Impact of Uncertainty on Industrial Product-Service System Delivery

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Abstract

Sufficient consideration of uncertainties is essential for successful Industrial Product Service Systems (IPS^2) delivery, due to their potential impact over cost, schedule and performance. The paper serves the purpose of structuring complexity in IPS^2 delivery by presenting the main categories and types of uncertainties and their impact on the delivery of IPS^2. Detailed description of the uncertainties and their influence on one another is explained. Additionally, the paper defines the complexity implications of these uncertainties on the IPS^2 delivery. The findings have been derived from the industrial interactions with four major organisations in the defence and aerospace industries and critically analysing the literature.

Keywords

Industrial Product-Service Systems, availability contracts, delivery, uncertainty, impact

1 INTRODUCTION

The focus of the customer in the defence and aerospace industries has been shifting from equipment purchase to functional capability [1]. This transition has typically been achieved through availability contracts, which are also known as performance based contracts. Contracting for Availability (CfA) is a commercial process which seeks to sustain an equipment/system/part at an agreed level of readiness, over a period of time, by building a partnering arrangement [2]. Fundamentally, to be able to deliver these requirements it is necessary to address the availability in terms of *what*, *when* and *where*. In academia, related research has been covered in the 'Product-Service Systems (PSS)' domain. Baines et al., [3] defines PSS as **"**an integrated product and service offering that delivers value in use". The approach takes a physical product as the initial point; a PSS is created only after the servitization of this product [4]. The specific case of a PSS, involving the business to business context, a physical product core and high net value is considered to be an Industrial Product Service System (IPS^2) [5], where CfA serves as an example.

IPS^2 delivery has progressively increased in scale and complexity. Examples range from the humble photo-copier through to major infrastructure projects (e.g. Private Finance Initiative -PFI- hospitals) and large defence projects (e.g. complete sea, air or land platforms). The shift to CfA promotes the use of performance criteria (e.g. key performance indicators) over the Product Life Cycle (PLC), which may last up to 40 years. Equipment availability, reliability and maintainability are some of the main areas of interest within these contracts. As a result, relationship between the customer and industry has been growing while co-creation of value has become a major theme across the industry [6]. CfA has become widely considered as win-win solutions for both the customer and industry. Some of the major reasons behind this include opportunities for cost reduction, incentivising flexibility in IPS^2 delivery, extending PLC through higher reliability, payment based on unit of service rather than resources, optimisation of use, postponing disposal costs, incentivisation of component re-use, and fixed income achieved over longer duration [3]. These positive outcomes have been achieved through the enhancement of the role of service in the delivery of customer needs. The significance of service arises due to its ability to ensure or to enhance the product performance expected by the customer throughout the whole PLC [7]. Services such as health checks, spares and repairs services, defect response, on-call service, performance assessment, process management and training have become widely offered across the defence and aerospace industry. Such services as part of an IPS^2 have enabled to tailor delivery to the individual customer needs [8].

