Information display for decisions under uncertainty

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INFORMATION DISPLAY FOR DECISIONS UNDER UNCERTAINTY

M. E. Kreye, Y. M. Goh and L. B. Newnes

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1 Introduction

To assure the success of a project or new product, the consideration of Through Life Costs (TLC) is an important factor for the success or failure of a project [Roy 2003]. The process of forecasting and decision making is essential to produce accurate estimates. In this context, the information given to the decision maker and the time available for a decision are often limited, especially in early design stages. The estimation of TLC deals with the future of the considered product or project and the future is not known. That means uncertainty is inherent to the decision making process in forecasting and cost estimation. In an uncertain world good decisions can lead to bad consequences and vice versa [Radner 2000].
To support the decision making process taking into account of uncertainty in TLC the research presented in this paper introduces an experiment undertaken to test the subjective processing of forecasting information in order to produce an estimate. First, the state-of-the-art of current research in forecasting and decision making will be explained. Then, the set-up of the experiment, realisation and results will be described. Finally, conclusions drawn will be explained and the impact on future research will be illustrated.

2 State-of-the-art

Within this literature review two research domains are critiqued. First the existing literature and points of views on the topic of forecasting are introduced and evaluated. The topic of decision making in general and game theory specifically are then reviewed.

2.1 Forecasting

Cost forecasting is applied across a number of sectors and has been acknowledged in many sectors and areas, both in research and practice [Zotteri and Kalchschmidt 2007; Hong 2008]. It is an important input factor for decisions about projects, production etc. Forecasting is the estimation of the future value of something, especially of future values or costs of certain variables/products [Tay and Wallis 2000].
Forecasting is a relevant method when there are deficiencies in the availability or certainty of the necessary information for example due to limited resources to obtain such information. It can provide important input information to problem solving and decision making [Adolphy et al. 2009]. When a more detailed analysis is not available either because it is not necessary, impractical or impossible due to restrained resources such as time or information, forecasting can be used [Pahl and Beitz 2001]. It offers a quick way to assess a situation where there is “no well defined best solution or design” [Goguen 1967].

2.2 Decision Making under Uncertainty

The problem of decision making has been discussed in many domains by many authors, especially in the field of economics and management [Clemen 1991; Abdellaoui and Hey 2008; Yager 2008]. Decision theory generally offers a framework for decision making under uncertainty [Pomerol 2001]. As the term "decision" is used in every day language, many research papers lack a definition or a clear distinction to other, related terms [Radner 2000; Arkes and Hammond 1986; Xu et al. 2007] What is intrinsic in all the papers reviewed is the interpretation of a decision as a final point or an action that separates two periods from one another [Hoffman and Yates 2006]. A decision can be defined as "making a choice of what to do and not to do, to produce a satisfactory outcome" [Tang 2006]. It can be interpreted as a commitment to an action with the constraint of serving the interest or value of the decision maker [Yates and Tschirhart 2006]. Hence, a decision is simply "made" whilst the decision process is more complicated than this [Hoffman and Yates 2006].

The decision process can be divided into a number elements, such as the decision problem, uncertain events of Nature, and the value of specific outcomes [Abdellaoui and Hey 2008]. A decision problem does not just include the choice between different alternatives of a product but can also be a choice between scenarios. The term scenario here depicts the outcome of a sequence of moves by the decision maker and Nature. In decision theory the term Nature describes the influence of uncertainty to the future outcome of the decision.

The possible moves of the decision maker and Nature can be numerous which results in a permutation of possible combinations. The occurrence of a certain state of Nature is beyond the control of the decision maker. In other words, it is independent of the decision maker's action [Radner 2000]. (Radner 2000). The influence of the limited ability of human beings to deal with or describe complex scenarios has been discussed and analysed by various authors [Sent 2004; Rubinstein 1998; Radner 2000]. Key words here are bounded rationality and robust decisions.

