Supporting Informed Decision-Making under Uncertainty and Risk through Interactive Visualisation

Mohammad Daradkeh, Clare Churcher, Alan McKinnon
PO Box 84 Lincoln University
Lincoln 7647 Canterbury, New Zealand
(Mohammad.Daradkeh, Clare.Churcher, Alan.McKinnon)@lincoln.ac.nz

Abstract
Informed decisions are based on the availability of information and the ability of decision-makers to manipulate this information. More often than not, the decision-relevant information is subject to uncertainty arising from different sources. Consequently, decisions involve an undeniable amount of risk. An effective visualisation tool to support informed decision-making must enable users to not only distil information, but also explore the uncertainty and risk involved in their decisions. In this paper, we present VisIDM, an information visualisation tool to support informed decision-making (IDM) under uncertainty and risk. It aims to portray information about the decision problem and facilitate its analysis and exploration at different levels of detail. It also aims to facilitate the integration of uncertainty and risk into the decision-making process and allow users to experiment with multiple “what-if” scenarios. We evaluate the utility of VisIDM through a qualitative user study. The results provide valuable insights into the benefits and drawbacks of VisIDM for assisting people to make informed decisions and raising their awareness of uncertainty and risk involved in their decisions.

Keywords: Information visualisation, Interaction design, Informed decision-making, Uncertainty, Risk.

1 Introduction
Decision-making is a central activity of human beings as situations that require making decisions constantly arise in almost all endeavours of their lives. All decisions, whether personal, business, or professional, are likely to bring about some future benefits to someone or something and involve choices. Some decisions such as which company’s shares to buy, involve making a choice among multiple alternatives while others such as whether or not to invest in a new product are more “yes/no” decisions. Whatever the type of decision, the information available is considered a key element in the decision-making process as it provides the basis for making informed and reasoned decisions.

Ubiquitous in realistic situations, the information on which decisions are based is often subject to uncertainty arising from different sources. Typical sources include the lack of knowledge of true values of decision variables/parameters and future possibilities and outcomes. For example, the decision about whether to invest in a new product depends on the uncertain market conditions (e.g. whether the demand will go up or down). The possible outcomes of the decision (e.g. making profit or loss) are also dependent on how much the demand goes up or down and its interaction with other variables (e.g. the price of the product). In this situation, the decision-maker usually evaluates the possible outcomes and their associated likelihood under different scenarios, and bases his or her decisions on this evaluation. Such decisions are inherently risky as the best alternative will generally involve some chance of undesirable outcomes.

Ignoring uncertainty and its associated risk may simplify the decision-making process, but it does not result in making informed decisions. Thus, the uncertainty should be explicitly considered from the beginning of the decision-making process as an integral part of the information on which decisions are based. However, the integration of uncertainty into the decision-making process poses significant cognitive challenges. It brings additional complexity and confusion to the task of decision-making which is already complicated. One example of such confusion occurs when comparing or ranking multiple alternatives, each with a range of possible outcomes. Moreover, the process of integrating uncertainty into the decision-making process is a highly technical subject, and often not transparent or easy to grasp by decision-makers who lack the necessary numerical skills.

Information visualisation can play an important part in assisting people to make informed decisions under uncertainty and risk. It provides an effective means for depicting information in ways that make it amenable to analysis and exploration. It also can facilitate the integration of uncertainty into the decision-making process and raise the awareness of decision-makers about its effect. Moreover, it can enhance the ability of decision-makers to process and comprehend information, thereby making more informed decisions (Tegarden, 1999; Zhu & Chen, 2008).

In this paper, we present an information visualisation tool, called VisIDM, for assisting people to make informed decisions under uncertainty and risk. The intention of VisIDM is to portray information about the key elements of the decision problem and facilitate their analysis and exploration at different levels of detail. It is also intended to facilitate the integration of uncertainty
and risk into the decision-making process and allow users to experiment with multiple “what-if” scenarios.

