The London School of Economics and Political Science

Extending the combined use of Scenarios and Multi-Criteria Decision Analysis for evaluating the robustness of strategic options

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Declaration

I certify that the thesis I have presented for examination for the MPhil/PhD degree of the London School of Economics and Political Science is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

I warrant that this authorisation does not, to the best of my belief, infringe the rights of any third party.

I declare that my thesis consists of 57,290 words.

Statement of conjoint work

I confirm that Paper 1 was jointly co-authored with Dr. Gilberto Montibeller and Dr. Alec Morton. I contributed 85% of this work.

I confirm that Paper 2 was jointly co-authored with Dr. Gilberto Montibeller. I contributed 90% of this work.

Abstract

Deep uncertainty exists when there is disagreement on how to model inter-relationships between variables in the external/controllable and internal/controllable environment; how to specify probability distributions to represent threats; and/or how to value various consequences. The evaluation of strategic options under deep uncertainty involves structuring the decision problem, specifying options to address that problem, and assessing which options appear to consistently perform well by achieving desirable levels of performance across a range of futures. The integrated use of scenarios and Multi-Criteria Decision Analysis (MCDA) provides a framework for managing these issues, and is an area of growing interest. This thesis aims to explore such integrated use, suggesting a new method for combining MCDA and scenario planning, and to test such proposal through a multi-method research strategy involving case study, behavioural experiment and simulation. The proposal reflects the three key areas of confluence of scenarios and MCDA in the decision making process. The first is based on systematic generation of a larger scenario set, focused on extreme outcomes, for defining the boundaries of the decision problem. The second proposal is based on providing less scenario detail than the traditional narrative, in favour of explicitly considering how uncertainties affect positive and negative outcomes on key objectives. This backward logic seeks to better address the challenge of estimating the consequences of each option and the trade-offs involved. Finally, it is proposed that option selection be based on a concern for robustness through cost-equivalent regret. The empirical findings reflect that the key benefit of integration appears to be a mechanism to improve the efficiency of elicitation and the robustness of options. However, effective application of scenarios and MCDA requires awareness of the desired degree of accuracy required and risk attitude of decision makers.

Contents

List of Tables

List of Figures

Preface

The thesis is organised as follows. The introduction chapter contextualises the research in light of developments in the relevant literature, followed by an outline of the overall aims of the research. It also summarises the papers that constitute the core of the PhD submission in terms of their individual research objectives and key findings. Each paper is separated by a brief interlude that aims to strengthen narrative continuity. The critical discussion and conclusion chapter relates key messages from each paper to the central research question and the potential contribution to theoretical discourse.

In each paper, I am the first author. However, the first paper was developed jointly with my two supervisors (I contributed 85% of the work), and the second with my main supervisor (I contributed 90% of the work). For the jointly-authored papers, I was responsible for developing the idea, researching the literature, planning and implementing the research methodology, and writing the papers. The format of the thesis does entail some repetition, particularly since the method proposed in Paper 1 acts as a foundation for subsequent papers. Each paper is referenced separately, as they were (or will be) in the relevant journals. All other references are placed at the very end of the submission.

I am grateful to a number of people without whom completion of this process would not have been possible. First and foremost, to the Government of Trinidad and Tobago for funding my entire tertiary education, without whom this opportunity would not have been possible. Second, I must offer sincerest thanks to my supervisors, Dr. Gilberto Montibeller and Dr. Alec Morton for painstakingly and patiently reviewing drafts of my work and advice on refining ideas. Third, I am grateful to those who devoted time to taking part in my fieldwork and for allowing me access to extensive resources. Fourth, to my colleagues, former tutors and support staff at LSE, who have made my time at the university an enjoyable and memorable one. I remain indebted to my employer, Decision Strategies International, for their feedback on my work, and for the time given to me to focus on the research. Finally, to my family and close friends, for their constant support and prayer.