It is assumed that the decision maker only has and expresses preferences among the consequences, not among the actions per se (Xu et al. 2007). For example it is no more appealing to a decision maker to conclude an insurance contract rather than not. He/she does, however, have preferences amongst the consequences, which can in general be described as the preference for a high payoff rather than a lower one. Furthermore, a decision maker is assumed to have a belief of the probability of a certain state of Nature to occur. The beliefs can be expressed in certain point probabilities or as ranges, eg between 40 and 50%. One major requirement is the independence of preferences and beliefs. Hence, the preferences of the decision maker concerning the consequences are independent of the states in which they occur, as well as the belief of the probability of the states occurring is independent of the accompanying consequences (Radner 2000).

One key word in decision theory is the instrumentally rational decision maker which means that every individual has preferences over various things. This individual will select the action that will best satisfy those preferences. In case of a preference of choice A over B and B over C, the person also prefers choice A over C. This assumption has been widely argued [Simon 1954; Sent 2004; Allais 1979] and the approach of bounded rationality was introduced [Radner 2000; Rubinstein 1998]. This area of research explores which limits and bounds for the decision makers rationality exist. This paper will explore these limits on the decision makers ability in the area of cost estimating and forecasting.

3 Experiment

The experiment presented in this paper was constructed to test how the subjective processing of information can be influenced in order to produce a credible forecast. The influence of subjective judgement of the decision maker within the literature was highlighted in the literature as being influential on the forecasting outcome [Tay and Wallis 2000; Goodwin and Wright 1993; Sanders and Ritzman 1992]. For this experiment the three key types of judgement identified from the literature were investigated, namely:

- to extrapolate information of past series to the future,
- to adjust statistical time series, and
- to integrate both time series and contextual information (holistic forecasts) [Goodwin and Wright 1993].

To investigate the decisions taken, it was necessary to identify the types of information typically available in a forecasting process. This includes time series information, labels and contextual information. Time series illustrate information of the past, eg the past development of the costs of a product. Labels are the representations of the forecast, eg monthly sales. Contextual information gives further background on the decision problem. However, the boundaries are not clear mainly due to judgement in terms of what is considered relevant/irrelevant to the problem. One of the objectives of this experiment was to find out where the boundaries of contextual information are.

3.1 Experiment Design

It was found that displaying information in a graphical display resulted in an improved understanding of data compared with using textual information [Speier and Morris 2003; Speier 2006]. Due to these findings the experiment focused on analysing people's decision making, based on different graphical displays.

The overall aim of the experiment was to ascertain the most appropriate way of displaying a forecasting problem. Two research questions to meet this were;

1. How much contextual information is needed?
2. How detailed the given information needs to be in order to be fed into a decision making process?

To achieve this, the experiment examines how;

- different representations of information,
- contextual information, and
- different levels of detail of contextual information,

are interpreted and used in a decision making process.

3.2 Experiment Set-up

The experiment consisted of two questionnaires to be completed by the decision makers (participants). To reduce the likelihood of the participants remembering what they selected in questionnaire 1, questionnaire 2 was completed by the participants after a significant time difference. Both questionnaires contained the same forecasting scenario: the person answering the questionnaire was asked to give forecasts of the price of a raw material for two different years in the future. Each questionnaire asked the participants six questions.

- First, they were asked to give an estimate for the future costs of the raw material for 2014, based on the information given.
- Then they were requested to give the reasons for their answer, which was phrased as an open question.
- Finally, they were asked to illustrate the confidence level for their own estimate. Six discrete intervals were given between which the participants could choose. Those were 0-20%, 21-40%, 41-50%, 51-60%, 61-80%, and 81-100%.

The same questions were asked for an estimate for 2018 (Questionnaire 2).

The two questionnaires differed in the amount of information that was given to base the decision on.

- Questionnaire 1 only gave some general information of the forecasting problem and a graph with the historical and estimated future price of the raw material.
- Questionnaire 2 included more detailed information on the forecast, eg what the different values meant and what the underlying assumptions were based on.

