CHARACTERISATION OF UNCERTAINTIES IN COSTING FOR AVAILABILITY CONTRACTS

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ABSTRACT

There is an emerging trend of offering combined products and services to customers as integrated solutions. These are implemented by contracts such as availability contracts. Uncertainties may arise due to the novelty of the process of designing and managing such offerings, prediction of equipment failure and multiple stakeholders involvement in addition to the long-term nature of the contract. Understanding through-life uncertainties and their impact on cost is critical to ensure sustainability and profitability of the companies offering such solutions. The focus of this paper is to (i) evaluate existing uncertainty classifications and (ii) propose essential considerations for characterising the uncertainties in availability contracts. Appropriate classification of uncertainties should improve the quality of cost estimation by stimulating an understanding and awareness of uncertainties and their characteristics.

1 INTRODUCTION

There is an emerging trend in the provision of services along with products. The combined offering of product and services by Original Equipment Manufacturers (OEM) has a profound impact on the organisations, as it requires the transformation of people, information and equipment (Ng *et.al*. 2011). New contracts must be designed to address the sharing of responsibilities and risks arising due to the provision of service (Vladimirova *et.al*. 2011). The resulting transformation can be described through the evolution of concepts shown in Figure 1.

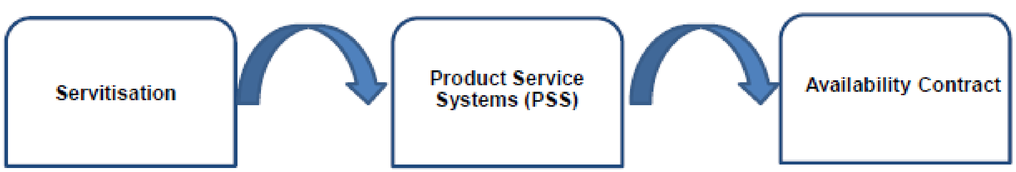

Figure 1: Evolution from concept to application

The concept of a Product Service-System (PSS) is a special case of servitisation, where inadequate experience in the pricing of unified packages of products and services prevails (Baines *et.al*. 2007). Availability contracts are a special case of PSS (Datta and Roy 2010). In availability contracts, service delivery is performed while retaining product ownership. The impact of through-life uncertainty on costing needs to be better understood to devise economically viable and sustainable contracts, where challenges may arise due to difficulties in assessing the value of service to the customer and the inclusion of human behavioural aspects into the cost model (Meier *et.al*. 2010). Additionally, customers desire for technological change to stay competitive and suppliers' performance in terms of productivity and quality are some of the uncertainties arising for the supplier and customer respectively in performance based contracts (Hypko *et.al*. 2010).

The aim of the research described in this paper is on characterising the uncertainties in availability contracts for improving cost estimation. It is hypothesised that an uncertainty classification would aid in analysing and modelling the uncertainty in cost estimate by providing a thorough consideration of their characteristics. The focus of this paper is to (i) evaluate existing uncertainty classification (ii) propose essential considerations for developing a suitable classification to characterise the uncertainties in availability contracts. The following section provides a review of the various uncertainty classifications proposed in literature. Section 3 describes framework analysis as the methodology adopted to characterise the uncertainties in availability contracts. Sections 4 summarises the analysis and findings and provides a proposal of key considerations for the uncertainty classification. Section 5 provides the conclusion and further work.

2 LITERATURE REVIEW

In literature, many uncertainty classification schemes have been proposed, but they have been developed for particular problem areas and no consensus has yet been established even within a specific discipline. A standard classification of uncertainty is required to understand the characteristics of uncertainty, identify and share uncertainty and model uncertainty (Meier et.al. 2010).The recurring core uncertainty characteristics are presented in Table 1. These have been identified from a wide range of literature in Life Cycle Assessment (LCA), Through-Life Costing (TLC), reliability engineering, innovation, organization theory, performance-based contracts, product design, safety assessment, nuclear engineering, service, business decision making and policy analysis.