The remainder of this paper is organised as follows. Section 2 discusses some related work in the area of information visualisation to support decision-making. Section 3 discusses the requirements and considerations underpinning the design of VisIDM. Section 4 describes the main components of VisIDM and demonstrates its practical use through an application example of a financial decision-making problem. Section 5 briefly describes a qualitative user study conducted to evaluate the usefulness of VisIDM. In this section, a summary of the results is presented while details of the results are reported and discussed elsewhere (Daradkeh, 2012). Finally, Section 6 concludes the paper and outlines some perspectives for future work.

2 Related Work

Several information visualisation tools that claim to be helpful in decision-making have been developed in many different areas. For example, the TreeMap (Asahi et al., 1995), a visualisation tool for hierarchical data spaces, has been applied to support decision-making based on the Analytical Hierarchy Process (AHP) developed by Saaty (1980). AHP is a multi-criteria decision-making approach that decomposes the decision problem into a hierarchical structure with three main levels: the decision space, the criteria of evaluation, and the available alternatives. The decision space is represented by the entire area (the base rectangle) of the TreeMap. For each evaluation criterion, the screen area is sliced (either horizontally or vertically) to create smaller rectangles with areas proportional to their relative importance or weight. Each criterion is then sliced into sub-criteria recursively, with the direction of the slicing switched 90 degrees for each level. The most interesting feature of the TreeMap is that adjusting weights for criteria is possible by resizing the areas of the rectangles. The total score for each alternative is automatically calculated based on the AHP and presented as a horizontal bar.

Dust & Magnet (Yi et al., 2005) has been applied to support the multi-attribute decision-making based on the weighted additive (WADD) decision rule (Keeney et al., 1999). Using the WADD rule, each alternative is given a total score based on multiplying the value of each attribute with its relative importance (subjective weight or probability) and summing these weighted attribute values. The alternative with the “best” score is chosen as the optimal solution. Using Dust & Magnet, the attributes are represented as black squares and work as magnets, whereas the alternatives are represented as black dots and work as dust particles. The Dust & Magnet metaphor is an intuitive representation of the weighted additive (WADD) decision rule. In addition, it is engaging and easy to understand because it involves animated interaction (Yi, 2008).

Another visualisation tool that has been designed to support decision-making based on the weighted additive decision rule (WADD) is ValueCharts+ (Bautista & Carennini, 2006). It displays the decision alternatives and evaluation attributes in a tabular paradigm, where each row represents an alternative and each column represents an attribute. It uses horizontal bars to represent the weighted value of a particular attribute (i.e., its value multiplied by its relative weight). These bars are then accumulated and presented in a separate display in the form of horizontal stacked bars, representing the total score of each alternative.

Decision Map and Decision Table (Yi, 2008) are two multivariate visualisation tools that have been developed based on ValueCharts+. These two tools were developed to complement each other in supporting a decision-making problem related to selecting a nursing home based on a set of attributes. The Decision Map is inspired by HomeFinder (Williamson & Shneiderman, 1992) and uses a web-based interactive map similar to Google Map1. It provides geographic information related to the alternatives (i.e., nursing homes). Conversely, the Decision Table displays the information in a tabular form with rows representing the available alternatives and columns representing their attributes. Similar to ValueCharts+, it uses horizontal bars to represent the weighted values of attributes.

Despite the availability of several information visualisation tools to support decision-making, the uncertainty and risk have often been neglected or treated in a superficial way. Most of the information visualisation tools are designed and applied based on the assumption that the information available to decision-makers is deterministic and free of uncertainty. Thus, each decision alternative leads to a specific, known outcome and there is no risk involved in decision-making. Such precise knowledge, however, is rarely available in practice. Most real-world decision problems typically involve uncertainty and risk which if not considered could result in infeasible and less informed decisions.

Owing to the nature of decision-making under uncertainty and risk, information visualisation to support decision-making faces special challenges such as dealing with uncertainty and its integration into the decision-making process. Focusing on this area of research, the next section discusses the information requirements and considerations that need to be addressed when designing information visualisation tools to support informed decision-making under uncertainty and risk.