In order to test different ways of displaying information, the participants were divided into three groups A, B, and C. They stayed in their groups throughout the whole experiment, i.e. somebody who answered questionnaire 1 from group A would also answer questionnaire 2 of that group. For each of the groups different graphical displays were used to represent the forecasting information, namely;

- a three point trend forecast for group A,
- a bar chart with minimum, medium and maximum estimates for group B, and
- a FAN diagram for group C

as shown in Figure 1. The graphical displays were used to assess the differences between different graphical representations of the data. Each of the graphs consisted of the same information and labels, a forecast scenario with minimum, medium and maximum values.

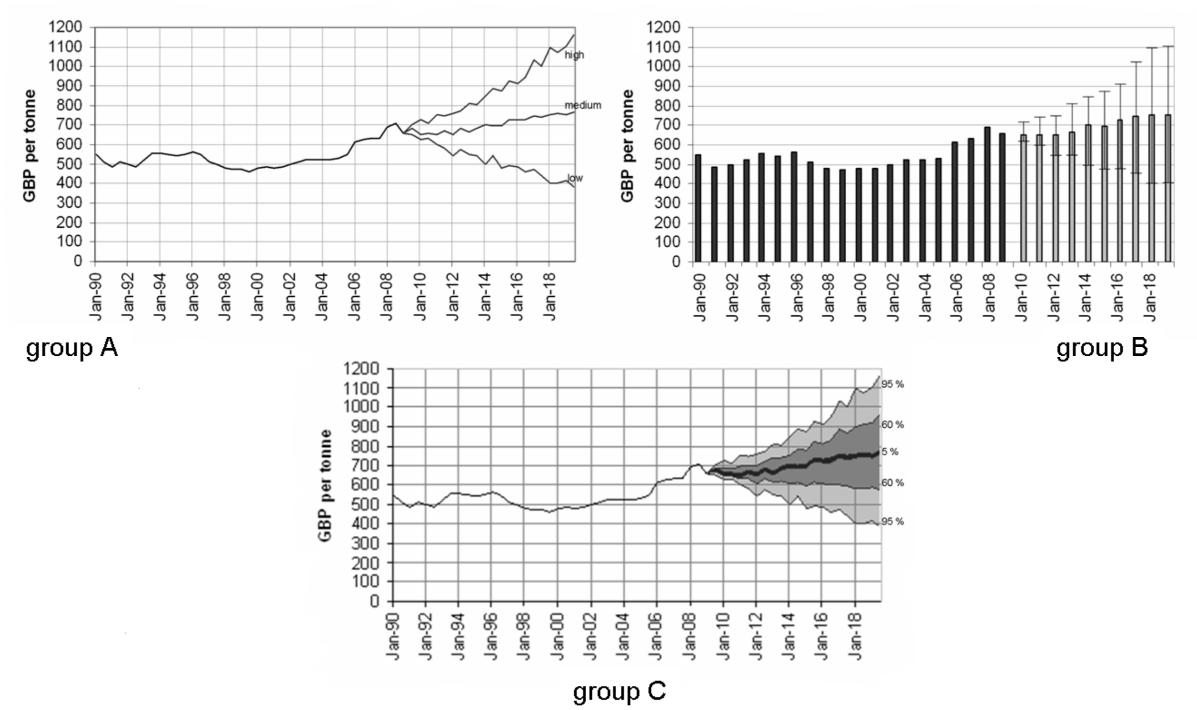

Figure 1 Graphical display of the forecasting problem

To reduce the influence of interpreting past trends and time series, the data was adjusted accordingly. Therefore, only five out of 45 participants of the experiment mentioned the influence of trends or past time series on their future estimate, four of which abandoned this idea when given more contextual information of the forecasts (Questionnaire 2).

3.3 Participants

The experiment was carried out at a conference attended by costing experts from the aerospace and defence sectors. The number of total participants was 45. To ensure that each participant would stay in the same group throughout the whole experiment, their name tags as well as the questionnaires were colour marked. The distribution among the groups was:

- 13 participants for group A,
- 14 for group B, and
- 18 for group C.