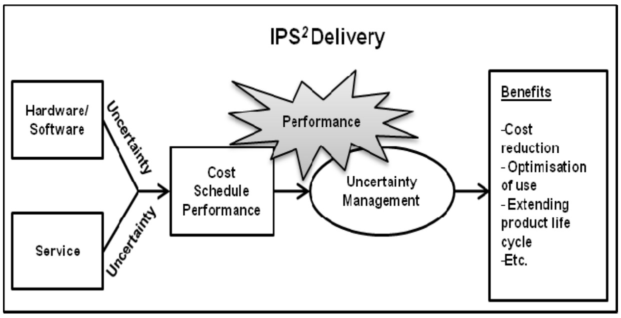

Figure 1: IPS^2 Delivery

There are a number of barriers that may hinder the possibility of benefitting from the potential advantages that CfA offers. From the industry perspective some of these aspects include difficulties in predicting costs, accuracy of concept design, and organisational issues across the service supply chain [9]. Furthermore, considerations for the IPS^2 delivery need to capture system innovation or upgrade requirements early on in order to meet profitability expectations. However, the required capabilities and knowledge in managing the delivery of services are different to managing products [9]. The challenge for industry arises from handling the balance between supply and demand, which affects the fluctuation of the delivered service quality over the long duration. On the other hand, for the customer, the barrier for adopting an IPS^2 relates to the uncertainties with regards to the offer in terms of unclear risks, costs and responsibilities [9]. Thus, both the customer and industry face challenges in agreeing these contracts, whilst the prediction of cost along with schedule and performance has proven to be challenging due to uncertainties which require the management of uncertainties that arise in achieving a targeted performance. Figure 1 represents this aspect as well as illustrating that benefits are expected from the delivery of IPS^2 (e.g. for customer, industry, and suppliers), which combines products (e.g. hardware and software) and services. In order to cope with uncertainty, flexibility needs to be built into the IPS^2 [10], however approaching this complex phenomenon requires a structured methodology. It is worth distinguishing between uncertainty and risk, where uncertainty involves the indefiniteness of the outcome of the situation and risk is considered to be the chance of loss or injury [11]. This paper focuses on uncertainties due to its broad view that encapsulates both threats/risks and opportunities.

Section 2 explains the research methodology. The paper, in Section 3, focuses on the types and categories of uncertainties that impact the delivery of IPS^2. The impact of uncertainties on IPS^2 delivery is clarified in Section 4.

2 METHODOLOGY

This research is aiming to establish a cost-uncertainty modelling methodology for IPS^2, as part of the 'PSS-Cost' project at Cranfield University. The project has been collaborated with three major defence companies and one defence customer in the United Kingdom. Initially, through literature review the state of the art in defining uncertainty and the uncertainty types that emerge in availability contracts or IPS^2 delivery was captured. This guided the research to be divided firstly to understand the nature of availability contracts, which has been studied in product-service systems. Secondly, research aimed to study the uncertainties that arise in IPS^2 delivery. This related to research in uncertainty, and uncertainty management conducted by the Ministry of Defence (MoD), Department of Defense (DoD), North Atlantic Treaty Organization (NATO) and NASA. As a last step, these two research themes were combined through the identification of the main challenges, related to uncertainties that are faced in availability contracts.

The outcomes of the literature review, led to semi-structured interviews with all four mentioned organizations. The research with the collaborators focused on understanding the challenges in cost uncertainty estimation that are present in service delivery (i.e. spares, maintenance and training). A total of over 40 hours of semi-structured interviews were conducted with cost engineers, project managers, support managers, engineering managers, and functional experts (i.e. on risk and uncertainty). In the interviews it was highlighted that the process of systematically capturing uncertainties in IPS^2 delivery is a major challenge. Thus, the research aimed to establish a list of uncertainties that typically affect an IPS^2 delivery. The list was developed based on examination of what occurred on previous programs (e.g. Work Breakdown Structure-WBS) and an overall understanding of the issues that are likely to arise on future programs. Furthermore, the list of uncertainties was generated bearing in mind their influence over cost drivers. This approach was taken due to the significant challenges that are experienced in cost estimation in CfA. The process of interaction with industry is represented in Figure 2.

Along with the pre-mentioned interviews, the list and the refinement of uncertainties was achieved through two workshops. These were attended by all four collaborators. The attendees, held positions such as project manager, engineering manager, service capability manager and cost estimators. In the first workshop the role of uncertainties over IPS^2 delivery was established. This involved considering all the uncertainties that impact the process. The contextual focus was directed towards the early phases, where information is limited for an availability contract. The second workshop validated the list of uncertainties that had been generated through interviews and the workshop. This led to the refinement of the uncertainty list and also conceptual scope of each type of uncertainty was defined.

