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A PREDICTIVE METHOD FOR BENEFITS REALISATION THROUGH MODELLING UNCERTAINTY IN FRONT END DESIGN

Joas Serugga[1], Mike Kagioglou[2], Patricia Tzortzopoulos[3]

ABSTRACT

Many projects continue to fail to deliver intended benefits amid uncertainty in benefits realisation (BR) programs. This is more so in Front End Design (FED) where processes remain not only understudied but also informal yet reliant on knowledge sharing. As a result, there is an emergent need for new decision support tools to support benefits delivery processes. The paper addresses uncertainty with FED processes as a way of facilitating decision making as an enabler to benefits delivery of construction projects using uncertainty modelling. The paper adopts a Dempster-Shafer approach using probability theory. This is combined with Quality Function Deployment for user and design requirements capture and management. A conceptual model is suggested that forms a basis for future validation and evaluations in action research in various contexts. The Paper introduces a novel approach to uncertainty modelling in FED to support decision making. The Dempster-Shafer Bayesian based approach also contributes to new ways for capturing contextual influences to benefits realisation.

KEYWORDS

Benefits Realisation, Dempster-Shafer Theory, Uncertainty Modelling.

INTRODUCTION

Bradley (2016) has defined BR as *‘an outcome of change, which is perceived as positive by a stakeholder’*. As such, BR is aimed at delivering satisfaction to the end-user in terms of benefits and utility, also called *‘Value-In-Use’* (Sweeney et al., 2018). It’s therefore apparent that the process of identifying requirements and managing them is a waste reduction process. There are still major challenges in AEC in the delivery of intended benefits in many projects (Burger et al., 2019, Bradley, 2016). This failure of delivery of project core objectives has been attributed in part to complexity and uncertainties inherent within many projects (Burger et al., 2019); and insufficiencies in applied BR decision support frameworks (Bradley, 2016). Moreover, research into uncertainty particularly in a lean project delivery system (LPDS) is still widely understudied. Some isolated process conceptual studies such as bidding (Aslesen et al., 2018), improving reliability in processes

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[1] PhD Candidate, Huddersfield, HD1 3DH, UK, +44 7553231992, joas.serugga@hud.ac.uk

[2] Professor of Process Management, Art, Design and Architecture, School., Dean, Univ. of Huddersfield, Huddersfield, HD1 3DH, UK, +44 1484472289, m.kagioglou@hud.ac.uk

[3] Professor of Integrated Design, Architecture and 3D Design, Depart, Univ. of Huddersfield, Huddersfield, HD1 3DH, UK, +44 1484472281, p.tzortzopoulos@hud.ac.uk

(Javanmardi et al., 2018) have been limited and specific. Recently, some authors such as Torp et al. (2018) have attempted to add to the existing body of knowledge looking at uncertainty into management integration in Last Planner System (LPS) of planning and control to improve benefits delivery success. At the sametime, authors continue to argue for renewed emphasis on benefits delivery away from traditional focus on project processes (Smyth, 2018) and tasks and activities (Kagioglou and Tzortzopoulos, 2016). Chesbrough et al. (2018) on the other hand argue that sometimes the issues arise out of deliberate *'conceptual ambiguity'*. Moreover, Bolar et al. (2017) highlights challenges in integrating end-users to collaboratively facilitate delivery of project benefits through requirements management. Such research reinforces the position that such factors as these affect the knowledge base that guides decision making resulting in unplanned reworks, over processing/production, 'making-do' and inventory among other wastes prevalent in FED processes .

Through BR, AEC processes are able to extend the notion of benefits beyond the immediate organisational/portfolio/program interface to collaborative processes involving end-users and other stakeholders, etc. in value co-creation.

In this paper, a conceptual benefits optimisation method is presented on the basis of quantified uncertainty modelling. The method provides a first step in the development of a novel approach to improve BR in Front end Design (FED) perspective. In so doing, BR processes can gain from decision support employing a combination of requirements capture using the Quality Function Deployment (QFD) – management and Design Requirements (DRs) transformation (Akbaş and Bilgen, 2017, Yazdani et al., 2017); Utility Theory (UT) for utility of benefits analysis (Keeney and Raiffa, 1993); and the Dempster-Shafer theory (Dempster, 2008, Shafer, 1976); in conjunction with Saaty (2001) Analytical Network Process (DS/ANP) for uncertainty modelling. The combined toapproach are able to combine requirements management and knowledge uncertainty modelling for decision support.