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1. Introduction

Discovering crucial factors in complex situations and designing strategic options to address identified obstacles lies at the core of strategy (Rumelt, 2011). Where prediction is feasible, choices are supported by deductive arguments that conclusively prove a particular choice is best. However, under conditions of deep uncertainty, which is the prevalent type of uncertainty in strategic decision making (Montibeller and Franco, 2011), proving that a particular choice is best under all possible circumstances is difficult. Deep uncertainty exists when there is disagreement on how to model inter-relationships between variables in the external/controllable and internal/controllable environment; how to specify probability distributions to represent threats; and/or how to value various consequences (Courtney, 2001; Walker et al., 2001).

The existence of deep uncertainty has three key implications for decision making. First, there is a need to expose biases and flaws in reasoning to address cognitive failures in accounting for the range of complex interactions between system elements. Second, conceptual analysis of the discontinuity that may arise from available information may be more amenable to understanding and addressing vulnerability. Third, options are neither good nor bad until placed in some social context. As such, the set of options considered may not necessarily be the best that could be devised (Cox, 2012). In short, deep uncertainty implies that a decision maker must make persuasive claims based on the extent to which a particular choice is consistent with strategic objectives, and an understanding of the circumstances in which it performs adequately (Lempert et al., 2003).

The combined use of Multi-Criteria Decision Analysis (MCDA) and scenarios is pertinent to addressing some of these needs (Stewart, 1997, 2005; Goodwin and Wright, 2001; Belton and Stewart, 2002; Montibeller et al., 2006; Wright and Goodwin, 2009; van der Pas et al., 2010). Scenarios help a decision maker understand how critical uncertainties in organisational environments might interact in surprising ways, thereby providing a frame of reference through which to consider strategic risks (Cairns et al., 2004; Coyle, 2004; Schwartz and Ogilvy, 1998). This addresses a critical gap in strategic decision making frameworks under uncertainty, including many of the MCDA approaches, which assume deterministic impacts and riskless choices (Goodwin and Wright, 2010). On the other hand, scenarios lack a systematic means of comparing options. MCDA provides a coherent framework for comparing how strategic options contribute to the decision objectives and thus the realisation of values. Collectively, scenarios and MCDA provide a means for understanding values and futures for which a particular choice is adequate. This may further afford early learning experiences to guide data collection so that threats may be mitigated (Salo and Hämäläinen, 2010).

Within this growing area of research, several open areas for investigation remain. These can be classified according to the three areas of confluence of scenarios and MCDA in the decision making process: definition of the decision problem; estimating the consequences of each option and the trade-offs involved; and option selection. For instance, there is scope for closer integration between the methods in the process of defining plausible boundaries for uncertainties and examining the implications of their outcomes for key objectives (Wright and Goodwin, 2009). The assessment of consequences may be conducted by using one MCDA model across scenarios (Goodwin and Wright, 2001), or through scenario-specific MCDA models (Montibeller et al., 2006). The number of scenarios and level of detail necessary for this task remains to be investigated. Option selection may proceed on the basis of robustness, for which multiple measures exist (Montibeller et al., 2006) or via the assignment of likelihoods (Phillips, 1986). The impacts of these approaches on decision quality, from a process and outcome perspective, have not been systematically assessed.

This thesis thus proposes three key elements for enhancing the integration of scenarios and MCDA, and examines their impact. The proposals focus on decisions where there is a high capital commitment, the decision is inflexible and irreversible, and is viewed as a stand-alone choice due to budget or other constraints. Given that the proposals together represent a method in-development, assessments of impact remain limited to a single decision maker to provide preliminary insights. The elements proposed are:

- Scenarios which consider a larger number of extreme possibilities than traditional scenario planning;
- Presentation of scenarios as snapshots (i.e. description of a plausible future state at a given point in time, rather than as an evolution of events) during option evaluation, based on the premise that the influence of environmental uncertainties on key objectives is explored during problem structuring;
- Regret as the basis for a robust choice.