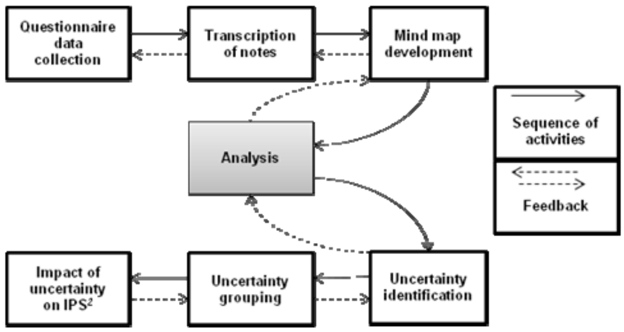

Figure 2: Research Methodology

3 UNCERTAINTIES IN IPS^2 DELIVERY

IPS^2 delivery combines product and service processes, where Figure 3 shows a comparison between the two. Conceptual similarities between these processes involve firstly identification of a need whether it be a product or a service [12]. Secondly, a plan is developed to fulfil the need and subsequently the implementation of the product delivery or service delivery takes place. Explicitly in the case of products, there needs to be an alignment between product policy formulations (e.g. defining equipment objectives), product objective finding (e.g. ideas generation and selection), product development (e.g. development, production, design and marketing), and product realisation [13]. The focus of traditional contracts centred on all of these aspects as well as the distribution and sales. The uncertainty in service delivery was distinguished from the product requirements. Whilst in the IPS2 context the integration of product and service is essential in order to achieve the performance requirements. This can be considered the basis of the shift in types of uncertainties when moving from a traditional contract into availability. As a result, the ranking of various uncertainties, for the Original Equipment Manufacturer (OEM), change as a proportion to the overall uncertainty level. For instance, with the increasing control/responsibility of the OEM in service and support activities uncertainty in maintainability (i.e. better handling of mean time between failure) is reduced while uncertainty related to service provision has grown (i.e. co-creation of value). Thus, in the case of service, all phases of the service processes including service creation (e.g. solution analysis, objectives, strategy), service engineering (e.g. generation of requirements, development, and implementation), and service management (e.g. delivery of service) need to be aligned with one another [13]. The implementation of product and service processes faces a different set of challenges arising from a different set of uncertainties.

The impact of uncertainty arising from the service delivery process may originate from many sources, which require the identification of uncertainty to be conducted systematically. There are a number of ways to identify the types of uncertainties including semi-structured interviews, brainstorming techniques, the nominal group technique, the Delphi technique, identification tools (e.g. systems dynamic models), identification aids (e.g. checklists), UML diagrams, SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis [14]. The identification of uncertainty is typically driven by expert judgment and experience [15]. To start with, in order to identify uncertainties it is necessary to recognize and document all associated uncertainties that are known. Though, the process is challenged by the dynamic nature of uncertainties over the life cycle of IPS^2. In order to systemically conduct an uncertainty analysis a generic list of uncertainties across IPS^2 can be considered. Taking a systematic approach facilitates the elimination or reduction of personal bias. Furthermore, this provides the opportunity to improve the chance of accurately assessing uncertainties (e.g. level of technical uncertainty) and to subsequently deliver an IPS^2. Through interviews in the defence and aerospace industry, uncertainties have been categorized into commercial, affordability, performance, training, operations and engineering areas, which the list has been referred to as CAPTOE. Figure 4 illustrates the uncertainty categories and types in each category, while also discussing their relationship with one another. This representation is in line with Roy and Cheruvu [16], which defines a competitive framework for IPS^2.

- Commercial uncertainty, considers factors that affect the contractual agreement, which is driven by certain requirements set by the customer. However, industry takes responsibility in defining these requirements based on its capability constraint. Responsibilities are driven by both the customer and industry
- Affordability uncertainty, considers factors that affect the ability to predict the customers funding for the given granularity of a project. Responsibility is driven by the customer
- Performance uncertainty, considers factors that affect industrial achievement in reaching the performance goals (Key Performance Indicators-KPIs) for the given project granularity level
- Training uncertainty, considers factors that affect industrial achievement in reaching customer needs for the delivery of training
- Operation uncertainty, considers factors that affect industrial achievement in reaching the required level of service and support delivery. It focuses on equipment level activities (i.e. onshore, maintenance) to deliver IPS^2
- Engineering uncertainty, considers factors that affect industrial achievement in managing strategic decisions with regards to the future service and support requirements (i.e. offshore, obsolescence management) to deliver IPS^2

The categories of uncertainties can be classified into strategic and operational level influence over the IPS^2 delivery. From a strategic view, the customer has a major role in commercial and affordability uncertainty categories, whilst the other areas are driven by industry. From an operational view the delivery of the IPS^2 is driven by training, engineering, and operation activities. In the case of training, along with uncertainties arising from delivering training, the process also has a knock-on effect on system performance. This is driven by the skill level of equipment users, which affect the failure rate and subsequently the availability level. On the other hand, engineering decisions can influence operational activities. For instance, planning for obsolescence will reduce problems that arise in finding spares, and this can enhance the efficiency of operations. In an IPS^2 delivery the focus is on performance, which is determined by strategic and operational level uncertainties, which for industry there are internal capabilities and external influences that affect the delivery processes (e.g. customer misuse). For the customer the scope of the requirement is constrained by its budget, which affects the affordability of an IPS^2.