Of all the participants, 75% stated that they had worked before with a diagram as presented to them in the experiment and 40% had used it in their work with differing frequencies. Of the ones who had used it in their work, the frequency ranged from weekly to occasional use:

- 13% stated that they used it once a week,
- 27% used it once a month,
- 20% used it once every other month,
- 20% used it once a year,
- 20% used it occasionally.

Table 1 summarises the results per group in terms of familiarity with the diagram in the questionnaire and whether they had used the type of diagram in their work.

Table 1 Participants' experience with diagram according to the groups

Question	Group A			Group B			Group C		
	Yes	No	Y/N-Ratio	Yes	No	Y/N-Ratio	Yes	No	Y/N-Ratio
Have you seen a diagram like this before?	81.8 %	18.2 %	4.5	80.0 %	20.0 %	4	64.3 %	35.7 %	1.8
Do you use this type of diagram in your work?	54.5 %	45.5 %	1.2	33.3 %	66.7 %	0.5	28.6 %	71.4 %	0.4

The results for groups A and B had similar proportion of persons who had seen a similar type of diagram to the experiment having a 4/4.5 ratio respectively. This ratio was significantly smaller for group C. The degree of expertise, in other words participants who had used this type of diagram in their work, was the highest for group A and alike for both group B and C. These numbers will be interpreted further in Section 4.

4 Results

In this section the results of the experiment are analysed and explained in terms of the contextual information, the type of diagram used to display the information and the reasons given for estimate selection from the participants.

4.1 Contextual Information

As mentioned previously the contextual information does affect how people make forecasting decision. An interesting observation in this experiment is the regions in which the estimates were taken from the graphs.

Figure 2 shows the proportion of the different forecasting values for 2014 and 2018 from questionnaires 1 and 2 for each group. If a range forecast was given, it was classified as either “low < medium” or “medium < high” depending on which side of the graph it was taken from. Figure 2 (group A) shows that there is a big adjustment in the forecasting values for group A between questionnaire 1 and 2. The participants consequently changed the value of their forecast with the extra information given from a value of “medium”/“medium < high” to lower cost estimates. This change can be explained by a conservative attitude of the decision makers in the beginning which changed into a more informed decision with rather adjusted answers to their beliefs when given more contextual information. This conclusion is supported by the fact that the estimates for questionnaire 2 are spread amongst more of the possible answers than for questionnaire 1.

Figure 2 (group B) illustrates how the answers for group B focused around a medium estimate, even more so for the 2014 estimate. There were no low or high estimates and the difference between questionnaire 1 and 2 is not significant. As expected, the 2018 estimates spread a bit more with a further orientation to a conservative estimate. Significant influences of contextual information can be found for group C shown in Figure 2 (group C). The contextual information caused the central majority of participants to place their estimate within “medium < high”, namely into the direction of a higher estimate. For 2018 almost 70% of participants chose an estimate in “medium < high” forecast compared to an almost equal value for “medium” and “medium < high” for questionnaire 1. This can be explained with most of the participants interpreting the additional contextual information in the same way. This development is opposite of the reaction for group A. This can be interpreted as the graphical display of the information in a three-point trend forecast as shown in Figure 1 (group A) made the participants more conservative than the display in a FAN-diagram (group C).