According to literature, processes can be optimised as part of the wider planning, monitoring and control process either through (i) analysis, (ii) inspection, (iii) demonstration, (iv) testing or (v) certification (Kukulies and Schmitt, 2018). Parts of this process are seen in lean practice in the LPS (Torp et al., 2018, Kim and Ballard, 2010) and application of BIM (Bataglin et al., 2017) to support decision making. The suggested optimisation processes proposed in this paper is at the planning stage in FED processes with two process aims: 1) Assessment and analysis of BR processes in meeting the delivery of intended benefits and 2) Identify FED deficits potentially impeding the delivery of these benefits. The two aims are interrelated in the fact that while the first draws relation between User Requirements (URs) and Design Requirements (DRs) and their potential conflicts and interdependences, the second sums up what might not go right in the process. The second aim therefore captures the non-value adding processes that affects delivery of intended benefits. Optimisation processes will in themselves bear costs and benefits relating to time and resources. For this reason, the proposed method employs QFD to refine and model information relating to user requirements and how they relate to design requirements and capture any interdependences between the various parameters to reduce on resource use. Bolar et al. (2017) study using QFD and Hidden Markov Modelling (HMM) changing end user expectations to address the challenges of end-user integration construction processes. Yazdani et al. (2017) describe the importance of sound supply chain selection in delivery of green aims for organisation and proceed to use QFD & MCDM to apply it to green supplier selection to improve organisational competitiveness. UT on the other hand is employed to analyse the utility of the benefits themselves and the nature of the decision maker again contributing to better refined information for the DS/ANP analysis. Uncertain information relating to context, opinions from stakeholders and related risks is still able to be analysed alongside the refined information. The reality according to Kukulies and Schmitt (2018) for design processes is fraught with incompleteness of information and knowledge (see **Error! Reference source not found.**).

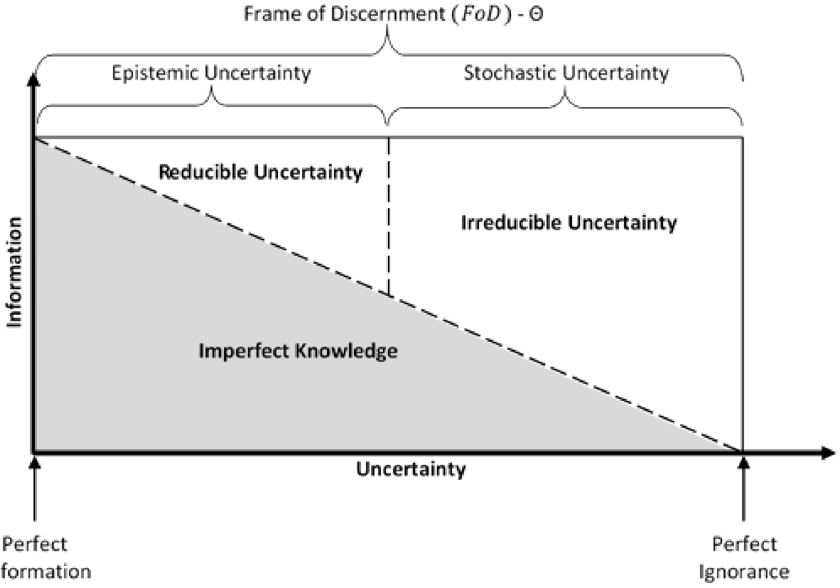

Figure 1 Relationship between Knowledge and Uncertainty(Adapted from Kukulies and Schmitt (2018)

Decision making process for example is unable to fully anticipate all the preference structures for all of the benefits. FED processes are therefore unable to definitively pronounce on all utilities and ultimately on value across the entire decision state space. This results in a three part state space in **Error! Reference source not found.** (Kukulies and Schmitt, 2018). The fully known part of perfect information where decision making is able to pronounce itself on the outcomes, the partially describable part of imperfect knowledge which accounts for most of the reducible uncertainty; and finally the indescribable part of perfect ignorance. The latter part is dominated by epistemic uncertainty. All these parts define the Body of Evidence (BoE) during uncertainty analysis.