3 Requirements and Design Considerations

3.1 Information Requirements

Decision-making under uncertainty and risk is usually described as a process of choosing between alternatives, each of which can result in many possible outcomes. These outcomes reflect the uncertain and stochastic nature of decision input variables and their propagation through models and criteria used in the decision-making process. Typically, not all possible outcomes are equally desirable to the decision-maker. Consequently, risk accompanies decisions because there is a chance that the decision made can lead to an undesirable rather than a desirable outcome. From this description, there are four basic elements of the decision problem under uncertainty and risk. These are: 1) the set of alternatives from which a

---

1 http://maps.google.com
preferred alternative is chosen; 2) the input data and their 
associated uncertainties; 3) the range of possible 
outcomes associated with each alternative and their 
probabilities; and 4) the risk of obtaining undesirable 
outcomes involved in each alternative. All these elements 
should be taken into consideration when designing 
information visualisation tools to support informed 
decision-making. This is because in the presence of 
uncertainty and risk, decision-makers usually base their 
decisions not only on the possible outcomes but also on 
the uncertainty and risk each alternative entails.

3.2 Analysis and Exploration of Alternatives at 
Different Levels of Detail

In addition to the aforementioned information, decision-
makers need to be able to explore and compare 
alternatives at different levels of detail. The presence of 
uncertainty in the values of input variables implies that 
there are many possible realisations (or values) for each 
input variable. This gives rise to the presence of many 
possible scenarios, where each scenario represents a 
possible combination of all values of input variables, one 
for each variable (Marco et al., 2008). In this situation, 
the visualisation tool should allow the generation of all 
possible scenarios. This requires facilities for enabling 
decision-makers to provide their own estimates of the 
values for each uncertain variable and its distribution. In 
addition, it requires computational facilities for 
propagating all uncertainties through models and criteria 
used in decision-making. Once all uncertainties are 
propagated through the models, the visualisation tool 
should then provide decision-makers with a complete 
picture of all generated scenarios and the distribution of 
uncertainties and risks anticipated to exist in these 
scenarios. At the same time, it should allow decision-
makers to interact with the decision model to allow 
experimentation with different possible “what-if” 
scenarios and exploration of the outcomes and risks 
associated with alternatives under these scenarios. The 
ability to analyse “what-if” scenarios is a key requirement 
for developing understanding about the implications of 
uncertainty, which in turn leads to making more informed 
and justifiable decisions (French, 2003).

3.3 Integration of Uncertainty and Risk into 
the Decision-Making Process

If uncertainty is integrated into the decision-making 
process, the criteria used to assess the performance of 
decision alternatives should reflect this. It’s widely 
recognised that, in the presence of uncertainty, the risk of 
obtaining undesirable outcomes is a frequently used 
criterion for exposing the effect of uncertainty and 
evaluating the decision alternatives (Maier et al., 2008). 
This is because the risk of obtaining undesirable 
outcomes offers a clear way to make sense of uncertainty 
and address it explicitly in the decision-making process 
(Keeney et al., 1999).

Our approach to making uncertainty an integral part of 
decision-making is to view the whole process as one of 

determining the risk associated with the decision. This 
approach is shown in Figure 1 where decision-makers 
specify the risk criterion to be used and also the 
uncertainty for each input variable. For example, in the 
case of considering an investment decision problem, the 
two components of the risk might be the probability of 
making a loss and the amount of money that could be lost 
as a consequence of making a decision. The decision-
maker is then interested in both the risk that the 
investment will make a loss, and how that risk is affected 
by his or her knowledge of the uncertainties in the 
variables relating to this particular investment.

4 Description of VisIDM

Based on the requirements and considerations discussed 
above, we have designed VisIDM which consists of two 
main parts: Decision Bars and Risk Explorer as shown in 
Figure 2. The left side of Figure 2 shows the Decision 
Bars which provide overview information on the 
available alternatives, their range of possible outcomes, 
and the overall risk of undesirable outcomes associated 
with each alternative. The right side of Figure 2 shows 
Risk Explorer which provides decision-makers with a 
detailed view of the alternatives and allows them to 
explore the uncertainty and risk associated with these 
alternatives at different levels of detail.

In the following sections, we describe the components 
of VisIDM in more detail and demonstrate its practical 
use through an application example of a financial 
decision-making problem.

