CIRP Journal of Manufacturing Science and Technology 7 (2014) 83–96

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

journal homepage: www.elsevier.com/locate/cirpj

Integrating design attributes, knowledge and uncertainty in aerospace sector

Tariq Masood [a,b,c,*], John Ahmet Erkoyuncu [a,c,d], Rajkumar Roy [a,c,d], Andrew Harrison [b]

[a] Manufacturing and Materials Department, Cranfield University, Cranfield, MK43 0AL, UK
[b] Life Cycle Engineering, Rolls-Royce plc, P.O. Box 31, Derby DE24 8BJ, UK
[c] EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services, Cranfield University, Cranfield, MK43 0AL, UK
[d] Operations Excellence Institute, Cranfield University, Cranfield, MK43 0AL, UK

ARTICLE INFO

Article history:
Available online 28 March 2014

Keywords:
Knowledge
Design
Uncertainty
Digital feedback
Life cycle

ABSTRACT

The delivery of integrated product and service solutions is growing in the aerospace industry, driven by the potential of increasing profits. Such solutions require a life cycle view at the design phase in order to support the delivery of the equipment. The influence of uncertainty associated with design for services is increasingly a challenge due to information and knowledge constraints. There is a lack of frameworks that aim to define and quantify relationship between information and knowledge with uncertainty. Driven by this gap, the paper presents a framework to illustrate the link between uncertainty and knowledge within the design context for services in the aerospace industry. The paper combines industrial interaction and literature review to initially define the design attributes, the associated knowledge requirements and the uncertainties experienced. The framework is then applied in three cases through development of causal loop models (CLMs), which are validated by industrial and academic experts. The concepts and inter-linkages are developed with the intention of developing a software prototype. Future recommendations are also included.

1. Introduction

The aerospace industry is experiencing a shift from ad-hoc service provision to integrated product and service solutions that enable the delivery of the availability and capability required from an engine [1]. This has promoted an emphasis of the life cycle implications of engine design due to the shift in the business model, which incentivises reduced maintenance cost whilst enhancing equipment operability/functionality [2]. The need to predict service requirements much earlier than the traditional model (e.g. spares sales) and the bundled nature of service delivery has increased the uncertainties experienced by the Original Equipment Manufacturer (OEM) [3,29]. As a result, the OEMs are facing challenges associated with the boundaries of their knowledge in delivering services within the emerging business model [27].

Knowledge can be defined in terms of a justified true belief [4]. It involves personalised information, which is processed in the minds of individuals [5]. In an industrial setting, knowledge is considered as an 'actionable understanding'. Knowledge has typically been classified into tacit and explicit knowledge and the associated contents depend on the context. Tacit knowledge refers to the personal and experience based nature of knowledge [6]. On the other hand, explicit knowledge involves formally documented, systematic, and well-structured language [4]. Knowledge in context of life cycle design includes a number of aspects associated to different phases of an aero-engine [7]. The existence of knowledge enhances the confidence in events that have been predicted.

Uncertainty refers to things that are not known or known imprecisely [8,15]. The sources of uncertainty have often been classified into two bases, including epistemic and aleatory [9]. Aleatory uncertainty refers to the uncertainty that arises from natural, unpredictable variation in the performance of the system under study [10]. On the other hand, epistemic uncertainty arises from lack of knowledge about the behaviour of the system that is conceptually resolvable [11]. It is worth recognising that uncertainty does not have to hold negative consequences, it may also lead to

* Corresponding author at: Department of Engineering, University of Cambridge, Cambridge CB3 0FS, UK and Centre for Process Excellence and Innovation, University of Cambridge, Cambridge CB2 1AG, UK.
E-mail address: tm487@cam.ac.uk (T. Masood).

http://dx.doi.org/10.1016/j.cirpj.2014.02.001
1755-5817/© 2014 CIRP.

positive outcomes. Though, it may have a constraining role from a decision-making perspective when designing an engine.

The link between knowledge and uncertainty has often been highlighted (particularly in the case of epistemic uncertainty). Ackoff [12] presents that with increased knowledge the level of uncertainty diminishes, whilst emphasising a close association. Understanding the relationship (e.g. root causes) between uncertainty and knowledge can enhance decision making during the design process, whilst influencing the life cycle [28]. For instance, it will be possible to conduct cost-benefit analysis to understand the value of changing the level of knowledge.

