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Design and Manufacturing Uncertainties in Cost Estimating within the Bid Process: Results from an Industry Survey

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Abstract
This paper discusses the issues of the bidding process with emphasis on the design and manufacturing uncertainties that can occur. The context of the paper is within manufacturing companies and in particular within the Defence sector. The paper presents the bidding process of a large Manufacturing company and details the main challenges and uncertainties that may occur. It also discusses the methods that are currently used to tackle uncertainty. The results of an industry survey compare the practices of other manufacturing companies and highlight the challenges at the bidding stage. The paper concludes that the development of an appropriate framework is necessary in order to effectively manage uncertainty at the bid stage.

Keywords:
Bidding Stage, Cost Estimation, Uncertainty

1 INTRODUCTION

The business of many organisations is based on performing contract work obtained by submitting and winning bids to client organisations in competition with other contractors. This paper describes the bidding process of a Manufacturing organisation within the Defence sector, common activities and the various challenges faced at this stage. It also presents the results of an industry survey within the Manufacturing sector in order to underline common issues. Each organisation aims to prepare accurate cost estimates at the bid stage of a project whilst maximising profit and adding value to the customer. During the project lifecycle, uncertainty diminishes as time progresses, revealing more information and increasing confidence. During the bid stage, however, uncertainty is not often foreseeable as the progression of a project may vary considerably from an early viewpoint. Therefore, uncertainty is at its peak during the bid stage, particularly when the bid team are considering new projects or products including innovative technological requirements. The scope of the project life cycle in this study is restricted up to the concept, assessment, demonstration and manufacturing stages of the Ministry Of Defence's (MOD) CADMID cycle. In-service and disposal stages are out of scope of this research. The focus is on cost estimation practices and challenges for the manufacturing of a tangible product.

2 RESEARCH METHODOLOGY

The industry survey was carried out using a semi-structured questionnaire. A face-to-face interview approach with mixture of open and closed questions was adopted to enable a clear understanding of the problems faced in a qualitative manner, as described by [1]. The results presented here involve the responses of 14 experts from 5 different organisations for various Manufacturing sectors including: aerospace (9), automotive (2), oil & gas (1) and consultancy (1). Figure 1 shows the nature of projects that each of the participants is responsible for. The average duration of each interview was approximately 90 minutes.

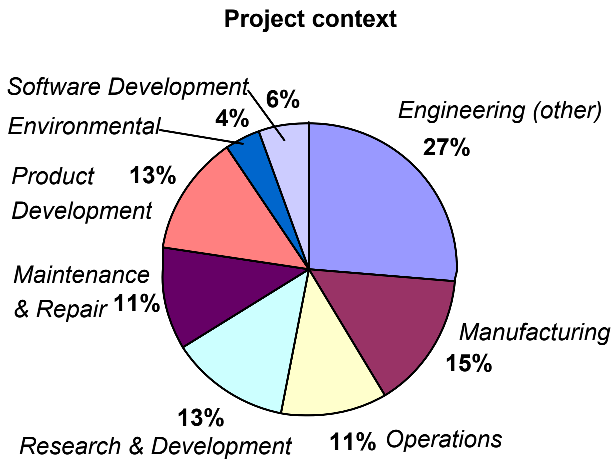

Figure 1. The project context for the participants

The results gathered were used to obtain an overview of uncertainty management and cost estimation at the bidding stage. Questions to set the context were the monetary size and type of industry sector of existing projects. The key areas of focus were cost estimation and uncertainty management, both within the context of the bid process. Cost estimation techniques and their utility and usefulness were explored. Some open questions were required to add knowledge to the study, such as where respondents identify the problems are when an estimate's accuracy is significant. Uncertainty questions were designed to name sources of uncertainty and methods used to identify them.

Analysis of the results involved compilation of each questionnaire and reviewing the answers based on the role category of respondent. This provides an indication of which area of work they are typically referring to. For example, a more senior level of staff will usually portray issues that occur from a high level such as: "poor statement of work documented". A design engineer may refer to: "poor verification" as a problem area.