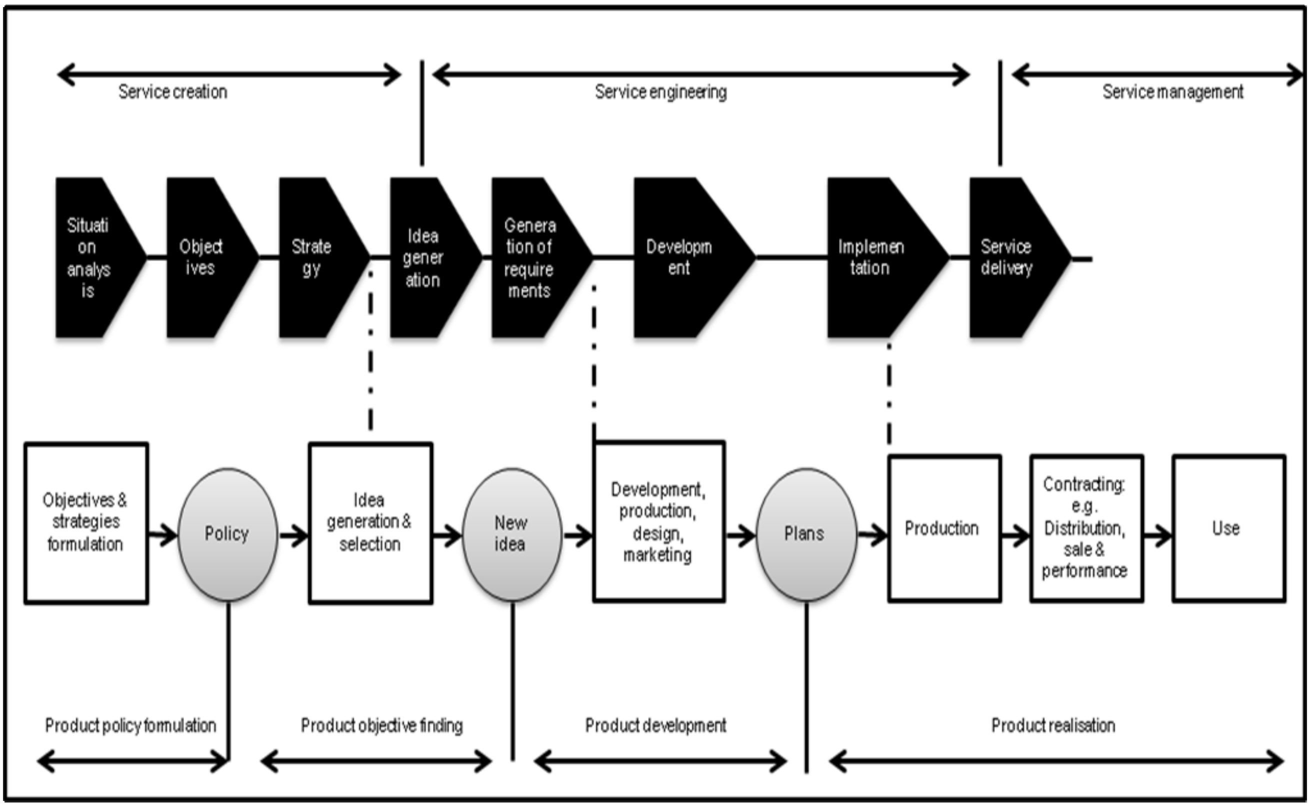

Figure 3. Comparison of product and service processes [Adapted from 13]