A systematic assessment of the value of these proposals requires attention to their independent as well as collective benefit. To this end, a multi-method research design to evaluating the impacts of these elements is used. This assessment hopefully places the proposals more coherently in the context of competing techniques in the growing literature on scenarios and MCDA. Impact is assessed in three ways:

- Practical: To what extent do the proposals provide a transparent (i.e. relationships between model inputs and decision recommendations can be readily understood) and meaningful evaluation process?
- Effort implied by scenario selection: What is the time/quality trade-off from using different levels of scenario detail in the MCDA process?
- Impact of different decision rules for robustness under deep uncertainty: To what extent and how do different decision rules for robustness differ relative to choice recommended by an ideal procedure?

The analysis and findings contained herein are intended for decision makers and decision analysts who are interested in new ways to understand the deeply uncertain future; and for scenario planners who wish to bring a more systematic approach to evaluating strategic options.

In the next section, the aspects of the scenario planning framework that make them relevant to problem structuring under deep uncertainty but challenging for option evaluation, are explored. This is followed by a review of how the use of MCDA and scenario planning together mitigates these challenges more effectively than either method on its own. Open areas for research to enable systematic development of scenarios and MCDA are then investigated. A rationale for the proposals and a critique of the research methods most appropriate for assessing these proposals are then presented. The final section explores how these are elaborated throughout the thesis, and provides a brief summary of findings and contribution.

2. Scenario-based option evaluation

Scenarios provide a powerful structure for sharing and understanding available information under deep uncertainty in three key ways. First, it bounds the future to capture the essence of the strategic challenge (Schoemaker, 2004). Second, the narrative approach provides details of particular contexts against which to assess what a reasonable course of action might be (Bowman et al., forthcoming; Beach, 2009; Schwartz, 1996; van der Heijden, 1996; Schoemaker, 1993; Wack, 1985). Third, scenarios may permit the assessment of robustness as the basis for choice (Bodwell and Chermack, 2010; de Vries and Petersen, 2009; Roubelat, 2000; O'Brien et al., 2007; Harries, 2003). An explanation of how the structure of the scenario planning framework promotes each of these features is explored next.

The bounding concept in scenario analysis is based on excluding what one believes could not occur, possibly due to some objective constraint in the system; or due to differing (subjective) thresholds of belief and knowledge of mechanisms, which are time and stakeholder dependent. The scenario planning framework facilitates the setting of problem boundaries through the plausibility criterion. Plausibility is met if scenarios that lead to events and states that seemed impossible become more possible, while those that seemed imminent or certain should become less possible within a time horizon which defines how far into the future today's actions are perceived to influence events (Hirschhorn, 1980).

The second significant element of scenario planning is the narrative, or qualitative description of how a series of events and trends coherently and consistently lead to a hypothetical future (Ramirez et al., 2008; Ringland, 2002). Without a belief that an extreme event can happen, and a concurrent belief that one can develop viable options to deal with such events, a scenario exercise may fail (Hodgkinson and Wright, 2002). The scenario narrative allows a decision maker to understand the imperatives implicit in the scenario so that he/she can articulate their belief and preference judgements appropriately (French et al., 2011). It also provides decision makers with the opportunity to think through the warning signs of differing futures and the responses they might make to such signposts (Schoemaker, 2002; Wack, 1985). Moreover, it is a mechanism for stimulating acceptance that many alternative futures are plausible in a multi-stakeholder setting, which help stretch as well as focus people's thinking (Burt and van der Heijden, 2003; Schoemaker, 1993).

The third element within the scenario planning structure is the provision of a means for finding robust decisions that work acceptably well for various outcomes, which is a widely accepted criterion for choice under deep uncertainty (Aissi et al., 2009; Yin et al., 2009; Kouvelis and Yu, 1997; French, 2003; Saltelli et al., 2000; Vincke, 1999; Cox, 2012). This is achieved by developing a range of scenarios that decision makers find comfortable and those that challenge conventional views (Lempert et al., 2003). This addresses the notion that decision makers will often reject projections of the future that deviate from what they expect or what they regard as comfortable.