3 RELATED WORK

The business of many organisations is based on performing contract work obtained by submitting and winning bids to client organisations in competition with other contractors. Cost estimation techniques are therefore critical when utilised in the bidding process of a project/product. The focus in the UK defence sector of the bidding process is that fixed-price bids are invited for a specified piece of work, and the contractor submitting the lowest bid and all other things being equal, is awarded the contract. The client's decision is relatively straightforward, but the contractor's decision on what price to bid is more difficult. Bidding low in the face of competition increases the chance of winning the contract but reduces profitability. However, bidding at a level which ensures a good return increases the chance that a competitor will win the contract by submitting a lower bid. The problem is compounded by the difficulty encountered in estimating the probability of winning with a given bid, and by uncertainty about the costs involved in performing the contract [2].

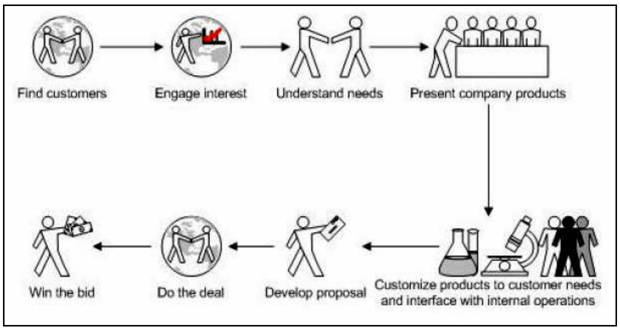

Figure 2. The bidding process (Behrens, 2003)

Figure 2 presents a graphical overview of the bidding process as presented by [3]. The first steps of the bidding process involve managerial/soft actions that include locating the customer, engaging interest and presentation of the company's products. For the bid to be acceptable, the company's products must be properly customised to meet the customer's needs. The next step is to develop a proposal and this is the step where cost estimation is largely involved. In order to develop a successful proposal that secures the deal and results in winning the bid, an accurate as possible cost estimate is required. What makes the bidding process important is that, according to [2] considerable expertise is required in preparing bids, since the terms of the bid not only influence the chances of winning, but also shape the working context for successful bids. Effective and efficient bidding processes which are based on a sound understanding of all the important issues, and the concerns of all parties involved, are critical success factors for contractor organisations.

3.1 Uncertainty Management

The focus of the current research is placed upon the identification and control of uncertainty in the context of the bidding process. Uncertainty is a relatively new concept in that it is not fully understood, even by those that are appointed to manage it. There is a lack of a coherent definition for uncertainty. There is considerable ambiguity between uncertainty and risk within industry. One reason for this confusion may be due to the fact that uncertainty is present within each risk. There are different types of uncertainty (e.g. epistemic and variability), whereas risk is a singular concept of an event leading to an unfavourable impact.

Uncertainty is comparatively different to risk. Uncertainty expresses a lack of definitive knowledge around a task or activity and for that reason, as opposed to risk/opportunity; uncertainty does not differentiate between positive and/or negative. However, the very idea of it being unclear can be intimidating since the precise impact is unknown. The importance of uncertainty has only recently become clear in terms of organisational performance [4]. When a project fails to meet the expected outcome, it is assessed to determine the areas that resulted in failure and this is where elements that were not anticipated may be identified. This section starts by defining uncertainty and identifying its main sources. It then continues by providing modelling approaches and methods to manage uncertainty.

There are essentially two common approaches to classify uncertainty. The first is to apply a classification based on the degree of uncertainty such as that presented by [5] shown in table 1. Uncertainties are allocated into groups according to how uncertain each element is perceived to be.

Lack of Knowledge
Lack of Definition
Statistically Categorised Variables
Known Unknowns
Unknown Unknowns

Table 1. Uncertainty Classification (Hastings, 2004)

Lack of knowledge entails elements that are not known or only known imprecisely, which can be reduced by acquiring available knowledge relevant to the uncertainty in consideration. This acquisition of knowledge can be through research or experimentation. Lack of definition refers to the areas of a project that have not been clearly specified. Time is a critical factor in this category as specifications need to be allocated appropriately. Thus difficulties may arise if definitions are placed too early or too late for specific elements. Solutions to such uncertainties are achievable through effective project management. Statistically categorised variables include events/conditions that are difficult to determine with absolute exactness but they can be modelled using statistics (e.g. probability distribution). The inflation rate is a suitable example for this category, in that the exact value difficult to ascertain but is often modelled with a range of values. Known Unknowns refer to events/conditions similar to the previous category but with increased vagueness in the probability of occurrence and its associated impact. A suitable example is the prediction of the inflation rate at a future date. Unknown Unknowns are the very problematic uncertainties as they are very difficult to determine and even when efforts are made to begin identification they may appear impractical to include in an estimate. A true and disastrous event relating to this category is the terrorist attack on the New York's Twin Towers.