BENEFITS REALISATION

A successful BR program aims to define benefits through management of stakeholder and end user requirements for implementation collaborative (Del Águila and Del Sagrado, 2016, Horkoff and Yu, 2016). BR cycle is thus a key element in FED for its overarching and collaborative approach between organisational strategy and end-user and stakeholder processes. Horkoff and Yu (2016) point to the fraught FED process in which requirements modelling is difficult; knowledge intensive (Del Águila and Del Sagrado, 2016), characterised by *'imprecision and ambiguity'* (Muñoz-Fernández et al.).

Problem Statement

Lean wastes affect production processes and in FED in particular waste in design processes will negatively impact projects leading to downstream project *dis-benefits*. This can be through unplanned reworks, making-do, transportation and motion or over processing and over production and even through inventory. AEC projects continue to fail to deliver on their intended objectives as a result. Numerous authors ague some problems in downstream processes can be traced back to FED (Kukulies and Schmitt, 2018).

In AEC, FED continues to be less understood, yet its processes are essential in capturing the elements that help shape the intended benefits both through user requirements management and design requirements transformation. It's also an important stage in setting collaborative aims for the project. Kagioglou et al. (2000) ealier highlighted wider challenges more generally in process planning among AEC projects that not only continue to be unlinear, but also largely *'uncoordinated and highly variable project processes'*. More recent research points to opportunities in FED. For example, by adopting a value co-creation approach Fuentes and Smyth (2016) and Smyth et al. (2018) separately argue that project benefit from information and knowledge sharing among collaborating multidisciplinary teams. However, FED processes are still largely little studied, remain highly unstructured and are prone to influences of both personal and contextual dynamics resulting in uncertainty across the entire project delivery cycle (Austin et al., 2001). These challenges precipitate in for example unplanned reworks (Koskela et al., 2013) , and *'making do'* (Koskela, 2004) , in FED processes that will result in delays and extra costs for the former and might affect the scope and quality of the project all affecting its intended benefits in the latter. Controlling these wastes according to authors can improve the BR cycle. For example, any needs for unplanned reworks can be detected early on; while uncertainty relating to designs processes without the full information can be assessed. Similarly, complex and over designs should be assessed for their contribution to the benefits cycle.

In the lean world, the LPS for planning and control (Javanmardi et al., 2018, Salazar et al., 2018, Torp et al., 2018, Kim and Ballard, 2010), choosing by advantages (CBA) - (Nguyen et al., 2009), Virtual First-Run Study (Nguyen et al., 2009), Language Action Perspective (Salazar et al., 2018) and BIM (Aslesen et al., 2018) have been widely applied to support planning, control and decision making. The works by Cortes et al. (2018) present some interesting perspectives in Multi Criteria Decision Making (MCDM) using CBA in delivering project benefits. However, there doesn't appear any evidence of accounting for uncertainty in the application of the tools. Despite the emergent body of research in BR, current methods are limited in supporting decisions on selection of critical benefits for optimisation and analysis; particularly on a quantitative and mathematical basis.

FRONT END DESIGN AND UNCERTAINTY

Definitions for uncertainty are varied and broad. Uncertainty in the context of this paper is that relating to fluctuations in knowledge and information lending to Klir (2004)'s definition as *'the appearance of an existing information deficit'*. Uncertainty categorisations on this basis are captured in **Error! Reference source not found.** to include stochastic – that relating to physical and nature events. This kind of uncertainty is non reducible in the sense that any further new information is unlikely to reduce it. This can involve such elements as nature or context specific physical features. For example, any further information about weather patterns may not necessarily change reduce the uncertainty related to it in FED. On the other hand, is epistemic uncertainty – that relating to knowledge deficit that's reducible. This essentially captures knowledge deficits and limitations in understanding relating to a *'phenomenon, a system or its environment'* (Kukulies and Schmitt, 2018). An example is knowledge of the location of glazing depending on the hemisphere is essential in improving design for maximum solar gain.