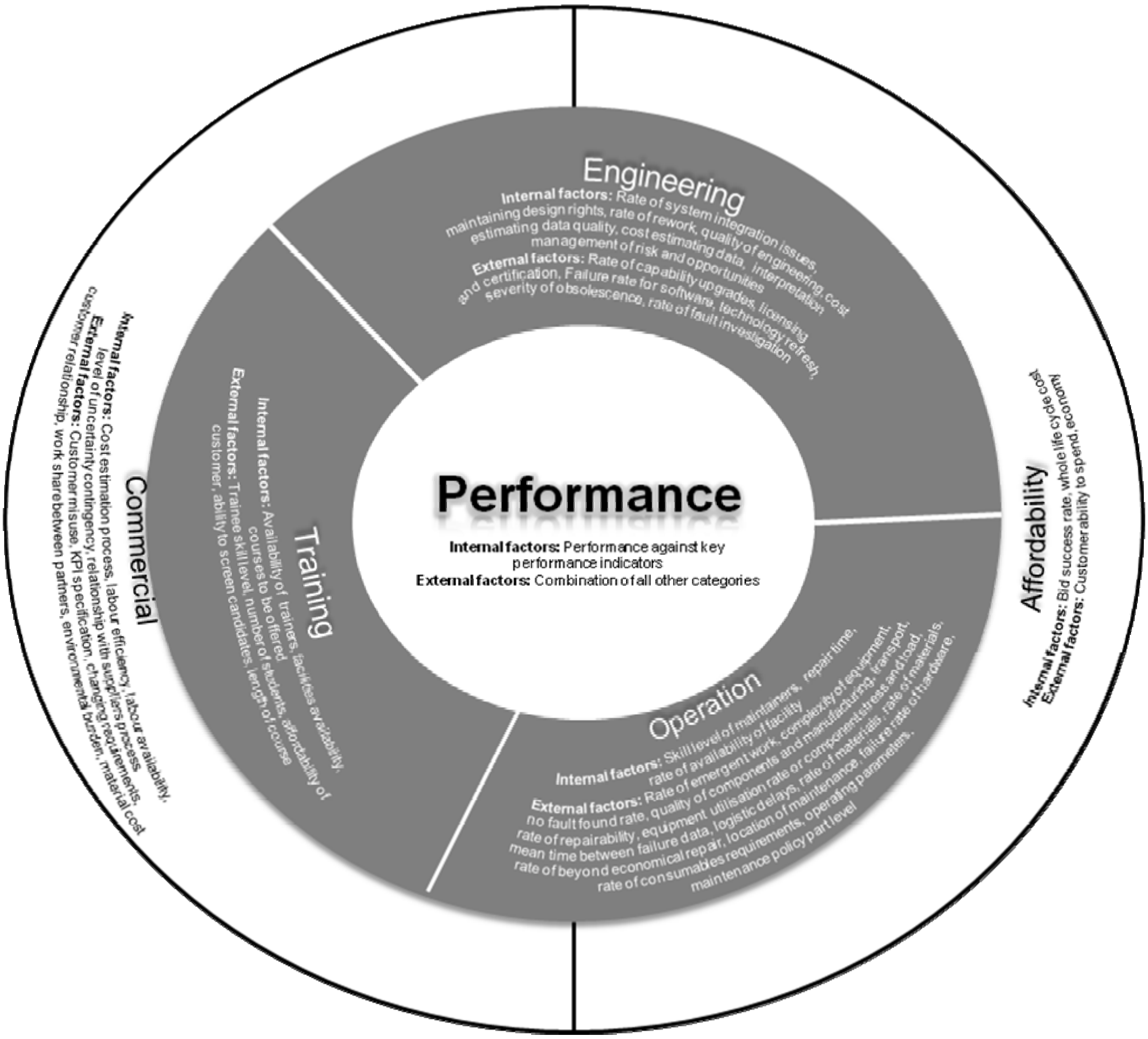

Figure 4. Categories and types of uncertainties in IPS^2 delivery

Each of these categories contains a number of relevant uncertainties, which influence IPS^2 delivery. In total 76 types of uncertainties have been captured. The list, which can also be interpreted as a risk register or a checklist, serves as the concepts that need consideration in developing an IPS^2. Although, the study was conducted specifically within the defence and aerospace industry, due to the focus on the early stages, driven by the level of available information, concepts are fairly generic and the list can be considered to be a starting point in order to develop an IPS^2 across other industries. For each category of uncertainties internal and external uncertainty drivers are explained in the following section. Internal factors take the view of industry, where capabilities are the driving force behind uncertainties that arise. On the other hand, external factors take a view of factors that originate outside of industry, which includes the customer or supply chain.