The second approach entails grouping uncertainties with similar characteristics forming an array of sub-categories. These can be highly diversified though examples of groups may include political, environmental, behavioural and so on. This is demonstrated by [6], who presents types of uncertainties from a variety of engineering perspectives as well as others, such as economics. His overarching types of uncertainties in complex systems are frequently referred to in literature. These are epistemic, aleatory, ambiguity and interaction (less common). Ambiguity is described as linguistic imprecision by this author and interaction uncertainty relates to unforeseen interactions between events. This interaction may result in multiple outcomes, which may be difficult to determine prior to occurrence. Epistemic uncertainty is also referred to as reducible, subjective, type B and state of knowledge uncertainty. This uncertainty is due to any lack of knowledge regarding the context under study. Hence, reduction in epistemic uncertainty can by accommodated by increasing relevant knowledge. Aleatory uncertainty is also known as stochastic, variability, irreducible, type A and inherent uncertainty. Attempts made to reduce this may fail as the nature of aleatory uncertainty is inherent and depicts variance in the available data, which cannot be reduced with more information [7]. The source of epistemic uncertainty is from outside the system, whereas aleatory uncertainty originates within the system as if part of it. Epistemic and aleatory uncertainties are more common amongst many authors including [8], [9], and [10]. [11] and [12], however they regard the use of this terminology ineffective as it does not place emphasis on how uncertainty should be managed. An uncertainty matrix was developed in [13] which was distinct from the two above, categorising uncertainty into three different dimensions. These are location of uncertainty, level of uncertainty and nature of uncertainty. Each dimension has further sub-categories to defining specific uncertainties.

The cost estimation process includes several inputs from a potentially large number of stakeholders across multiple functions of an organisation. As a result, the level of subjectivity is high and the question arises whether suitable bias, such as relevant domain knowledge, has been introduced. This will enable more realistic and well defined estimates rather than ambiguous suggestions from inexperienced members. The bid stage may regularly face projects that have limited information so that subjective input from an expert would be required. The level of subjectivity increases as objectivity reduces. Objectivity is viewed as historical data from previous projects and subjectivity is that which is provided by a subject matter expert (for example a predicted value from personal experiences) who may not have complete information. It is important to note that computer simulations may also tend towards subjectivity as their assumptions are provided by expert individuals. Objectivity and subjectivity are notions that are difficult to isolate, however this appears to be dependent upon those bidding for a project. A completed project will have elements of objectivity, such as the final result(s). The subjective components can be identified in the early life of the project. It is possible to understand both these aspects at each stage of the project and form relationships to comprehend efficiency at the bid stage.

4 QUESTIONNAIRE RESULTS

An overview of the results is described in this section, giving a summary of the responses provided. One of the first questions investigated the average project size in the participating companies. The responses regarding the average size of projects (in monetary terms) usually undertaken by the companies were recorded. Here, the majority (49%) of the projects are above £10million and 25% between £1m and £10m. Therefore this sample of projects require an effective bidding process. Errors made within the pre-concept phase of a project may have critical impact on cost, performance and schedule and since most of the projects deal with such issues at such large scale in terms of cost, it is important to ensure that projects are estimated and bid for in an efficient way.

Another question was concerned with the number of the bids that each company has to prepare on an annual basis. With the exception of the 3 respondents who prepare a significantly large number of bids (between 40 and 50), the average bids per participant lies around 10. One respondent is also an exception with zero bids as he comes from an insurance position. Having to prepare and bid for ten projects per year can be a frustrating process where each successful case can play an important role as the department's performance indicator. Therefore, it is important to have a robust and effective bidding process in place that limits uncertainty and ensures successful cases. The participants were also asked to propose any improvements on the current bidding process that they follow. Many of them proposed a framework which will provide organised feedback of lessons learned, data and benchmarking. Also an accurate statistical analysis of the main risk factors and a clear understanding of the bidding purpose along with clear focus from the customer were proposed. The overall feeling was that there is a need for better data capture and metrics.