In light of the challenge of achieving optimised engine design, this paper aims to develop a framework/methodology to demonstrate the influence of knowledge on uncertainty and the implications of changing the level of knowledge on the level of uncertainty experienced in life cycle design. The objectives include:

- Capture uncertainties;
- Capture design attributes; and
- Build a mechanism that links the level of knowledge and the level of uncertainty.

Uncertainty in design, design attributes, and knowledge are discussed from academic and industrial contexts in the following sections. A digital decision making framework based upon these is also presented along with its application through CLMs. This is followed by validation, conclusions and future work.

2. Methodology

An iterative process was followed to accomplish the objectives of this paper. Close industrial interaction was achieved with four major organisations. A number of suitable research strategies have been considered in formulating the research design to this study. Throughout the research a range of research strategies were applied including, workshops and interviews. The selection of these approaches has been driven by the industrial context of the study and the research focus, which has necessitated an in-depth interaction to understand the current practice and experienced challenges and to validate the developed framework. Fig. 1 demonstrates the steps that were followed as part of the overall methodology for this paper, integrating design attributes, knowledge and uncertainty (DKU).

The first phase focused on understanding the context, where extensive literature analysis and outcomes from attended conferences supported in understanding the types of uncertainties, knowledge and attributes that are commonly considered during the design stage. A rigorous keyword search using service, engine design attributes, uncertainty, cost, design and risk register guided the study. During this stage, industrial interaction was also achieved through collaboration with four major defence and aerospace organisations in the UK. This involved conducting semi-structured interviews. Initially, the focus was on the outcomes of the literature review and the aim was to assess the types of uncertainties, knowledge and engine design attributes that were realised from literature. A total of over 40 h of semi-structured interviews were conducted with designers, attribute owners, cost engineers, project managers, support managers, engineering managers, and functional experts (e.g. in risk and uncertainty). The triangulation approach was adopted to analyse outcomes from the interactions. This involved transcription of the interviews, developing mind maps and writing reports to illustrate the learning to collaborating organisations. Samples of the key questions used in the interviews included:

- What are the attributes considered during engine design?
- What are the types of uncertainties experienced across design attributes?
- How does knowledge affect uncertainty?

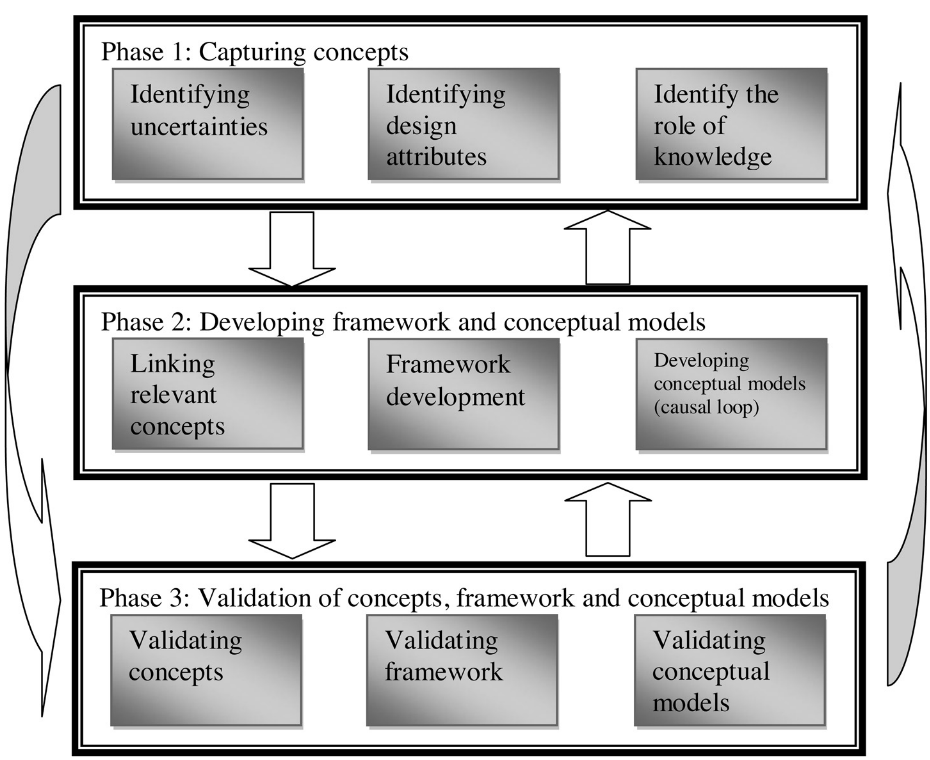

Fig. 1. Methodology – DKU.