Various approaches exist for achieving this balance. The inductive approach to scenario development examines combinations of extreme outcomes on the two uncertainties that attain the highest impact and unpredictability scores (Schoemaker, 2002). The deductive or La Prospective approach asserts that scenarios should emerge from discussion and exploration of potential drivers, based on an understanding of the interrelations among system variables (de Jouvenel, 2000). A more mechanistic approach can also be used that selects scenarios according to criteria such as consistency, degree of difference between scenarios selected, coverage (Comes et al., 2011; Tietje, 2005), or degree of exposure (Lempert et al., 2003).

Each of these features also poses various challenges for option evaluation. For instance, a participative approach to scenario development, and the views ‘remarkable people’ who can challenge assumptions, are suggested in the scenario planning literature to help establish plausible but challenging uncertainty boundaries. The effectiveness of this strategy remains empirically untested (Goodwin and Wright, 2009). Moreover, a focus on plausibility runs the risk that (misplaced) confidence in a given scenario will unfold (Liebl, 2002), unless perhaps each scenario represents an ideal outcome for different stakeholder groups (French et al., 2011). Another strategy to address misplaced confidence in the occurrence of a particular scenario is generating a larger number of causal scenarios, which has the effect of lowering perceived likelihood (Dougherty et al., 1997; Hirt and Markman, 1995). This may demand a higher degree of cognitive effort and time, which is a barrier to scenario use (Grant, 2003).

The scenario narrative faces two major challenges in option evaluation. First, the narrative developed is largely independent of actions and objectives, so there is nothing inherent in the scenario planning armoury to encourage the exploration and identification of undiscovered values (Durbach and Stewart, 2003). This reflects a broader criticism that scenario development is rather ad-hoc, isolated and mostly geared towards indirect decision support such as agenda-setting and issue-framing (Volkery and Ribeiro, 2009). Second, the long causal links may lead to biases in information selection during evaluation. In a complex environment, if this task is not decomposed and explored in a structured way, it might be left to inadequate and simplistic heuristics (Durbach and Stewart, 2003).

Even though scenarios may permit choice based on robustness, the corporate culture or cognitive style of managers who place value on quantitative and quasi-quantitative methods often reinforces a desire to select a choice that is best once-and-for-all (Millet, 2009). This has fuelled a long-standing debate about whether and when probabilities should be assigned to scenarios. Scenario ‘‘likelihoods’’ are not recommended because the scenarios are incomplete descriptions and cannot in general be expected to represent the same dimensions in probability space (Stewart, 2005). It has also been asserted that the focus is less on numbers and more on world views, mental models and strategic dialogue (Ringland et al., 2012). By focussing on the joint effect of multiple uncertainties, scenarios result in certain combinations magnifying each other's impact or likelihood in complex ways (Schoemaker, 2004). There is instead an argument for scenario weights, which should be interpreted as relative ''swing'' weights on performance in different scenarios (Durbach and Stewart, 2012).

Nonetheless, various methods exist for achieving robustness in decision aiding, and can be classified in terms of the extent to which they are driven by scenarios (outside-in) or values and preference (inside-out). For instance, methods such as robust decision making (Lempert et al., 2003) and adaptive policy analysis (Walker et al., 2001) fall in the former category as they characterise risk by defining the scenario set in terms of the threat/vulnerability posed to promising options. Methods for addressing exogenous uncertainties within a decision analytic framework can be classified as inside-out approaches. Sensitivity analysis and the incorporation of variance as a criterion fall in this category. Stochastic Multi-criteria Acceptability Analysis (SMAA), which ranks options based on Monte Carlo simulation of preference distributions; or fuzzy sets defined to contain the range of key stakeholder/group member preferences (Herrera-Viedma et al., 2007; Dias and Climaco, 2005; Kim and Choi, 2001; Salo and Hämäläinen, 1992) also start with the objectives and preferences of the decision maker, and examine these in different contexts. However, these methods fail to address interdependence among elements, and may be practically difficult.