Two of the questions were related to uncertainty, and both were open-ended. The first involved the perception and definition of the participants towards uncertainty. The second sought to investigate the sources of uncertainty within the cost estimate of the proposed design at the bidding stage. The definitions given about uncertainty reveal the diversity of understanding around the subject. A common denominator in all the answers was related to unknown events. Uncertainty towards an event's impact was a frequent occurrence from the interviewees. The responses provide a wide range of explanations but not confident definitions. The respondents' definitions often referred to risk rather than uncertainty itself. Several answers were very generic and vague, whilst some were expressed in the context of cost estimation although that was not required. Five responses referred to the impact of an occurring event, which is related to project risks and not uncertainty. The respondents were more specific on the sources of uncertainty. According to a significant number of participants, the sources of uncertainty are identified by the steps in a risk management process. For example using brainstorming and/or multi-disciplinary workshops to identify risks and evaluate probability and impact. Also in terms of the bidding process, the bid team are asked to identify the level of uncertainty associated with the bid. Regarding the sources of uncertainty, it is interesting that although the respondents were specific, very few responses have common elements. Cost, technology and future are identified as three of the factors that were mentioned by most of the respondents.

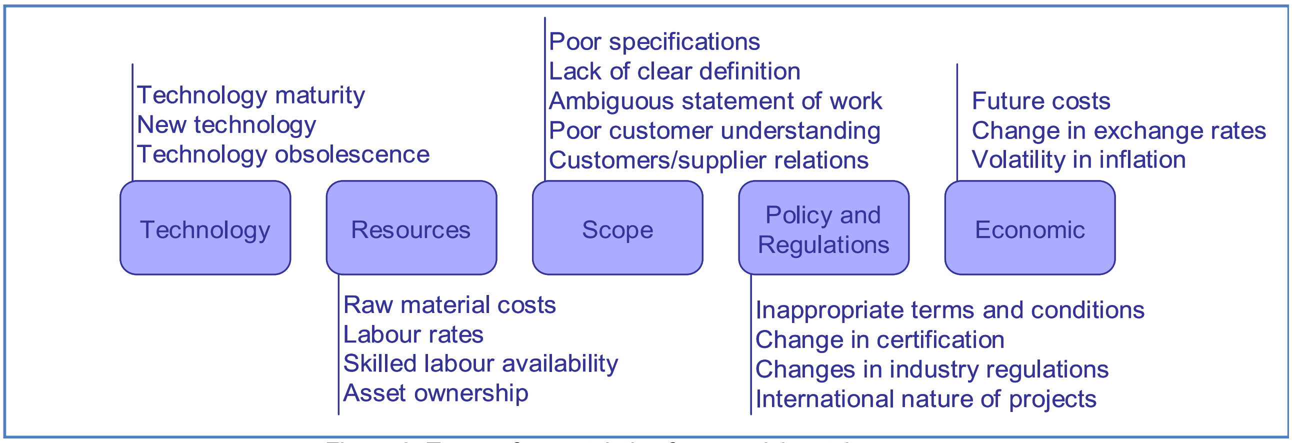

Figure 3. Types of uncertainties from participants' responses

Figure 3 shows these responses along with types of uncertainties in groups. These are typical uncertainties involved in long term contracts/projects at the bidding stage. In relation to figure 3, an alternative uncertainty classification methods [5] and [6] are presented, which is part of a framework developed in decision making.

One reason for confusing uncertainty and process complexities may be due to current management of uncertainty. Currently, uncertainty is assigned to elements of a process such as a Work Breakdown Structure (WBS). Therefore, it may be assumed a complicated WBS suggests a complex level of uncertainty, which is not necessarily true. From reviewing all the responses, there may be a tendency to incorporate a high level of subjectivity when dealing with uncertainty.