4.1 Application Example: Financial Decision 
Support

The example problem to be explored and visualised is 
a decision-making scenario of choosing an investment 
based on uncertain information. Some examples of such a 
scenario include the decision on whether or not to buy a 
property for investment and rental income, or a decision 
to select from among a set of projects available for 
investments. In making such decisions, decision-makers 
usually specify evaluation criteria (e.g. a potential profit 
and an acceptable risk of making a loss associated with 
the investment). The decision-makers also define the key 
variables that influence the evaluation criteria and their 
possible values (e.g. the income from the investment and 
its running cost). Then, they use a financial model to 
predict and evaluate the profitability of the investment 
under multiple scenarios and base their decisions on this 
evaluation (Tziralis et al., 2009).
To predict and analyse the profitability of an investment, a financial model for investment decision-making called Net Present Value (NPV) is commonly used (Magni, 2009; Tziralis et al., 2009). The NPV model is emphasised in many textbooks as a theoretically and practically sound decision model (e.g. Copeland & Weston, 1983; Koller et al., 2005). It represents the difference between the present value of all cash inflows (profits) and cash outflows (costs) over the life of the investment, all discounted at a particular rate of return (Magni, 2009). The purpose of NPV is basically to estimate the extent to which the profits of an investment exceed its costs. A positive NPV indicates that the investment is profitable, while a negative NPV indicates that the investment is making a loss. A basic version of calculating NPV is given by Equation 1:

\[
NPV = C_0 + \sum_{t=1}^{n} \frac{(CI_t - CO_t)}{(1 + r)^t}
\]

(1)

Where

- \(C_0\) is the initial investment.
- \(n\) is the total time of the investment.
- \(r\) is the discount rate (the rate of return that could be earned on the investment).
- \(CI_t\) is the cash inflow at time \(t\).
- \(CO_t\) is the cash outflow at time \(t\).

As shown in Equation 1, in its basic form, the NPV model consists of five input variables. In practice, each of these variables is subject to uncertainty because the information available on their values is usually based on predictions, and fluctuations may occur in the future. Consequently, the investment decision can lead to many possible outcomes (i.e. different values of NPV). Since not all possible outcomes are equally desirable to the decision-maker, the investment decision involves a degree of risk. The risk is present because there is a chance that the investment decision can lead to an undesirable rather than a desirable outcome.

### 4.2 Decision Bars

As shown in Figure 3 from top to bottom, the Decision Bars interface consists of three panels: Outcome, Risk and Likelihood Bars.
possible outcomes. For example, the dashed blue line of alternative 4 is skewed to the top showing that the higher outcomes are more likely.

The Risk Bars shown in the middle panel of Figure 3 provide information on the overall risk of obtaining undesirable outcomes (in this case, the probability of obtaining negative NPVs). The risk associated with each alternative is shown as a vertical bar. The height of the bar represents the degree of risk (i.e. the probability of undesirable outcomes). The higher the bar, the higher the risk of obtaining undesirable outcomes. For example, the middle panel in Figure 3 shows that among all possible outcomes of alternative 4 about 5% will result in a loss compared to about 13% in alternative 2.

The Likelihood Bars provide information on the likelihood of a particular alternative having the highest outcome. In other words, these bars show the percentage of outcomes of a particular alternative that are better than all outcomes of other alternatives. The higher the bar, the higher the percentage. For example, the bottom panel of Figure 3 shows that about 40% of the outcomes (NPVs) of alternative 5 are higher than all outcomes (NPVs) of other alternatives.

4.3 Risk Explorer

Risk Explorer, shown in Figure 4, adds to the other parts of VisIDM a visualisation tool for exploring and analysing the uncertainty and risk associated with available alternatives at different levels of detail. It allows the user to specify the range of values for each input variable through the corresponding text boxes. Then, it portrays the distribution of risk (i.e. the probability of undesirable outcomes) in a uniform grid layout. The grid also displays the range of possible values of each input variable divided into a number of divisions (cells in the grid).