More recently, efforts have been focussed on achieving a better integration of the concerns of deep uncertainty with decision analytic approaches. Within these approaches, scenarios help a decision-maker process more information about a complex world from an outside-in view, whereas the decision analytic framework complements this by providing an inside-out perspective on how objectives might be achieved. For example, scenarios and goal programming (Durbach and Stewart, 2003) specifies levels of desired performance and bases choice on an option's ability to attain these thresholds under the scenarios considered. Within the framework of scenarios and MCDA (Stewart, 1997, 2005; Goodwin and Wright, 2001; Belton and Stewart, 2002; Montibeller et al., 2006; Wright and Goodwin, 2009; van der Pas et al., 2010), finding a robust option requires generating or selecting multiple scenarios, defining and calculating a measure for a "good" choice for each scenario while considering potential improvements to the option set, then making a final recommendation by synthesising multiple outputs. Multiple techniques exist for each of these stages, which imply different roles for decision makers in the choice process. As a growing area of research, the advantages of and scope for further development of this particular integrated method are explored next.

3. MCDA and scenarios for the evaluating the robustness of strategic options

The advantages of combining scenarios and MCDA are rooted in three key areas of the decision making process at which they intersect (Stewart, 1997, 2005; Goodwin and Wright, 2001; Belton and Stewart, 2002; Montibeller et al., 2006; Wright and Goodwin, 2009; van der Pas et al., 2010). The first stage in the decision process is definition of the decision problem. In the MCDA process, this involves identifying the problem boundaries (options, objectives, key stakeholders, constraints). Under deep uncertainty, consideration of the interactions among variables in the external environment become increasingly relevant, and scenarios are structured to support this aspect of the problem definition. The second stage in the decision process is estimating the consequences of each option and the trade-offs involved. This process is conducted in a somewhat ad-hoc manner in the scenario literature, and largely limited to holistic judgments on the performance of options. MCDA offers synergy through its structured process for evaluating options given competing objectives, in the context of each scenario. The final stage of the decision process is option selection. The scenario planning (Schoemaker, 1995) and multi-criteria communities (Roy, 2010; Aissi and Roy, 2010; Hites et al., 2006; Roy, 1998), as well as the broader field of Operational Research (Rosenhead, 2001) endorse the use of robustness when evaluating options under deep uncertainty. While definitions of robustness vary according to decision contexts and philosophies, applications involving scenarios and MCDA have defined a robust option as one that attains a reasonable and stable performance across scenarios considered (Montibeller et al., 2006; Stewart, 1997, 2005; Belton and Stewart, 2002; Goodwin and Wright, 2001). This can prompt option improvement aligned to values (Montibeller et al., 2006), in a way that does not conflict with strategy development techniques such as the TOWS matrix[1] (O'Brien, 2004) or a portfolio-based view on robust, fragile and flexible organisational capabilities needed to succeed across the scenario set considered

[1] The scenarios help one identify relationships between environmental threats and opportunities, which are then crossed with an organisation's strengths and weaknesses to develop strategies in four areas: (i) leverage organisational strengths to mitigate threats; (ii) leverage organisational strengths to capitalise on opportunities; (iii) mitigate organisational weaknesses and environmental threats; (iv) mitigate organisational weaknesses and capitalise on opportunities implied by the scenarios.

(Schoemaker, 2002). MCDA achieves this by using formal methodologies to think about values in a systematic way (von Winterfeldt and Edwards, 1986; Keeney, 1992); and appropriate presentation of information and extensive discussion (Belton and Hodgkin, 1999).

Various open questions remain regarding the effective integration of scenarios and MCDA. These include the role of MCDA in bounding the scenario space (Wright and Goodwin, 2009); the number of scenarios needed for effective application of MCDA and how they should be constructed (Stewart, 2005); as well as the role of robustness in supporting option development and choice. This thesis will propose and assess the impact of extensions which reflect an alternative strategy for addressing these questions in the context of the three areas of intersection for scenarios and MCDA discussed above. The rationale for these extensions is explored next.