4.1 The bidding process of a Manufacturing Defence Company

This section describes the bidding process of a large Manufacturing company from the Defence sector and describes the key uncertainties identified. Although uncertainty is a concept crossing several industry sectors, scope may not always extend beyond the requirements of the Defence sector as the solutions offered by other disciplines may not facilitate it. In order to gain a practitioners perspective, a series of face to face interviews were carried out using a semi-structured questionnaire lasting approximately 1 hour. Topics included uncertainty management, existing bid processes and the issues surrounding these aspects. This approach was taken to best acquire knowledge from industry practitioners as the semi-structured questionnaire allowed room for interviewees to expand upon selected topics, surfacing problems that were not originally considered.

Description of the bid process

The bid process captured is shown in figure 4. Initially the company carries out market analysis to identify potential customers. Once interest is expressed, the needs of the customer are assessed alongside current market conditions and company objectives. This leads to the starting point of the process shown in figure 4 where the company must decide whether or not to go ahead with the project or not. If a particular project is of no interest then the bidding process would cease, due to incurred cost of the process itself. If the decision is to proceed with the bid, the process begins with three initial steps, occurring simultaneously. There is communication between all three. Alternative solutions to the bid will be presented relative to the design requirements. Concurrently, plans and schedules will be introduced into the project, consisting of historical data from previous projects.

The approach by analogy is taken when utilising these to assign relevance to this particular project. A separate team will be preparing the bid proposal, dealing with requirements and structure of the bid. Communication within these three phases is crucial as each is essential in generating the proposal.

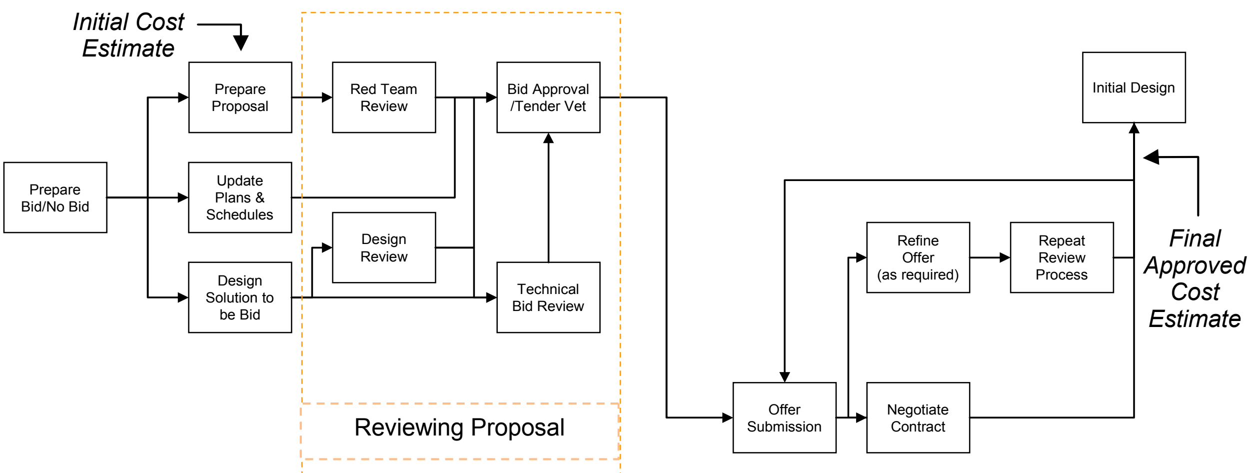

Figure 4. The Bid Process of the Manufacturing Defence Company

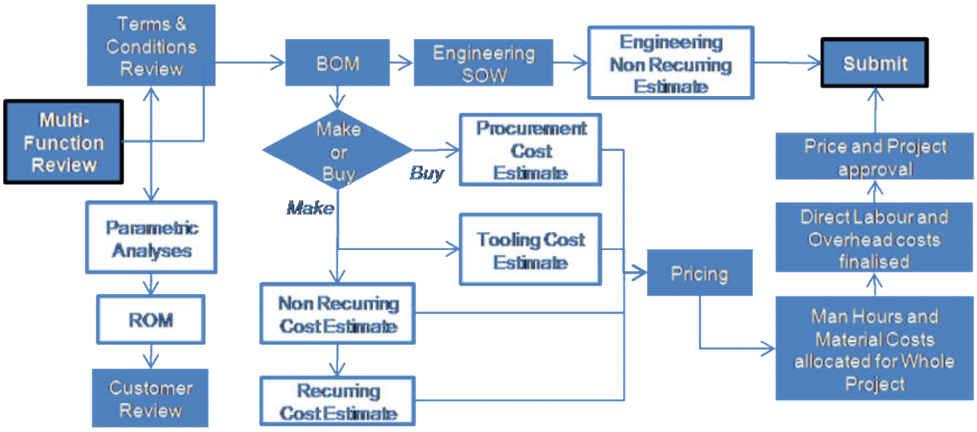

Figure 5. The Cost Estimation Process (manufacturing context)