UNCERTAINTY MODELLING

Current lean approaches have largely adopted qualitative approaches to uncertainty management in AEC processes more generally; see (Javanmardi et al., 2018, Salazar et al., 2018, Torp et al., 2018). In mathematical modelling, various models of uncertainty modelling exist but mainly probability based and classed as levels 1 and 2 (Kukulies and Schmitt, 2018). In the first level, simplistic approaches such as Monte-Carlo sampling are used to model known stochastic distributions for the unknown yet dependent target value with a yet unknown distribution. The process therefore aims to calculate a distribution function of the dependency of the input variable and the target value. This type of modelling however fails to capture uncertainties relating to stochastic and epistemic uncertainty arising out of deficit in knowledge, data sets, conflicting information and even conflicting personalities. These uncertainties can however be accounted for by level 2 modelling which is a lot more complex. Epistemic uncertainties are also considered in the Frame of Discernment (FoD). Kukulies and Schmitt (2018) contribution is an highlight to this emergent body of research to employing uncertainty modelling in bring stability to design process through reducing unplanned reworks. The Dempster-Shafer Theory is used for this paper's proposed methodological approach.

THE DEMPSTER SHAFER THEORY OF UNCERTAINTY

Current MCDM methodology is insufficient to account for actions spaces of imperfect knowledge (Hua et al., 2008). Today, many research approaches make use of Bayesian theoretic of conditional probability and related adaptations like the Dempster-Shafer (DS) theory (Dempster, 2008, Shafer, 1976); to account for uncertainty in decision making (Hua et al., 2008, Beynon, 2005). The key importance of the DST according to many authors such as Denœux et al. (2018), among others is its ability to account for uncertain and unknown knowledge areas through providing the Frame of Discernment (FOD) and the basic probability assignment (BPA) to facilitate uncertainty information modelling. Incomplete BoE is assigned basic probability assignments (bpa) to describable and partially describable focal elements and the indescribable/FOD all assigned as DS mass functions $[m(.)]$ in an action space (Denœux et al., 2018). The following is the preliminaries of the DST.

A finite non-empty set of mutually exclusive set of acts is denoted as $\Theta = \{S_1, S_2, \ldots, S_i, \ldots, S_n\}$ is called the Frame of Discernment (FOD). The power set 2^{N} is the full set denoted as $2^{\Theta} = \{\emptyset, \{S_1\}, \{S_2\}, \ldots, \{S_N\}, \ldots, \{S_1, S_2\}, \ldots, \{S_1, S_2, \ldots S_i\}, \ldots, \Theta\}$. The mass function on the other hand is a set from $m(.): 2^{\Theta} \to [0,1]$ such that $m(\emptyset) = 0$, and $\sum_{A \epsilon 2^{\Theta}} m(A) = 1$. $m(A) > 1$ captures the strength of belief/evidence in a benefit proposition and is called a focal element – essentially an alternative benefit for analysis while $m(\Theta)$ is the level of ignorance meaning the non-discernible weight of evidence among the focal elements. In a BoE with n as set of focal elements in a BoE $m(.)$ defined as $s_1, s_2, \ldots, s_n$, with corresponding weights of $b_1, b_2, \ldots, b_n$ respectively, according to Beynon (2005), the BoE could be represented as:

$$m(s_i) = \frac{b_i p}{\sum_{j=1}^{d} b_i p + \sqrt{n}}, j = 1,2, \ldots, n \ and \ m(\Theta) = \frac{\sqrt{n}}{\sum_{j=1}^{d} b_i p + \sqrt{n}} \qquad (1)$$

Where p is the weighting for the criteria and Θ the FoD. The basic probability assignment (bpa) can also be represented by a belief function $Bel\ (A) = \sum_{\emptyset \neq B \subseteq A} m(B)$ and a Plausibility function $Pls\ (A) = \sum_{B \cap A \neq \emptyset} m(B)$. For two independent mass functions $m_1 and\ m_2$, the Dempster rule of combination can in this case be used to combine the two as follows:

$$m(A) = m_1 \oplus m_2(A) = \begin{array}{ll} 0, & A = \emptyset \\ \frac{1}{1-k} \sum_{B \cap C = A} m_1(B) m_2(C), & A \neq \emptyset \end{array} \qquad (2)$$

Where k is defined as:

$$k = \sum_{B \cap C = \emptyset} m_1(B) m_2(C) \qquad (3)$$

k is also a normalisation constant reflecting the degree of conflict between $m_1 and\ m_2$