While there is agreement that scenarios should be representative of the range of possibilities, perspectives differ on whether this should be achieved by a small number (i.e. no more than four) of narratives that focus on extreme outcomes (Wack, 1985; Mietzner and Reger, 2005; Huss and Honton, 1987) or a larger set of scenarios that result in high coverage of the uncertainty space, assuming that scenario consequences can be modelled in some way (Lempert et al., 2003). This thesis proposes a mid-way strategy for scenario selection based on the use of a larger set of scenarios than traditional scenario planning, but still small enough to engage a decision maker in a debate around consequences and trade-offs.

The selection of uncertainties and relevant boundaries is based on a proposal in the recent scenarios and MCDA literature that rather than moving forward through causal chains to arrive at scenarios, one can work backwards from an organisation's objectives (Wright and Goodwin, 2009). Using this approach, the ranges of possible achievement (worst possible and best possible case) for each of the main objectives can be extended (i.e., made more extreme) and decision makers asked whether they could envisage particular interactions that make these, more extreme, best- and worst-case levels of achievement plausible. The business-as-usual outcome is used as an anchor for this discussion.[2] The uncertainties, defined by their possible extremes, could then be mapped on to an importance/unpredictability matrix as in traditional scenario

[2] It is not important to account for all the possible outcomes of each uncertainty; simplifying the range of outcomes is sufficient. The purpose here is not to cover all possibilities, but to describe a wide range (Schoemaker, 2004).

planning (Schoemaker, 2002) to select the key uncertainties to form the basis for scenarios. Exploring the boundaries in this way could simulate conversation on the enablers and barriers to success across which to examine the validity of options (Lafley et al., 2012). In so doing, the aim is to create a tighter integration between scenarios and MCDA, by reflecting the notion that values determine what information is of central importance in making decisions and what can be ignored (Keeney, 1992; Morecroft, 1985).

The next step is the selection of scenarios. The aim is to maintain the principle that scenarios should explore possibilities for significant change from the status quo (Schoemaker, 2002); confer a sense of ownership (Wack, 1985); but also provide a representative sample to better support weighting of judgments as advocated by decision analytic frameworks (Fiedler et al., 2000). To achieve this, all possible combinations of best-case, business-as-usual and worst-case outcomes for the key uncertainties identified define the scenario space. Given that extremes help one to consider a large range of variability for key uncertainties identified (Masini and Vasquez, 2000), extreme scenarios are defined as those that are significantly different from the business-as-usual scenario. The distance from the business-as-usual outcome is calculated in terms of the percentage of overlap of outcomes between that scenario and another in the set (Tietje, 2005). Characteristics of those scenarios that are most different from the business-as-usual scenario (i.e. low similarity to the business-as-usual scenario) are considered in the method here proposed. For any number of uncertainties, this set is characterised by the scenarios with best possible outcomes on all uncertainties; scenarios with worst possible outcomes on all uncertainties; and scenarios with the worst possible outcome for one uncertainty given best possible outcomes on all others (repeated for each uncertainty); and vice versa.

A further consideration for a relatively larger scenario set is the appropriate level of scenario detail, on the basis that it could lead to reluctance in using scenarios for strategy formulation due to perceived costs of developing and disseminating the scenarios in terms of management time (Grant, 2003). While the benefits of developing a scenario narrative should not be understated (Kahane, 2012; Bowman et al., forthcoming; Beach, 2009; Volkery and Ribeiro, 2009; Wack, 1985), various findings suggest that it may be less useful as a backdrop for assessing and comparing potential outcomes based on the perceived relative importance and performance of criteria. First, additional levels of detail in an already complex decision problem may simply add to the complexity of the elicitation task (Goodwin and Wright, 2009). Heuristics/ selection of a few key cues may be used to reduce the effort involved in managing additional complexity (Shah and Oppenheimer, 2008), effectively reducing the benefit of deriving the narrative in the first place. A study on preferences for presentations of uncertainty found weak support for scenarios being easy to understand and explain to decision makers, but that they did not convey information for planning in general or to specifically evaluate plans (Groves et al., 2008). Second, brief scenarios, not causally linked, do not impact the cognitive benefit of accepting a wider range of outcomes (Kuhn and Sniezek, 1996). Third, the judgments of experts and non-experts can be described by a small number of significant cues (Shanteau, 1992). Consequently, scenario snapshots/vignettes are used here. Each snapshot is comprised of a common module (trends) and an experimental cues module (combinations of uncertainty outcomes selected). They are presented to the decision maker for feedback on their clarity before applying the MCDA framework (Rungthusanatham et al., 2011).