Once the proposal is complete, it undergoes the "Red Team Review". This essentially is a group of experts that were not involved in producing the initial proposal. The review reduces inappropriate data, possibly due to optimism or pessimism bias. The review is conducted to give the proposal a "second look" to identify, correct and report potential issues and to check bid sensibility. The Technical Bid Review comprises of experts assessing the engineering costs and the associated uncertainties. This does not include the entire proposal itself but only the specific design solution selected. All the data gathered and processed will be presented to experts of selected functions in a formalised report. This will be reviewed at great detail to ensure all aspects have been covered and to question those that may be ambiguous. Uncertainties are challenged at this stage, whether it be new ones not considered or those included. This review is also known as Request for Bid Approval (RBA). If successful through all the reviews the offer is submitted to the customer. It is important to note that the customer and associated suppliers may be involved at various stages of reviews. This is to ensure that all aspects have been covered and iterations of the review process is minimised. The feedback received from the customer may entail some form of negotiation of the contract the company has submitted. If any changes have been suggested the proposal will be modified accordingly where reiteration(s) of the review process follow. If successful this will lead to project initiation and the contract will be realised.

The bid team faces many problems at this point in a potential project's lifecycle as the level of uncertainty is highest. This is usually due to incomplete information, lack of experience and further pressure introduced by allocating a time limit to submit the proposal. Major issues faced at the bid stage include both internal (organisation processes) and external functions (supply chain operation).

Internal issues include lack of clarity surrounding uncertainty and its communication to multiple levels of the organisation's hierarchy. A cost estimate will be calculated based on subjective input from multiple functions. With this large array of information, deciphering a final cost estimate proves to be a difficult task. This may lead to poor decisions by senior members, who may not have the correct level of information at that time. There also seems to be a high level of dependency on experienced staff members due to the insufficient amount of time available for junior or less experienced staff to complete bid activities. A key internal issue is that concerning historical data and its validity. There is a lack of confidence in using historical data. This is due to poor recording of data during a project's life, which is therefore uncertain. This is currently overcome by applying three point estimates to historical data but this gives rise to additional uncertainty that will prove difficult to justify and rationalise when compiling the final cost estimate.

Proposed solutions and their requirements may not be coherent, practical or affordable. These are addressed by working closer together but these interactions may be lengthy and require considerable effort to understand what the customer actually wants. In terms of suppliers, there may be a number of areas where double counting may occur, thus affecting the cost. These may be reduced by working closer with the suppliers, however, with limited time, interfacing at length with both customer and suppliers poses a threat to a project and/or the organisational strategy.

The Cost Estimation Process – an overview

A summary of the cost estimation process is shown in figure 5, which is indicated as the 'prepare proposal' box in the bid process (figure 4). At this point the project has been approved to bid for and a multi-function review will take place to evaluate the contents. The terms and conditions will be one of the outputs at an early stage, ensuring the legal and regulatory issues have been managed. The white boxes with a blue outline are estimates (or part of an estimate) produced by the relevant functions. These are compiled together and adjusted according to the project requirements through a number of iterations, alongside several reviewing stages, as shown in figure 4. Note that figure 5 is a generic process representing milestones completed at various stages.

4.2 Challenges in Uncertainty Management for Cost Estimates at the Bid Stage

The cost estimating process was found to be lacking general planning [14]. With uncertainty at its peak at the bid stage, correct planning and methods must be potentially utilised in its prediction for the lifecycle of a project. Whatever is uncertain today will be more certain as time progresses (see figure 6) but the problem lies in predicting the actual impact of each uncertainty. Duplication of any risk or uncertainty is reduced by initially developing the base estimate without uncertainty and risk. They are reviewed around the base line estimate at a later stage which involves multiple iterations. The process deals with both risks and opportunities, though the latter involves realisation costs to achieve a positive result.