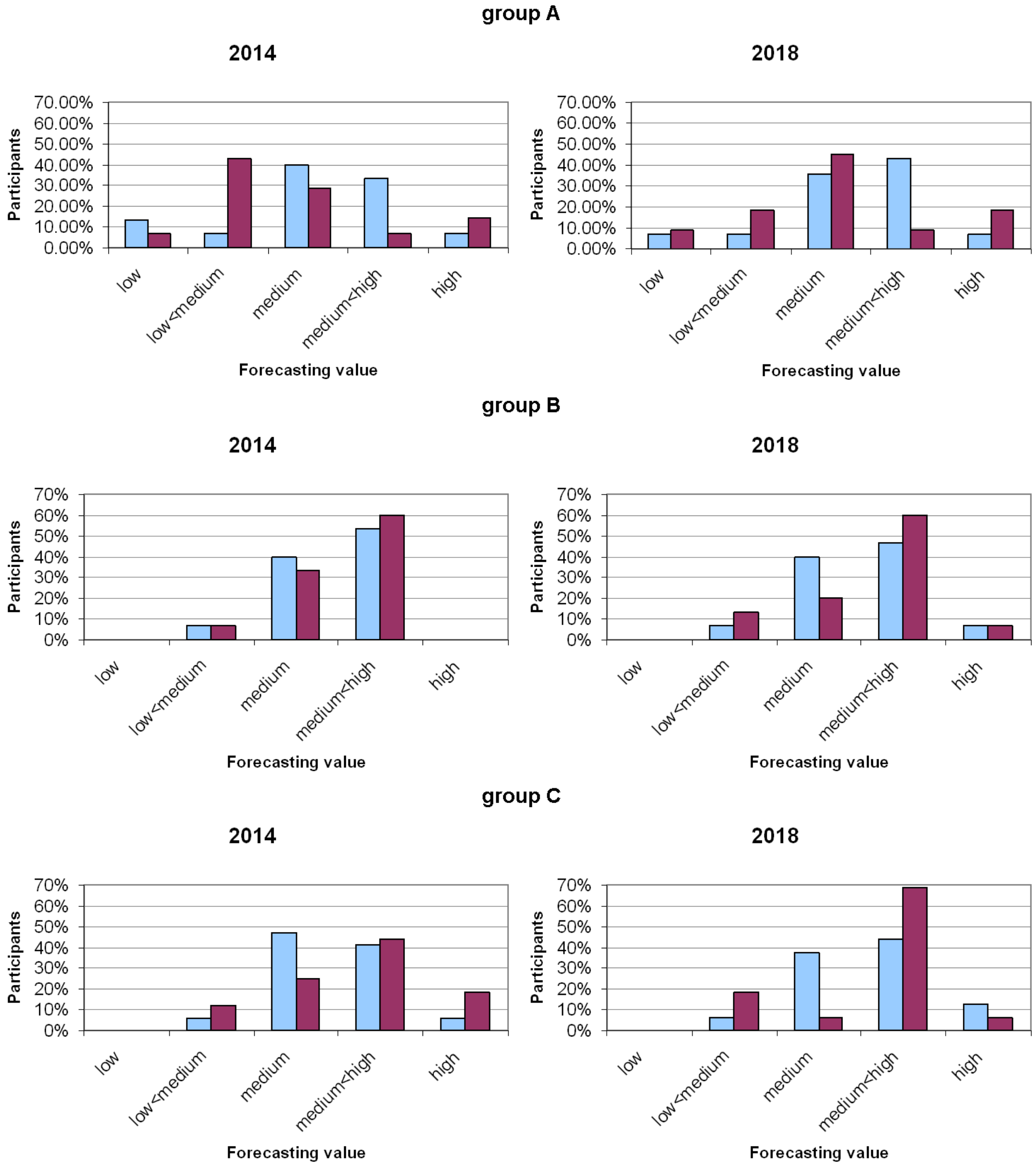

Figure 2 Forecasting values by each group in comparison

4.2 Different Approaches to Displaying the Information

In order to interpret the understanding of uncertainty of the participants the kind of forecast that was given was also analysed. If a range of possible outcomes was set, it was assumed that the decision maker was aware of the uncertainty connected to forecasts of costs. The allocation of the forecast types can be found in Table 2. The difference to 100% of the forecasts in group C's questionnaire 1 for 2014 is caused by the fact that one participant stated that he was not able to give any forecast because of the little information given in that questionnaire. The specification of the range was given in one of the following ways:

- three point forecast in the way of a given value ± a certain percentage or a certain value,
- a range between a minimum and a maximum value,
- uncertainty included in a narrative way, eg "around £700" or "approximately £700".

