- Ng, I.C.L., Parry, G.C., Wild, P., McFarlane, D., Tasker, P. (Eds.), 2011. *Complex engineering service systems: Concepts and research*. Springer, Berlin.
- Ngai, E.W.T., To, C.K.M., Ching, V.S.M., Chan, L.K., Lee, M.C.M., Choi, Y.S., Chai, P.Y.F., 2012. Development of the conceptual model of energy and utility management in textile processing. A soft systems approach. *Int. J. Prod. Econ.* 135 (2), 607–617.
- Payne, S., 1999. Interview in Qualitative Research. In: Memon, A., Bull, R. (Eds.), *Handbook of the psychology of interviewing*. J. Wiley, Chichester, England, 89–102.
- Perrow, C., 1984. *Normal Accidents: living with High-risk Technologies*. Princeton University Press, Princeton, NJ.
- Phumbua, S., Tjahjono, B., 2012. Towards product-service systems modelling. A quest for dynamic behaviour and model parameters. *Int. J. Prod. Res.* 50 (2), 425–442.
- Pilbeam, C., Alvarez, G., Wilson, H., 2012. The governance of supply networks. a systematic literature review. *Supply Chain Manag.: Int. J.* 17 (4), 358–376.
- Richards, L., 1999. *Using NVivo in Qualitative Research*. Sage Publications, London.
- Rijsdijk, C., 2013. Predicting availability. *Maintworld* 5 (3), 24–26.
- Romano, P., Formentini, M., 2012. Designing and implementing open book accounting in buyer-supplier dyads: a framework for supplier selection and motivation. *Int. J. Prod. Econ.* 137 (1), 68–83.
- Rosenblatt, P.C., 2002. Interviewing at the Border of Fact and Fiction. In: Gubrium, J.F., Holstein, J.A. (Eds.), *Handbook of interview research: Context & method*. Sage Publications, Thousand Oaks, Calif, 893–909.
- Ryan, G.W., Bernard, H.R., 2000. *Data Management and Analysis Methods*. In: Denzin, N.K., Lincoln, Y.S. (Eds.), *Handbook of qualitative research* 2nd ed. Sage Publications, Thousand Oaks, CA, 769–802.
- Sagasti, F.R., Mitroff, I.I., 1973. Operations research from the viewpoint of general systems theory. *Omega* 1 (6), 695–709.
- Sayama, H., Pestov, I., Schmidt, J., Bush, B.J., Wong, C., Yamanoi, J., Gross, T., 2013. Modeling complex systems with adaptive networks. *Comput. Math. Appl.* 65 (10), 1645–1664.
- Schulze, S., Seuring, S., Ewering, C., 2012. Applying activity-based costing in a supply chain environment. *Int. J. Prod. Econ.* 135 (2), 716–725.
- Selviaridis, K., Wynstra, F., 2015. Performance-based contracting. A literature review and future research directions. *Int. J. Prod. Res.* 53 (12), 3505–3540.
- Selviaridis, K., Norrman, A., 2015. Performance-based contracting for advanced logistics services. *Int. J. Phys. Distrib. Logist. Manag.* 45 (6), 592–617.
- Settanni, E., Newnes, L.B., Thenent, N.E., Parry, G.C., Goh, Y.M., 2014. A Through-life costing methodology for use in product-service-systems. *Int. J. Prod. Econ.* 153, 161–177.
- Settanni, E., Newnes, L.B., Thenent, N.E., Bumblauskas, D., Parry, G., Goh, Y.M., 2015. A case study in estimating avionics availability from field reliability data. *Qual. Reliab. Eng. Int.* 32 (4), 1553–1580.
- Shapiro, J.F., 2007. *Modeling the supply chain* 2nd ed. Thomson, Belmont, CA.
- Snook, S.A., 2002. *Friendly fire: the accidental shutdown of U.S. Black Hawks over Northern Iraq*. Princeton University Press, Princeton, NJ.
- Snyder, D.E., McNeese, M.D., Zaff, B.S., Gomes, M., 1992. Knowledge acquisition of tactical air-to-ground mission information using concept mapping. Proceedings of the IEEE National Aerospace and Electronics Conference, Dayton, OH, 18–22 May 1992.
- Srai, J.S., Gregory, M., 2008. A supply network configuration perspective on international supply chain development. *Int. J. Oper. Prod. Manag.* 28 (5), 386–411.
- Vasantha, G.V.A., Roy, R., Lelah, A., Brissaud, D., 2011. A review of product-service systems design methodologies. *J. Eng. Des.* 23 (9), 635–659.
- Vaughan, D., 1997. *The Challenger launch decision: risky technology, culture, and deviance at NASA*. University of Chicago Press, Chicago, IL.
- Vermaas, P., Kroes, P., van de Poel, Ibo, Franssen, M., Houkes, W., 2011. A Philosophy of technology. From Technical artefacts to sociotechnical systems. *Synth. Lect. Eng., Technol. Soc.* 6 (1), 1–134.
- Wilson, B., 2001. *Soft systems methodology: conceptual model building and its contribution*. Wiley, Chichester, New York.
- Woltjer, R., 2009. *Functional Modeling of Constraint Management in Aviation Safety and Command and Control* (PhD Thesis) Department of Computer and Information Science. Linköpings universitet, Linköping, 2009.
- Yin, R.K., 2009. *Case study research: design and methods*. Sage, Los Angeles, CA.
- Zhu, H., Gao, J., Li, D., Tang, D., 2012. A web-based product service System for aerospace maintenance, repair and overhaul services. *Comput. Ind.* 63 (4), 338–348.
- Zio, E., 2009. Reliability engineering. old problems and new challenges. *Reliab. Eng. Syst. Saf.* 94 (2), 125–141.