3.1 Commercial Uncertainty

The internal factors are driven by the capabilities of industry. This firstly involves a cost dimension, which includes uncertainties that may arise from the cost estimation process, and the ability to define the uncertainty contingency for the given project. Secondly, it requires consideration of labour requirements. Uncertainties may arise in the process of allocating labour for responsibilities, and achieving labour availability. The level of relationship set with suppliers is also considered as a capability that may influence the quality of the delivered service. On the other hand, external factors consider uncertainties that arise from the customer, supply chain and environmental burden. The customer may create uncertainty in the process of specifying KPIs, by equipment misuse, by changing requirements. The customer is also, to a large extent, responsible for the relationship with industry, which may influence the delivery of service. From the supply chain perspective, various uncertainties include material cost (e.g. spares), and the output of the collaboration with peer groups which involves a common goal (e.g. PFI initiatives). Finally, environmental burden refers to the uncertainty in the environmental requirements that needs to be adhered to.

3.2 Affordability Uncertainty

The internal factors are classified into two areas. Firstly, with IPS^2 delivery a life cycle view of cost is necessary and there are uncertainties within this process that industry needs to take responsibility for. Secondly, driven by the organisations' bid success rate across projects, opportunities to reduce cost may arise, which may be reflected in the price negotiations. In turn this may influence the affordability level of a project. As for external factors, customer ability to spend which is determined by budget constraints is an influential factor over customer affordability. The progression of the economy is another factor that influences customer affordability. The implications may arise from a supply (e.g. increasing prices, due to diminishing supply) or demand (e.g. decreasing budget) perspective.

3.3 Performance Uncertainty

Achieving required performance is an internally driven process that is measured based on KPIs. Performance being the main goal of the IPS^2 delivery is driven by many factors that concern the process of delivery (e.g. activities). Elements covered in affordability, commercial, training, operations and engineering feed in to the level of performance delivered. Thus, managing performance requires a multi-dimensional approach in order to encapsulate the affects of many uncertainty sources.

3.4 Training Uncertainty

Uncertainties that can be managed internally, relate to the availability of trainers, facilities availability (e.g. computers, lecture rooms), and the number of courses that are likely to be offered. The external factors are driven by the customer and trainees that attend the courses. For instance, the main uncertainties include trainee skill level, number of trainees to attend courses, ability to screen candidates (e.g. examining trainee skill level). Finally, the length of the course will be determined based on the customers' requirements and the skill level of the trainee in order to achieve the performance level.

3.5 Operation Uncertainty

The internal factors are driven by the skill level of maintainers, repair time, rate of availability of facility (e.g. for maintenance). The external factors that contribute to uncertainty are classified based on equipment originating factors, customer and supply chain. Equipment originating uncertainties include rate of emergent work (e.g. additional work needed to conduct repair), complexity of equipment (e.g. based on knowledge requirements to maintain), quality of components, and failure rate of hardware. On the other hand, customer originating uncertainties that affect the operational level of IPS^2 include equipment utilisation rate or component stress and load, rate of repairability, operating parameters (e.g. temperature, moisture), and maintenance policy part level (e.g. defined maintainability level). The final factor relates to supply chain originating uncertainty. This includes transport (e.g. degree of logistics as a result of spares/maintenance requirements), location of maintenance (e.g. distance to travel), mean time between failure data (e.g. uncertainty with the data), no fault found rate (e.g. no need to replace/repair), beyond economical repair (e.g. need for new part), logistic delays (e.g. originates from transportation), rate of consumables requirements, rate of materials (e.g. spares requirements).

3.6 Engineering Uncertainty

Engineering uncertainties, internally, capture skill and cost related capabilities. Skill considers the ability to handle system integration issues, rate of rework (e.g. refitting spare), quality of engineering, management of risk and opportunities (e.g. devising appropriate strategies). Also, uncertainty exists in retaining design rights, which is driven by the customers' satisfaction of delivered services. From a cost perspective estimating data reliability or quality, cost estimating data interpretation emerge as the main uncertainties with regards to engineering activities. The external factors relate to uncertainties that arise from the rate of capability upgrades, licensing and certification (e.g. customer driven), failure rate for software (e.g. considered as an engineering activity), technology refresh, severity of obsolescence, and rate of fault investigation (e.g. equipment driven requirements).