UNCERTAINTY BASED BENEFITS REALISATION PLAN

FED is information intensive, iterative and relies on knowledge to define and manage user requirements, transform these into design requirements that deliver the expected benefits. Thus feedback mechanisms are part and parcel of the process to enable information refinement from design optimisation processes such as analysis, data fusions, and design drawings including schemas, concepts, 3D-models and other imagery in the definition of benefits. These activities are what links the BR and uncertainty modelling. This link has yet to receive the required scrutiny in research and academia. The two conceptualisations i.e. BR on one hand and uncertainty modelling on the other are in the main discussed separately if at all in a FED perspective. The proposed model links these two conceptionalisations presenting a new method that can support prediction of *(dis)* benefits starting at a project's FED.

UNCERTAINTY BASED BENEFITS REALISATION PLANNING MODEL

Error! Reference source not found. is the proposed uncertainty based Benefits Realisation Planning for FED.

What's intended in the model is for the methodology to draw on the link between benefits realisation processes in FED and related uncertainty and uncertainty modelling using the DS/ANP theory. The seven Step methodology employs various tools for information capture, management, modelling, optimisation and iteration. This includes following steps:

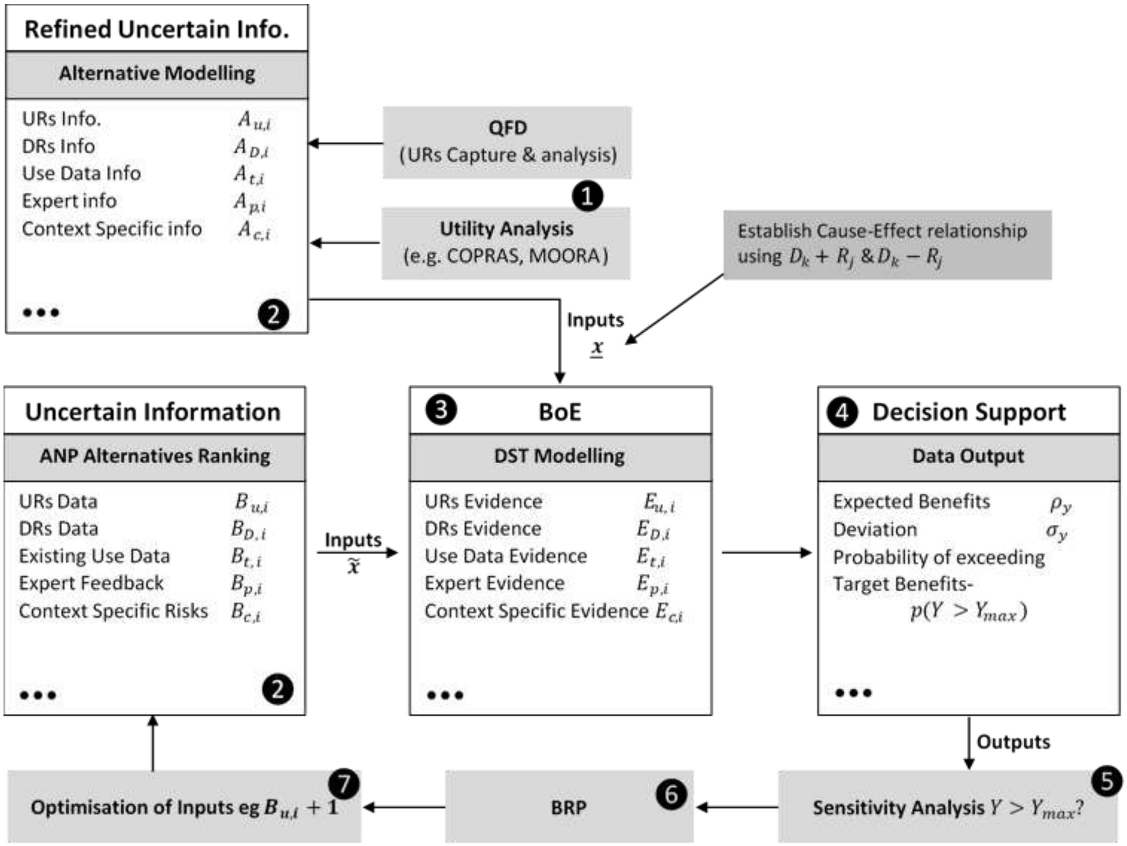

Figure 2 A conceptual Approach to Uncertain Based Benefits Realisation Planning

Step 1 – Define both refine-able and raw data and target benefits and related information. In this step, it's important that information able to support a BR and BRP process is gathered relevant to the specific analysis. Some of this data is able to be refined using pre-analysis modelling tools seen below while other information can be treated as raw data. Multiple variables can be dealt with even with varying lower level attributes. The project core purpose is perhaps the starting point in definition of potential benefit variables plus higher and lower level goals. BR has a particular focus on change management at the organisation-portfolio-program interface where some of these goals will already be defined. Stakeholder input in just as important so a collaborative approach can best serve this approach in defining scope, costings and delivery times while end users can be invaluable in guiding on user desires for example. Any approach to BR has first and foremost to set parameters that define the degree to which benefits can be achieved and how these can be planned and optimised. Secondly, risks to achieving these benefits have to be defined in the same light including identifying critical non value adding processes. FED processes aim to manage URs and transform these into design requirements. As such it's important that in this stage, QFD is suggested as a useful tool to identify both URs and corresponding DRs on the basis of the expected benefits of the project.