Table 1: Core uncertainty characteristics

Uncertainty Characteristics		**Description**	**References**
Nature	**Epistemic**	Epistemic uncertainty is due to lack of knowledge and is considered reducible by acquiring further knowledge. Aleatory uncertainty is due to the inherent behaviour of the system/agent and is considered irreducible.	Oberkampf (2004); Walker *et.al.* (2003)
	Aleatory		
Cause/ Source	**Human Factor**	Ambiguity, vagueness, linguistic imprecision, lack of understanding, errors is associated to human factors as a cause of uncertainty. Data availability, information systems are data related uncertainties. Uncertainty related to obsolescence etc. comes under technological uncertainty. A measured valued has uncertainty due to measuring system, measurement procedure etc. Phenomenological uncertainty is due to unknown unknowns.	Walker *et.al.* (2003); Boehm et.*al.*(2000); Goh *et.al.* (2010); Wazed *et.al.* (2009); Wilhelm *et.al.* (2001); Kreye *et.al.* (2011)`
	Data/Information		
	Technology		
	Measurement		
	Phenomenological		
Level/ Scale	**Level of knowledge – Complete determinism to total ignorance**	The spectrum of knowledge reflects the different degrees of uncertainty. At the experimental level, uncertainty due to experiment design, results etc. may arise whereas vagueness etc. act at the cognitive level. Uncertainty in individual experiences etc. and economic factors etc. at the organisational level are specified as micro and macro levels of uncertainty	Walker *et.al.* (2003); Ayyub and Gupta (1994); Kramer (2004);
	Experimental and cogni-tive Level		
	Micro and Macro level		
Location/ Manifestati on	**Context Exogenous/Endogenous**	Depending where the uncertainty arises and the degree of control in dealing with it, contexts are endogenous and exogenous.	Walker *et.al.* (2003); Kreye *et.al.* (2011)
	Model	It is the uncertainty due to simplification of real scenarios.	Goh *et.al.* (2010); Refsgaard *et.al.* (2007);
	Input / Parameter	It is due to depiction/selection of the relevant features of the base system, which is fed into the model. Parameters are those inputs which have fixed value in the chosen context	Oberkampf (2004); Walker *et.al.*(2003)
	Environment	Uncertainty manifested in the individual perceptions and /or in the objective characteristics of the organisational environment	Meijer *et.al.* (2006); Kramer (2004)
	Task	Task uncertainty depends on task complexity, job design etc.	Wilhelm *et.al.* (2001)

Nature, Cause, Level, and Location of uncertainty are the main categories in uncertainty classification (Walker *et.al.*2003; Refsgaard *et.al.* 2007 and Meijer *et.al.* 2005). There are a plethora of literature on uncertainty, hence only key references are included in Table 1. An attempt to consider multiple views of uncertainty including decision makers' view, modellers' view as well as agent's view who is facing the uncertainty upfront while performing a task has been intended. Kreye *et.al*. (2011) introduced an additional category of uncertainties namely 'Expression' which characterises uncertainty as qualitative and quantitative depending on how it has been communicated. Although these have been identified in literature in terms of modelling approaches to uncertainty, they have not been used exclusively used for characterising uncertainty. From the core uncertainties identified, it was found that the five layers of uncertainty classification framework (Kreye *et.al.* 2011) is the closest to the research context of service contracts and therefore this has been adopted in this research.

3 METHODOLOGY

A methodology based on framework analysis, which is a qualitative research method, has been used to guide this research. Framework analysis involves five steps including (i) familiarisation, (ii) identifying a thematic framework, (iii) indexing, (iv) charting and (v) mapping and interpretation (Srivastava and Thompson, 2009). This paper applies the five-layer uncertainty classification framework (Kreye *et.al.* 2011) to characterise the uncertainties in availability contracts identified by Erkoyuncu (2011) by the application of framework analysis. Familiarisation step entailed in understanding the definitions of all the uncertainties listed by Erkoyuncu (2011). He investigated the uncertainties arising in availability contracts through extensive empirical studies and assigned these into categories such as commercial, affordability, performance, training, operation and engineering. The identified uncertainties are the most comprehensive literature available in relation to the research context and therefore it was used to further explore the fundamental characteristics of the uncertainties. Although the list is comprehensive, it requires further refinement in terms of uniformity in granularity. Some of the uncertainties described were highly abstract such as supply chain logistics, whilst others were more specific like the hardware failure rate.