Risk Explorer uses colour to convey the risk of undesirable outcomes. The colour of each cell in the grid conveys the degree of risk (i.e. the probability of undesirable outcomes) associated with the alternative based on the variable’s value shown in the cell. Yellow means no risk (i.e. the probability of obtaining undesirable outcomes = 0). Dark orange represents the highest risk (i.e. the probability of obtaining undesirable outcomes = 1). The risk of undesirable outcomes is calculated based on fixing the value in the cell and taking every possible value of all other variables and calculating what proportion of these combinations will result in undesirable outcomes. The numerical values of the risk of undesirable outcomes can also be retrieved by hovering over the cells. For example, the popup window in Figure 4 shows that if the discount rate is 10% then if we consider all other possible combinations of values for the other input variables about 78% (probability 0.778) will result in an undesirable outcome of a loss.

Risk Explorer also displays the range of possible outcomes resulting from the uncertainties in the input variables as horizontal red/green bars (see Figure 4). The range of possible outcomes is calculated by allowing all input variables to vary within their ranges of values and calculating all possible combinations of these values. The horizontal red/green bar informs the user about the maximum and minimum potential outcomes under all possible scenarios (i.e. all possible combinations of the variables values). In addition, by observing the red part of the bar, the user can identify the proportion of undesirable outcomes (e.g. the negative NPVs that will make a loss as in the example shown in Figure 4). Conversely, he/she can identify the proportion of desirable outcomes (e.g. the positive NPVs that will make a profit) by observing the green part of the bar.

As shown in Figure 4, Risk Explorer displays the information in a uniform grid which facilitates the presentation of the uncertainty and associated risk of undesirable outcomes in an organised way. It makes it easy to see and follow the change in the risk degrees across the cells, which in turn facilitates the recognition of trends and relationships between the uncertain values of input variables and the risk of undesirable outcomes. Furthermore, all input variables are bounded by known maximum and minimum values and all possible values in between are discretised into a finite number of divisions. Therefore, they can be mapped onto equal-sized cells. In this way the decision-maker can run through or compare several scenarios with various values and easily determine the risk level at various degree of uncertainty. Colour was chosen for the purpose of presenting risk of undesirable outcomes because it is widely used for risk visualisation and communication. In addition, it is an important visual attention guide that can highlight levels of risk (Boström et al., 2008).

4.3.1 Providing an Overview of the Uncertainty and Risk of Undesirable Outcomes

Risk Explorer provides an overview of all possible scenarios (i.e. possible values of input variables) and the risk of undesirable outcomes associated with the decision alternative under these scenarios. By observing the colour variation across the grid cells, the decision-maker can quickly and easily get an overview of the risk of undesirable outcomes and its distribution. The decision-maker can use this overview to compare alternatives in terms of the risk involved in each alternative before focusing on a specific set of scenarios. For example, as shown in Figure 5, when comparing alternatives 1 and 2, the decision-maker can recognise that the risk of making a loss associated with alternative 1 is much higher than that associated with alternative 2; the colour of many cells in the grid of alternative 1 is much darker than that of alternative 2. The same overview information can also be obtained from the Decision Bars interface (see Figure 3). However, Risk Explorer provides an explanation of the factors that form the risk of undesirable outcomes associated with the decision alternatives.
4.3.2 Analysis and Comparison of Multiple Alternatives at Several Levels of Detail

Risk Explorer allows the user to focus on particular scenarios (i.e. specific values of input variables) and compare alternatives under these scenarios. To focus on a specific scenario, the decision-maker needs to fix the values of input variables that represent the scenario. This can be done by clicking on the cell containing a specific value of one of the input variables. This will open up a new grid showing the new range of risk of undesirable outcomes with this value fixed. Values of other input variables in the new grid can also be fixed. For example, Figure 6 shows an example of exploring and analysing alternatives 2 and 5 under specific scenarios based on fixing the two input variables initial investment at $35000 and discount rate at 10%. As shown in Figure 6, the first fixed value of $35000 in the top grid is highlighted and a new grid is shown for each alternative. The new grid shows the risk values for the other three input variables. The risk values are calculated by fixing the values in the highlighted cells and taking every possible value of the other variables and calculating what proportion of these combinations will result in undesirable outcomes. This process is then repeated by fixing the discount rate to 10% in the second grid. In addition to the resulting grid, a new red/green bar is shown to the right of the grid for each alternative. The red/green bar shows the range of possible outcomes resulting from fixing the variables’ values in the highlighted cells while varying the other variables within their ranges of values.