Table 2 Summary of given answers for each group and each questionnaire

	Group A				Group B				Group C			
Questionnaire:	**1**		**2**		**1**		**2**		**1**		**2**	
	2014	**2018**	**2014**	**2018**	**2014**	**2018**	**2014**	**2018**	**2014**	**2018**	**2014**	**2018**
range forecast quoted (% of participants)	7.7	7.7	0	0	14.3	7.1	6.7	0	16.7	11.1	25	25
point forecast quoted (% of participants)	92.3	92.3	100	100	85.7	92.9	93.3	100	77.8	77.8	75	75

Table 2 summarises the linguistic information from the questionnaires. The percentage of range forecast was found to be higher in group C both for questionnaire 1 and 2 than in group A and B overall. This can be interpreted as the increased awareness of uncertainty that is caused by the FAN-chart shown to group C. As stated, these results may provide an indication to the reduced level of confidence provided by the participants in this group. It is also interesting to note the fact that in group B and C some forecasts stated as a range in 2014 were reduced to a point forecast in 2018. This can be explained with the phenomenon that a development in further future can be regarded as less uncertain because certain diffusion caused by short term incidents will not spread as far as that.
These results are particularly surprising as the degree of expertise was the lowest for group C compared with group A and B as discussed in Section 3.3 where circa 65% of the participants for group C had seen/used the graph before, only 30% had used it in their work. Despite the lower degree of expertise this way of displaying forecasting information made the participants more aware of the existence of uncertainty.

4.3 Reasoning for Estimates

To understand the rationale used by the participants in providing their estimates, the narrative answers were examined closely. For every forecast the contestants were asked to give a reason or further explanation as to why they chose a certain estimate. The reasons given have been categorised. Some of the participants, mostly within the first questionnaire, mentioned the lack of information to give a good estimate. Some chose the medium point as the most likely to occur, some chose a conservative answer which includes the highest cost estimate or a point between medium and high. Another common explanation was the subjective interpretations of the future development of the world economy. Finally, some stated the existence of uncertainty as a reason for their estimate. Table 3 shows the allocation of the answers per category.

Table 3 Linguistic explanations per category

	Group A		Group B		Group C	
Questionnaire	**1**	**2**	**1**	**2**	**1**	**2**
more information (% of participants)	15.4	0	21.4	7.1	12.5	0
medium (% of participants)	38.4	38.4	21.4	21.4	31.2	31.2
conservative (% of participants)	15.4	15.4	28.6	42.9	25	12.5
world economy (% of participants)	15.4	46.2	14.3	14.3	12.5	12.5
uncertainty (% of participants)	15.4	0	14.3	14.3	18.8	43.8

The table shows that the distribution for the first questionnaire (no contextual information) is similar for all groups. The answers showed a wide spread between the categories and a slight rise for the medium estimate for groups A and C and for the conservative estimate for group B. A common outcome from all the groups was the requirement of more information for the task. This was significantly higher for group B, even when given additional contextual information this reason was stated. With the additional contextual information the distribution of reasons changed significantly and in a different way for each group.

However, within group A the person who referred to uncertainty as an influence on their estimate in the first questionnaire changed their mind in the second one. All participants of the category “uncertainty” in questionnaire 1 switched to the development of the world’s economy to reason their answer. One participant even changed from a range forecast with upper and lower boundaries to a point forecast. One explanation for that is the interpretation of the term “uncertainty” as those participants did not interpret it in the sense of the definition discussed in Section 2.2, but in a more informal way. The additional contextual information therefore enabled them to express their estimate more accurately. The participants who asked for more information in the first questionnaire changed their answer to either a medium or a conservative forecast. Almost half the participants for group A reasoned their estimate in the second questionnaire with their opinion about the development of the world’s economy. This also explains the drop of the confidence levels for the second questionnaire, as the development of the world’s economy is a very uncertain factor in the future.