The five-layer classification of uncertainty (Kreye *et al.* 2011) is the thematic framework used, which claims to be a holistic characterisation of uncertainty oriented towards decision making in service contracts bidding. It characterises uncertainty according to its Nature, Cause, Level, Manifestation and Expression. In the indexing step, each of the 70 uncertainties from Erkoyuncu (2011) was propagated through the five-layer classification leading to refinement in terms of a detailed understanding of each uncertainty as shown in Figure 2.

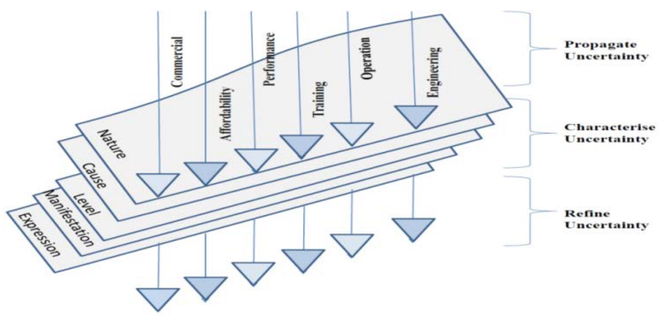

Figure 2: Characterisation of Uncertainties (Kreye et.al 2011and Erkoyuncu 2011)

The uncertainties were not forced to fit into the five-layer classification, facilitating scope for further improvement. This is in accordance with the rules of framework analysis where researcher does not force the data to fit with priori issues (Srivastava and Thompson, 2009). In the charting step, uncertainties are placed in charts that have headings and sub-headings drawn from the framework, few examples are shown in Table 2. Mapping and interpretation step is the analysis of the key characteristics as laid out in the charts and is discussed in the following conditions.

4 ANALYSIS AND FINDINGS

This section presents the key considerations for developing an uncertainty classification for availability contracts.

4.1 Lifecycle perspective of uncertainty

As seen from the core uncertainty characteristics, the location of uncertainty is usually discussed from the modelling perspective (Walker *et al.* 2003). The situations in which uncertainty arise are an important

Table 2: Charting of uncertainties

Uncertainty	Nature	Cause	Level	Manifestation	Expression
Maintainer performance	Aleatory/Epistemic	Lack of information; Poor communication (fault reporting); Human errors	Set	Endogenous; Computational (i.e. how the maintainers performance translates to cost)	Qualitative
Rate of rework	Aleatory/Epistemic	Inexperience (in skill of technician); Lack of information (about future upgrades, part changes); Human error (Insufficient or excess of solder joints)	Interval	Endogenous; parameter (a pre-set leverage for rework)	Quantitative
Rate of systems integration issues	Epistemic /Aleatory	Lack of information; Changes in personnel –System integration happens at the various phases of the long PSS life cycle. Human error – precision in system assembly	Interval	Endo/exogenous; Mathematical/Computational; Data variation/incompleteness (historical data);phenomenological(unknown damage during part transport, weather impact on logistical delays)	Quantitative
Operating parameters	Epistemic	Lack of information, Poor communication (Customer updating OEM of the environmental conditions of equipment operation)	Set	Exogenous; Data variation/inexactness; Computational; Phenomenological- unknown courses of nature	Quantitative/ Qualitative
Cost estimating data reliability or quality	Epistemic	Lack of information and imprecision; Poor communication process - misinterpretation and lack of quality awareness among the estimators working in a group; Conflicting evidence -different experts with different viewpoints; Human errors - In documentation; Human volition – Depends on the judgment of the forecaster and his/her perception of the situation	Interval	Endo/Exogenous; Mathematical/ computational; Data inexactness/incompleteness	Quantitative/ Qualitative

consideration as model predictions are immensely case-dependent (Norton *et al.* 2006). PSS are based on life cycle perspective (Datta and Roy, 2010). Uncertainties arising from the various phases of the lifecycle would be another consideration in the classification. The life cycle phase would determine the type of modeling method to be used, data available as input to the model and the kind of information to be extracted from the model (Asiedu and Gu 1998). Goh *et al.* (2010) have enlisted a number of uncertainties in each lifecycle phase and characterized the nature of uncertainties in TLC. As the lifecycle progress, uncertainty reduces this aspect is well presented in the cone of uncertainty (Boehm *et.al.*2000).