Based on the resulting grids and red/green bars, the decision-maker can evaluate and compare alternatives in terms of the risk of undesirable outcomes and the range of possible outcomes under different scenarios. For example, the new grids and red/green bars in Figure 6 show that if the two input variables initial investment and discount rate are fixed at $35000 and 10% respectively, then about (27%) of NPVs of alternative 2 will result in a loss compared to about 20% for alternative 5 (see the popup windows shown in Figure 6). Conversely, according to the red/green bars, the maximum loss and profit potential associated with alternative 5 (-$16046, $40816 respectively) are greater than those associated with alternative 2 (-$8464, $21862 respectively).
5 User Study

We conducted a qualitative user study to explore how VisIDM was used by participants and what features supported their exploration and perception of information. Twelve postgraduate students (2 females and 10 males) from different departments in the Faculty of Commerce at Lincoln University were recruited. The number of participants was not predetermined before the initiation of the study, but rather was determined by reaching a saturation point (Patton, 2005). Recruitment ceased when the information being collected became repetitive across participants and further information and analysis no longer yielded new variations.

5.1 Setup and Procedure

The study was setup in a lab-based environment. A case study of an investment decision-making problem under uncertainty and risk that was relevant to the knowledge and experience of the participants was utilised in this study. The decision problem consisted of five investment alternatives. The data was prepared so that each investment alternative had a different risk/profit profile. Because all alternatives involved the investment of dollars, the Net present Value (NPV) model was used for evaluating and comparing the profitability of alternatives (refer to Section 4.1 for a description of NPV model). We put the participants in the situation of making decisions taking into account the uncertainty and risk associated with each alternative.

The procedure used in this study was as follows: the participants were given a brief introduction to VisIDM and the study procedure. Then, they were given a set of practice tasks to familiarise themselves with VisIDM. After completing the practice tasks, the participants were given a scenario for decision-making consisting of a set of investment alternatives. Then, they were asked some open-ended questions where they had to make decisions taking into consideration the uncertainty and risk associated with each alternative. We designed the questions to be of an open-ended nature because we were not intending to quantitatively record the performance of our participants, but rather have them exercise all parts of VisIDM and get their feedback on its utility.

The following open-ended questions were given to the study participants:

- What do you think are the best two alternatives? (Ranking problem)
- From among your best two alternatives, which alternative do you prefer the most? (Choice problem)
These questions were designed to be consistent with the ultimate objectives of decision-making. Generally, decision-makers are interested in either choosing one alternative (a choice problem) or obtaining an order of preferences of the alternatives (a ranking problem) (Nobre et al., 1999). To achieve these ultimate objectives, the participants had to utilise different types of information provided by VisIDM and perform several tasks.

While they solved the open-ended questions, the participants were instructed to follow a think-aloud protocol. Data was collected using observations and content analysis of participants’ written responses and answers of open-ended questions. Each session lasted from approximately 90 to 120 minutes.

5.2 Results and Discussion

The results of the study provide valuable insights into the usefulness of each feature of VisIDM for informed decision-making under uncertainty and risk. They allow us to shed light on how the participants utilised the given interactions and visual representations of information to arrive at their final decisions. They also allow us to explore how VisIDM affected their perception and interpretation of the uncertainty and risk information.

5.2.1 Decision-Making Processes

The results show that the participants were able to perform several tasks to arrive at their final decisions. Examining these tasks, we note that the participants adopted different strategies for decision-making. For example to decide on whether one alternative is better than another, some participants compared them first based on the maximum NPV, which was interpreted as the maximum profit potential. Then, they further compared them based on the minimum NPV, which was interpreted as the maximum loss potential. At this point, they stopped searching for further cues and made their decisions based on the maximum and minimum NPV values. Other participants preferred to continue searching the visualisation interfaces for other information (e.g. proportions of positive and negative NPVs) and made decisions based on this information. This result supports the proposition that people rarely appraise and use all available information in a systematic way when making decisions under uncertainty and risk. Rather, they often rely on simplistic modes of thinking (heuristics) to reduce the effort and processing required (Tversky & Kahneman, 1974).