Step 2- Model Input data as refine-able and uncertain variables ready for DS/ANP modelling. This is part cleaning process where some data can be pre-modelled prior to input into the DS/ANP model. The proposed model suggests the use of QFD, Utility analysis employing the Complex Proportional Assessment of alternatives (COPRAS) and multi-objective optimization on the basis of ratio analysis (MOORA) to refine and rank URs and DRs using first a QFD analysis that yields ranking for URs and follow on comparison with identified DRs. data can be capture and pre-modelled for example as user benefits information. This is adopted through use of House of Quality (HOQ) importance weighting for the matrix (Yazdani et al., 2017). The three methodologies are not discussed in this paper owing to the limitation of scope. However, their combination contributes to the refined set of data to run alongside the uncertain data from other raw sources. Rankings for URs and DRs basing on a weighting can be obtained and the utility of benefit established among alternatives. Decision makers are adjudged to have propensity for maximisation of Utility of benefit. For utility to be maximised or minimised, equation (4) captures the scenarios when l is the objective to be maximized and r is those to be minimized For $x \in X = [x \geq 0]$:

$$Max\ E[U(x)] = U(y_1 x, y_2 x, \dots, y_l x), Min\ E[U(x)] = U(y'_1 x, y'_2 x, \dots, y_r' x) \quad (4)$$

The matrices U and G in Equation (5) capture the URs interdependences (Sahu et al., 2018) and DRs pairwise comparisons respectively.

$$U = \begin{bmatrix} 0 & y_{12} & \cdots & y_{1j} & \cdots \\ y_{21} & 0 & \cdots & y_{2j} & \cdots \\ y_{31} & y_{32} & \cdots & y_{3j} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nj} & 0 \end{bmatrix}, G = \begin{bmatrix} 1 & x_{12} & \cdots & x_{1j} & \cdots \\ x_{21} & 1 & \cdots & x_{2j} & \cdots \\ x_{31} & x_{32} & \cdots & x_{3j} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & 1 \end{bmatrix} \quad (5)$$

G is normalised by $X = k.a$ where $k = \max_{1 \leq i \leq n} \left(\sum_j^n a_{ij} \right)^{-1} (j = 1,2, \dots, n)$ and thereafter through matrix transformation computing for the total relation matrix $T = X(I - X)^{-1}$ to establish for each criterion how it's ith criterion is influenced by its jth (Sahu et al., 2018). Ranking are obtained by $D_k + R_j$ where $D_i = \left[\sum_{j=1}^n t_{ij} \right]_{nx1} = [t_i]_{nx1}, (i = 1,2, \dots, n)$ and $R_j = \left[\sum_{i=1}^n t_{ij} \right]_{1xn} = [t_i]_{nx1}, (j = 1,2, \dots, n)$. At the end of this step, two sets of data in steps 2 should be defined forming the BoE.