4 IMPACT OF UNCERTAINTY ON IPS2 DELIVERY

The different sources of uncertainty including incomplete information, inadequate level or understanding of information, and undifferentiated alternatives [17] may create major impacts on IPS^2 delivery. Furthermore, consideration of uncertainties enables more effective project planning. The impact, typically, on cost, schedule or performance requires attention. Table 1 presents the potential impact of the uncertainty categories shown in Figure 4. This list is not exhaustive and illustrates some of the potential impacts for each category.

Table 1. Impact of uncertainty on IPS^2

Category	*Source*	*Impact*
Commercial	Internal	Low availability level, penalties, inadequate flow of material across supply chain, bad cost estimates
	External	Too ambitious KPIs, high cost from supply chain, inadequate collaboration with partners
Affordability	Internal	Too ambitious cost estimates, and price reduction (when in competition)
	External	Downfall of the economy, diminishing budget
Performance	Internal	Unsuccessful in reaching KPIs, penalty
	-	-
Training	Internal	Inadequate training service, penalty
	External	Low trainee skill level causing longer courses, unprofitability
Operation	Internal	Low equipment availability, penalty
	External	Higher than expected cost, re-negotiation of utilisation rate, penalty to customer
Engineering	Internal	Inefficiency in design which reduces ability to achieve customer needs, inadequate cost estimates
	External	Equipment failure above expectations, equipment upgrade above expectation

Improper planning may cause decisions to be based on distorted foundation- 'propaganda' and 'lies' [18]. This in essence will impact the project through threats or unrealised opportunities. Thus, appropriate uncertainty management strategy needs to be implemented in order to reduce or prevent the impact of uncertainty on IPS^2 delivery.

5 DISCUSSION

IPS^2 delivery needs flexibility in order to respond to opportunities and threats that uncertainties create over a given time scale. CfA take a long life view, which uncertainties are exposed to growth due to the complexity of IPS^2 delivery. Morelli [19] stresses that complexity arises due to the complex exercise of interpretation during interactions between various actors and the unpredictability of their behaviours. It is the uncertainties that create complexity in IPS^2 delivery. This may be driven by a number of factors, (1) lack of understanding of systems by all stakeholders, (2) lack of predictability of system behaviour, (3) lack of control of functions in particular environments [20]. Complexity is an inherent feature of IPS^2, and is characterised by:

- Typically, a large number of interacting individual components of the system, which do not have a static interaction between the system and its environment
- System adaptation is necessary, but system usefulness and functionality must not be undermined within this process

There are three levels of responses to uncertainties; operational, tactical and strategic. Operational level response involves correcting an uncertainty within the equipment. Tactical response, involves controlling operating parameters such as temperature, pressure, and humidity. Finally, a strategic level response involves continuous improvement of quality and cost by collaborating and guiding employees and suppliers. This paper has presented the types of uncertainties that arise in IPS^2 delivery, which responses can be at all three of these levels.

For future work, uncertainties that arise in various forms of IPS^2 delivery needs to be examined. Whilst the focus of this paper has been on CfA, trends suggest that the defence and aerospace industry will adopt the capability contract approach in the future. This will further enhance industry's' responsibilities within the operational phase, while focusing on providing required outputs by the customer. The challenges that are faced within such a model, due to uncertainties will require consideration from industry.

6 SUMMARY

Uncertainty emerges as the main barrier in delivering IPS^2, because it encapsulates many factors that are prone to variability or unpredictability. For this reason there is a need to understand types of uncertainties and their potential impact over delivery. This paper contributes in this area by providing a list of uncertainties and their potential impact on IPS^2, collated from literature review and interaction with the MoD and three major companies in the defence and aerospace industry. The contextual focus has been the bidding stage of availability contracts, which are considered to be a form of IPS^2. In total 76 types of uncertainties have been classified into six categories: commercial, affordability, performance, training, operation and engineering. It is envisaged that awareness of these uncertainties and their impact, when designing the delivery of an IPS^2, will enhance capability in project planning, where customer affordability, required profitability for industry and the sustainability of the supply chain is facilitated.

7 ACKNOWLEDGMENTS

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