Uncertainty is regarded as the inherent variability around a 'most likely' point. It is regarded as uncertainty due to its ambiguity and lack of precise knowledge towards each scenario. There are no categories allocated for different types of uncertainty unlike some examples found in literature ([5], [6] and [13]). Categorisation processes,

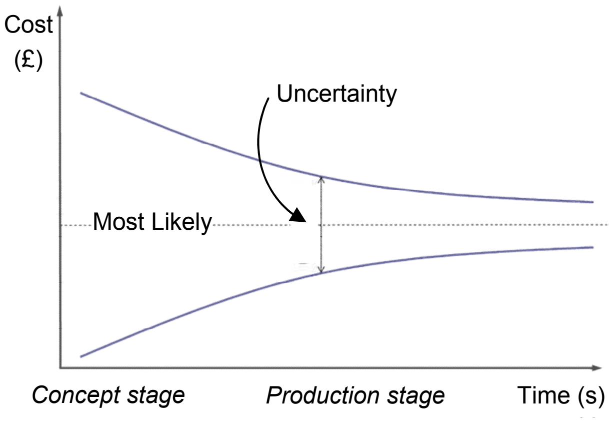

Figure 6. Uncertainty in a Cost vs. Time perspective

specifically for the types of uncertainty, may be too extensive to integrate within a business environment, which may already comprise of complex processes. Allocating uncertainty to each element of a work breakdown structure (WBS) or a cost breakdown structure (CBS) is one method practiced in the Defence sector.

Workshops are often used to assess relevant risks and opportunities, usually composed of stakeholders from multiple functions/departments in order to cover all aspects of a project. A checklist of questions is also a common approach to cover general aspects of uncertainty from company documentation. Another approach for surfacing uncertainties is by assessing similarities and differences of two or more independent cost estimates for the same project. Issues such as optimism bias, which potentially leads to underestimates, can be tackled at this stage by introducing more than one perspective and method.

Monte Carlo simulation is the common method of modelling uncertainty as it has proven to be an effective tool within industry. The inputs used are three point estimates, which are produced with increased precision. For example, the minimum and maximum values are not simply tails of a probability distribution but are values that have been assessed and have rationale. In some cases they will be related to budget, where the minimum will be the minimum budget. Once Monte Carlo simulation has been used another tool, tornado charts, are used to observe the sensitivity of each cost element and how it affects the final cost estimate. Prior to simulation, experts will perform rough order of magnitude (R.O.M.) estimates which can be compared to that of simulation later in the bid process. Common practice may also involve the development of 'as is' and 'to be' models to understand the requirements against the capabilities.

4.3 Uncertainty at the Design Stage

There are two areas of uncertainty at the design stage. One is the uncertainty around the product being developed and the second being the process of design itself. This section is in the context of the latter. The effectiveness of the design process is crucial to the development of the product and so must be thoroughly managed. Any errors made at this stage may cause significant impact in terms of cost, schedule, performance and quality, as this will dictate the nature and functionality of the product. It affects all the stages of the life cycle. For example, if a product has reached the end of its life, it may be revealed that the cost of disposing this is much greater than expected. Thus qualified and experienced personnel must be allocated appropriately. Uncertainties are shown in figure 7.

4.4 Uncertainties at the manufacturing stage

This stage is one of operations that aims to manufacture the product that has been designed. If there are issues with the product from the onset then manufacturing staff may not be able to address it as they may not be aware of it. Uncertainties mainly exposed to largely involve resources (labour, materials & tooling), equipment (machines) and overheads. All procurement activities need to be efficient at this stage in order to maintain an efficient production line. Communication with multiple functions is important at this stage as staff need to be aware of schedules (particularly the critical path), in order to prevent overruns. Typical uncertainties at the manufacturing stage can be seen in figure 7.