The analysis of each participant’s process for decision-making provides valuable insights into the benefits and drawbacks of each feature of VisIDM. The Outcome Bars were used by all participants mainly to identify the extreme values of possible outcomes (i.e. the maximum and minimum possible NPV values) for each alternative. These two values were used by participants to evaluate and compare alternatives in terms of the maximum potential profit and loss. Three out of the 12 participants utilised the mean value of the possible NPV values of each alternative to rank and choose the most preferred alternative. According to these participants, the higher the mean value of possible NPV values, the better the decision alternative. For example, one participant commented: "my criterion is that...if we have a higher mean value I’ll definitely choose this alternative.”

However, only a few used the probability distribution of these outcomes to inform their decisions. A possible explanation of this result is that some participants may not understand the significance of the distribution.

The Risk Bars were used by all participants to compare alternatives in terms of the overall risk of making a loss. They were also used to confirm the previous decisions made using the Outcome Bars. This suggests that the Risk Bars are useful for conveying comparative information about the risk and people can understand the risk information when it is presented as percentages. One participant commented: “I’ve gotten more information about the likelihood of getting loss so it is better than just having information about how much money you will make as a profit or loss.”

The Likelihood Bars that show the probability that an alternative would have the highest outcomes provided misleading information. The majority of participants were not able to understand the concept and misinterpreted the information conveyed by these bars. For example, one participant commented: “Initially I thought that the likelihood bars would be helpful, but they didn’t add much to the previous information. Also, I found them confusing.” Another participant commented: “The Likelihood Bars adds more information but it can be misleading and it’s difficult to utilise information of the likelihood bars.”

The Likelihood Bars could be eliminated from future versions of VisIDM and replaced by something easier to understand and use. For example, it could be a useful idea to replace the Likelihood Bars by bars that present information about the probability of obtaining desirable outcomes. This would allow VisIDM to provide more balanced presentation of potential risks and benefits of available alternatives, thus allowing decision-makers to make better informed decisions.

Risk Explorer was used by all participants to get an overview of the risk associated with alternatives through colour coding. Prior to focusing on specific scenarios, all participants made comparisons between alternatives in terms of the risk of making a loss based on an overview of all possible scenarios. They also used the horizontal red/green bars to compare alternatives in terms of their profit and loss potential.

Risk Explorer was also used to analyse and compare the uncertainty and risk associated with alternatives under particular set of scenarios. Some participants made comparisons between alternatives in terms of the risk of making a loss and profit potential under similar-value scenarios (e.g., similar amount of initial investment). To do so, they identified and fixed similar or nearly similar values of one or more variables. Then, they explored and analysed the resulting risk of making a loss and range of outcomes (i.e. range of possible NPV values) of alternatives based on the selected scenarios. Other participants made comparisons between alternatives in terms of the risk of making a loss and profit potential under similar-case scenarios (e.g., worst-case or best-case scenarios). For example, one participant made a comparison between alternatives under pessimistic
(worst) and optimistic (best) estimates of cash inflow. Other participants used different variables (e.g. one participant made a comparison between alternatives under worst and best initial investment). Some participants also made comparisons between alternatives under worst and best cases of more than one variable. For example, one participant made a comparison of alternatives in terms of the risk of making a loss and profit potential based on fixing the cash inflow at the minimum value and discount rate at the maximum value.

The use of colour gradations to convey risk magnitudes enabled participants to compare alternatives when they have different risk profiles; i.e. when the difference between the risk of making a loss with one alternative and the risk of making a loss with another was clear and can be distinguished. This suggests that the use of colour to represent the risk (in this case, the probability of making a loss) can be useful for attracting and holding people’s attention. However, in many scenarios, the participants were not able to compare alternatives in terms of the risk of making a loss by observing the colour variation across the cells; particularly, when the scenarios had similar risk profiles. In such cases, the participants relied on the red/green bars to identify the risk of making a loss. In particular, the participants used the maximum potential loss (i.e. minimum NPV), and the proportion of negative NPV values (the red part of the resulting bars) to form their impressions about the risk, regardless of probability.