4.2 Context of uncertainty

It is found that many uncertainties cannot be assigned as internal and external to the OEM from the availability contract perspective. This can be attributed to the system issues in contracts of this nature where the customer and supplier come inside the systems boundary in a complex setting that is non-linear and highly dynamic and much more is accomplished for both parties by working closely (Ng *et al.* 2009). To address this issue, endogenous context characterisation of uncertainties should be further sub-divided into inter and intra-organisational context (Figure 3). Inter and intra-organisational context, makes distinction between uncertainties which emerge and hence be managed by the OEM solely (intra) or uncertainty arising due to close collaboration of OEM, suppliers and/or customer and requires a cooperative effort to mitigate the uncertainty(inter). Costing approaches in intra and inter-organisational context is explored by Bastl *et al.* (2010), where he states that traditional costing methods applied to inter-organisational context are inadequate and proposes inhibitors for adopting such approaches. Uncertainties outside of the PSS is classified as exogenous uncertainties, where inflation rates, exchange rates etc. are examples of such uncertainties. Figure 4 presents the uncertainties which fall into inter-organisational context.

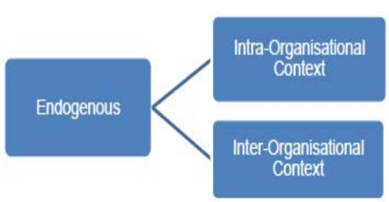

Figure 3: Endogenous Context

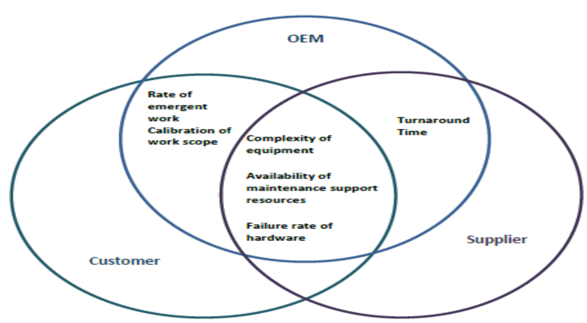

Figure 4: Inter-Organizational Context of Uncertainties

4.3 Nature of uncertainty

Uncertainty classification is inherently subjective, an uncertainty may appear to be epistemic to one actor and aleatory to another depending on one's viewpoint. This is illustrated by Davidson (1996), where he assigns a decision makers inability to assign a probability to an event as epistemic due to his mental and computational limitations rather than aleatory due to the complexity of reality. In availability contracts, an uncertainty previously treated as aleatory (for example, equipment failure rate) now needs further investigation as the OEM bears its impact on cost. There are more incentives to acquire knowledge (reduce epictemic uncertainty) about the systems which was previously thought unnecessary.

4.4 Interaction uncertainty

Interaction uncertainty arises from the unanticipated interaction of many events which should have been foreseen (Thunnissen 2003). Incorporating interaction uncertainty as one of the cause into the classification would aid in modelling of the uncertainties, which have interdependency with other uncertainties. For example, Availability of maintenance support resources (OEM) is affected by the rate of material, OEM logistics/supply chain logistics, equipment utilisation rate (customer), failure rate of hardware and maintainer performance (e.g. maintainers decision to replace a part instead of repair results in usage of more spares). If availability of maintenance support resources is to be modelled, it can be expressed quantitvely as a probability distribution function. Maintainer's performance is expressed qualitatively as expert opinion of a supervisor. This requires the amalgamation of two different data types into the model. Kishk (2004) reviewed various methods used to combine stochastic and subjective data in the context of whole life costing. Many such interdependencies between the uncertainties were unveiled from the uncertainties identified by Erkoyuncu (2011) and will require further investigation.

5 CONCLUSION AND FURTHER WORK

The paper has adopted framework analysis as the methodology to analyse the suitability of an existing five-layer classification (Kreye *et.al.* 2011) to characterise the uncertainty in cost estimation for availability contracts. The uncertainties identified by Erkoyuncu (2011) were propagated through the five-layer classification. Essential considerations in terms of Cause, Nature and Location of uncertainty were proposed. Further work would adapt the classification and apply it to aid in analysing and modelling the uncertainties in availability contracts. One of the key areas of research has been identified in the modelling of interaction uncertainty and the handling of heterogeneous uncertainties. The classification will be validated using industry experts by employing empirical studies including a detailed study of the risk registers. This would involve eliciting any additional uncertainties at the same level of granularity and propagated through the proposed uncertainty classification for validation.

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