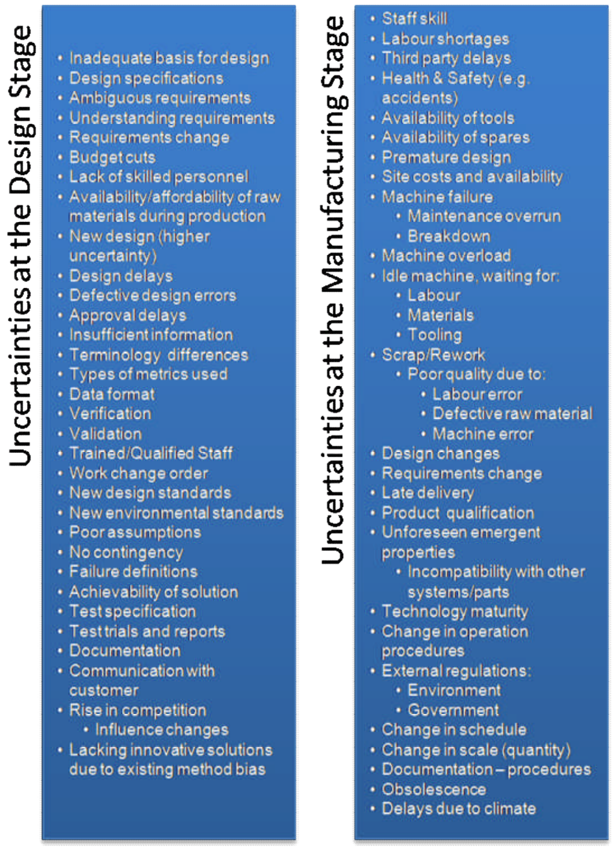

Figure 7. Design & Manufacturing Uncertainties

5 DISCUSSION AND CONCLUSIONS

There have been several issues raised regarding uncertainty. It is proposed that a formal definition and methodology is required to improve the integrity of future projects. Clear distinction between uncertainty and process complexity must be made to reduce the level of project complexity and lack of understanding, if entered into a new business domain. However, there is very little knowledge on how extreme cases (low probability of occurrence) of uncertainties are handled at the bidding stage. Examples of such uncertainty are unknown unknowns, which are those that have not been considered but may still have a damaging impact on the project/organisation. Also, there is not enough understanding of the distribution of a cost estimate, whereas some regard it as not being wide enough to include uncertainties that may have been overlooked.

The communication of uncertainty is not as clear as it should be. As a result, uncertainty is not understood in the same manner by all stakeholders from engineers to senior management. A varied background would lead to a variation in terminology [15]. A solution would be to map customer requirements to effectively design solutions. It may be well received in qualitative form but may require attention when transferring to a quantitative form. Another solution would be understanding uncertainty in the new business environment of service solutions by retrieving accurate historical data. Current approaches create ambiguity in the accuracy of data, reducing confidence. This may have to start with techniques that have effective ways of recording the data to enable accurate retrieval.

What was also noticed was high dependency on experienced members of staff. Inexperienced staff members require more time to complete tasks than the bid allows by using multiple software programs during the bid that are not integrated. Also, the communication of the bid document to senior members of staff is an issue as they may not fully understand how the confidence levels were arrived at or what uncertainties have been taken into consideration and where. As a result, more emphasis should be placed on each variable's behaviour towards the final cost estimate.

Many aspects can be considered that can offer solutions to in order to address several issues by offering a methodology that may be developed into a software model. Examining the design and manufacturing stages shows the need to clarify uncertainty and communicate it effectively. The following are possible areas the research will contribute towards a more reasonable cost estimate.

- A formalised methodology used during bidding to help identify and manage the uncertainties involved up to and including the manufacturing stage.
- An effective mapping system that allows visibility of the capabilities required by the customer as functional requirements and their respective design solutions.
- Offer a method to identify uncertainties in a simpler fashion that will allow those with little experience to complete the tasks in the time allocated without too much involvement from experienced staff members.
- Develop an effective means of communicating uncertainties to all the stakeholders, across all hierarchies, involved in the bid process. This will give more meaning to the final cost estimate and justify its distribution and not just the 'most likely', 'worst case' and 'best case' scenarios.

This paper presented the bidding process of a large Manufacturing company in the Defence sector, which discussed the key challenges and uncertainties that may occur during the process. It also presented the results of an industry survey regarding these issues. The paper concludes that the development of an appropriate framework is necessary in order to effectively manage uncertainty at the bid stage. The focus areas of the framework have been identified and involve areas of modelling and managing uncertainty in an effective way.

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