Step 3 – Define the Uncertainty Modelling parameters and Model the variables in the DS/ANP model. This step is the application of the DS/ANP modelling process outlined briefly in section 0. In so doing, the process establishes firstly uncertain information from the previous step from the various sources about the yet undetermined benefit(s) as model input variables. Secondly, draw relation between the benefit(s) information and inputs on a quantitatively. Thirdly, establish and analyse the uncertainty using one of the various methods such as $u(\{b_i\}) = Pls\ (\{b_i\}) - Bel\ (\{b_i\})$ or more elaborate methods of dissonance, such as the

Generalised-Hartley method or Average Width within the BoE to the extent of delivery of the intended benefit(s). Lastly, develop decision support basing on the results to attempt to reduce the uncertainty or validate the conditions for benefit(s).

Step 4 – Produce and Analyse Preliminary Results. This phase involves setting threshold parameters for analysis of the results. Combined evidences from the BoE are collected alongside their uncertainty calculations from the FOD. Rankings can for example aim to define Expected Benefits (ρ_y), deviation (σ_y), and defining the probability of any assessed parameters of exceeding Target Benefits- $p(Y > Y_{max})$. This step is important in the definition of a BRP on the basis of results from the DS/ANP modelling.

Step 5 – Carry out Sensitivity Analysis: In this step, depending on how far the uncertainty in an alternative is from the threshold, a sensitivity analysis can be carried out to establish what's the most contributor is to the uncertainty. By identifying such intricate information about a specific uncertainty, it's possible to model the decision support process to best meet the required benefits. It might suffice that more reliable information is needed in which case uncertainty in a benefit will be reduced. Alternatively, new data as evidence on a given specification can have the same desired effect. The BRP can thus engage with the process of reducing uncertainty to influence the true utility of benefit.

Step 6 – Define the Benefits Realisation Planning (BRP) program on the basis of the results from the sensitivity analysis as part of a feedback process with information about modelled uncertainties. The BR process established benefits to be analysed from a set of alternative parameters. It might suffice that uncertainty modelling reveals irreconcilable results to the level that data from data sources cannot be refined any further to support uncertainty reduction. In this case its prudent that the BRP has room to take account of this data and consider redefining the benefit in question. Conversely if the data supports the BoE in the benefit(s) then the BRP can adopt the results as decision support.

Step 7 – Iterate over uncertain information for results that do not meet criteria as new input variables. These results can then form part of a new iterative analysis as additional input variables that will yield a higher value weighted BoE in regards to the benefit. The whole analysis process can thus be updated potentially leading to improved values of uncertainty about the benefit. Should the results improve to meet or exceed the threshold, they can be adopted in the BRP. If they don't, then the process can iterate over the previous steps again.

CONCLUSIONS AND FURTHER RESEARCH

The proposed model presents a predictive mechanism for BR on the basis of uncertainty modelling. Waste among FED and AEC processes in general will affect the level and quality of information and knowledge that results in uncertainty among processes and ultimately affecting the delivery of project intended benefits. Current BR practice doesn't quantifiably account for this uncertainty yet the challenges remain in knowledge management in design processes. At the same time, uncertainty modelling promises a unique opportunity for predictive modelling using the DS/ANP approach that's gaining wide appeal among many other sectors of industry and new frontiers in AI. The proposed uncertainty based BR methodology is on the basis of existing concepts and methods such as QFD, UT and ANP. These methods and tools are used to improve some data while the model still accepts raw uncertain data to be compared alongside in establishing the BoE. The DS Bayesian theoretic is used to account for the FoD that accounts for the uncertainty within a BoE and assigning Belief and Plausibility mass functions. The results are dependent on quality input data during BRP mechanism a major challenge to the method for it to support improved delivery of planned benefits in FED. None the less the proposed method promises a practical basis for decision support for project management when implemented as an IT based system (BR Evaluation App) and also for validation and evaluation action research. This novel approach to uncertainty modelling presents opportunities for deep state understanding of design process to provide that significantly improves for decision making. Further evaluation in various project contexts will aim to assess the effectiveness of the method to assess how contextual factors influence the nature of decision making on the basis of context. It will also help draw comparisons of any improvements from the proposed methodological application as opposed to existing practice in terms of the results.

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