For group B the changes were not as significant as for group A. Most of the participants who asked for more information in the first questionnaire reasoned their estimate as conservative in the second questionnaire. This shows that the additional contextual information made the participants more cautious. Only one still found the contextual information as not sufficient to give an estimate. The other categories were mentioned as often as they were in the first run.

The additional information had interesting effects on group C. All the participants who asked for more information in questionnaire 1, changed their reason to uncertainty in the second one which none of the contestants of group A or B did. The percentage of participants who cited uncertainty is the highest at about 44% in questionnaire 2. Also, some of the participants grouped in either world economy, medium or conservative changed their reason to uncertainty. Two of the contestants of that group even calculated the level of uncertainty in this forecast and based their confidence level on their calculation.

5 Discussion

The overall aim of the experiment was to ascertain the most appropriate way of displaying a forecasting problem. To meet this, two research questions were;

3. How much contextual information is needed?
4. How detailed the given information needs to be in order to be fed into a decision making process?

To achieve this, the experiment examined how;

- different representations of information,
- contextual information, and
- different levels of detail of contextual information,

are interpreted and used in a decision making process as explained in Section 3.1. The results given from the experiment and explained in Section 4 answered those as follows:

- The different approaches of displaying the information can impact how it is perceived and interpreted. Out of the three displays tested the FAN diagram was the most effective as it made the participants most aware of the associated uncertainty.
- The participants were able to give their subjective evaluation of confidence associated with their estimate. In general, the confidence levels were low, but only few used statistical calculation.
- Point estimates were common despite the uncertainty inherent in the information given. Even when the existence of uncertainty was stated in the reasoning, a point estimate was a common answer.

- The contextual information played an important role in forecasting in addition to the graphical information. Many of the participants found it essential to give their estimate.
- The contextual information was interpreted differently according to every different way of display. In general it can be stated, that the additional information made the participants more aware of uncertainty.

The results and outcome can be used in future experiments and research. By doing so, however, one has to be aware of the limitations connected mainly to the decision making environment. Given the fact that the participants of the experiment were drawn out of their usual original organisational and political environment and put into the laboratory environment of the conference, not all the impacts of possible influencing factors can be simulated [Goodwin and Wright 1993]. Some of the motivations to produce a correct estimate may simply not be possible to include in the experiment situation. Those motivations can be rewards for an accurate forecast as well as caused by the organisational conditions the decision maker works in [Goodwin and Wright 1993]. As the experiment was carried out in the professional environment of a conference and workshop connected with the topic those limitations can be accounted as only partly applicable.

As discussed in Sections 2.1 and 2.2 the subjective, judgemental influence into the forecasting process can be divided into the interpretation of past time series, labels and contextual information. For this experiment it was aimed to test the interpretation of information as well as the context and therefore, it was necessary to exclude any past trends in the data. Although the data was adjusted accordingly, some contestants still interpreted some trends into the data which happened significantly more often for the first questionnaire (only graphic information) than the second one. It can therefore be inferred that more contextual information is important to form an estimate from the forecasting data.

6 Conclusions and Further Work

This paper has introduced the problem of forecasting in the context of Through Life Costing as an essential consideration for the success of a project or product. It explained the state-of-the-art of research in forecasting and decision making as applied in TLC estimation. Furthermore, an experiment was introduced which tested the subjective interpretation of information put into a forecasting problem. The results were explained extensively in Section 4.

The information drawn from the experiment discussed in this paper will be expanded and used further in future experiments. In a follow-on experiment, the idea of Game Theory will be introduced to the scenario. Game Theory has been applied to illustrate different decision making processes [von Neumann and Morgenstern 1944; Theodorakopoulos and Baras 2008]. A realistic decision scenario of bidding against an (unknown) opponent will be tested. This experiment will show how the existence of a rival situation influences the forecasting and decision making process as a general conservative behaviour in face of uncertainty will not lead to the success of the project.

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Corresponding Author:
Melanie E. Kreye
Postgraduate Researcher
University of Bath, Department of Mechanical Engineering
Claverton Down, Bath, BA2 7AY, UK
Email: M.Kreye@bath.ac.uk