5.2.2 Risk Perception and Interpretation

The results show that the participants have problems in understanding and interpreting the uncertainty and risk information. In particular, they have a tendency to ignore the importance of probability information and rely, in large part, on the values of undesirable outcomes to form their impression about the risk.

Using the Outcome Bars interface, most participants did not use the probability distribution to evaluate the risk of undesirable outcomes associated with each alternative. Rather, they focused their attention on the minimum possible NPV, which represents the maximum potential loss. Consequently, they perceived the alternative with higher potential loss as more threatening than that with lower potential loss, regardless of probability. The same issue of risk perception was also observed when the participants used Risk Explorer. Some made use of the red/green bars, which show the range of possible outcomes to evaluate the risk of making a loss. Others evaluated the risk by observing the colour variation across the cells of the grids. Interestingly, the majority of participants did not try to retrieve numerical values of the risk (i.e. the probability of making a loss), although they clearly understood how to do so in the practice phase of this study.

The literature on risk perception and decision-making suggests several possible explanations for the observed issue of risk perception; i.e. ignoring the importance of probability and relying on the outcomes to form the impression about the risk. Some of these possible explanations seem consistent with the observed risk perceptions of participants in this study. In the case of the Outcome Bars interface, it seems that the way information pertaining to the risk was presented led to the outcomes being made more prominent and easier to identify than their probabilities. Consequently, the participants focused their attention on the outcomes rather than their probabilities. This explanation seems consistent with previous research suggesting that prominent information is more likely to draw attention, be given more consideration, and have a stronger effect on risk-related behaviour than less prominent information (Stone et al., 2003). A second possible explanation for the observed issue of risk perception could be related to the attitude of the participants towards the risk. The majority of participants showed a preference for minimising the loss rather than maximising the profit. This might lead them to overestimate the risk involved in the alternatives with high potential loss. This bias in estimating the risk has been previously reported in the graphics perception literature, suggesting that people are poor at estimating “objective risk” (Stone et al., 2003). They have a tendency to perceive the low probability/high consequence outcomes as more risky than high probability/lower consequence outcomes (Schwartz & Hasnain, 2002).

6 Conclusions and Future Work

This paper presents an information visualisation tool to support informed decision-making under uncertainty and risk called VisIDM. It consists of two main parts: the Decision Bars and Risk Explorer. Decision Bars provide overview information of the decision problem and available alternatives through three panels: Outcome, Risk and Likelihood Bars. Using these bars, decision-makers can compare and then choose preferred alternatives before focusing on particular alternatives for detailed analysis and exploration. On the other hand, Risk Explorer provides decision-makers with a multivariate representation of uncertainty and risk associated with the decision alternatives. Using Risk Explorer, decision-makers can interactively analyse and explore the available alternatives at different levels of detail.

To explore the benefits and drawbacks of each feature of VisIDM, we have conducted a qualitative user study. The results suggest that VisIDM can be a useful tool for assisting people to make informed decisions under uncertainty and risk. It provides people with a variety of decision-relevant information and assists them in performing several tasks to arrive at their final decisions. It also can make people aware of the uncertainty and risk involved in their decisions.

Participants’ feedback confirmed that further research is needed to improve the design of VisIDM, so that it provides decision-makers with a better understanding of uncertainties and risks associated with decision-making. Some participants found it difficult to make use of probability distribution information. Hence, it could be improved so that it provides the probability information in a clearer and more informative format. Some alternative formats for portraying the probability information are available in the literature on risk visualisation. For example, cumulative distribution functions, histograms, and box plots can show different
types of information that people usually seek for decision-making purposes (Gresh et al., 2011). It would be useful to explore whether these formats can provide probability information in a more intuitive way. Perhaps, though, there is a need to develop much more innovative approaches for conveying probability information.

More evaluation studies are also needed to provide more evidence of the usefulness of VisIDM to support informed decision-making under uncertainty and risk. These studies should be expanded beyond hypothetical decision-making scenarios and lab-based environment to real world settings. They should also be expanded to include different measures and factors related to informed decision-making such as measures of beliefs, attitudes, perception of risk, and knowledge (Bekker et al., 1999).

Acknowledgements
We would like to acknowledge all participants without whom the study would not have been completed.

7 References