With respect to elicitation, the second stage at which scenarios and MCDA intersect, a MCDA model per scenario is constructed, on the basis that it would not only be cognitively easier (Montibeller et al., 2006), but practically meaningful when consequences are very different depending on whether a particular event occurs or not (French et al., 1997). Another advantage of this approach is that it allows one to use different value trees for different scenarios. However, it means that elicitation of weights is based on swings for ranges deemed plausible within a particular scenario. Similarly, a value assigned to a criterion in a positive scenario is defined by a different scale from a value assigned to the same criterion in a negative scenario due to the existence of enabling features in a positive scenario, which may lead to lower sensitivity to certain issues. As such, the values assigned across independent MCDA models are not easily comparable.

Various approaches are available for comparing options using different functions for describing preferences. For instance, the odds ascribed to the future states of the world that render a candidate robust option vulnerable may be compared to cost implications for that option (Lempert et al., 2006). This approach does not determine choice, but reduces deliberation on choice to a small number of trade-offs that the decision-maker must ponder. Another approach is event conditional attribute modelling, which requires a judgment of indifference which relates two sets of consequences (French et al., 1997). For multiple scenarios, this can become very cumbersome.

The cost-equivalent mechanism is used here to address this issue (Keeney, 1992). Its main advantage over alternatives is that it is easy to understand and implement. In addition, it does not rely on market considerations and observed prices. This is typical of many public policy decisions where no market prices exist for consequences such as lives lost and habitat destroyed, and where multiple stakeholder perspectives must be considered. Instead, the cost to society to eliminate one unit of each consequence may be developed through a review of literature on the value of life and statistical analysis of damages, with estimates erring on the high side (von Winterfeldt et al., 2004). Nonetheless, it is a measure to be used with caution, as it may lead to awkward and difficult interpretations (e.g. value of intangibles such as lives, ecological worth, old versus young).

In order to address the robustness concern, the position is taken here is that in comparing results of MCDA performance across multiple scenarios, one should be able to compare the performance of options within a particular scenario to identify scope for improvement relative to other options, as well as across scenarios. This would help one to understand the spread of performance (Montibeller and Franco, 2011; Durbach and Stewart, 2003), and provide a decision maker with an outside-in and inside-out approach to choice. Understanding performance of options for a given scenario could stimulate thinking on what can be done to enhance an option's chances of success in the face of externally imposed threats and opportunities. Understanding the performance of a given option for the scenario set considered could further stimulate thinking on how objectives might be better achieved given that consequences of a particular choice will be judged with hindsight very differently whether positive outcomes for key uncertainties occur or not.

Measures such as inter-scenario risk and robustness have been proposed for assessing robustness (Montibeller and Franco, 2011), but regret is proposed here due to its ability to consolidate learning in two main ways that remain consistent with the philosophy of scenario planning:

i. Process regret: Despite mixed findings on anticipated/predicted regret[3] and experienced regret, the measure could motivate one to think about how an

[3] It has been found that predicted regret and experienced regret correspond quite well (Mellers et al., 1999). However, there exists a counter argument that people generally anticipate more regret than they will actually experience because they underestimate the efficacy of the psychological defences they will deploy (Gilbert et al., 2004). This aligns with findings that it may only take some simple and subtle manipulations to increase curiosity and overcome regret aversion (van Dijk and Zeelenberg, 2007).

event could have happened and how one could change it, or prevent its future occurrence (Zeelenberg et al., 1996). In so doing, the aim is not minimising risk but the articulation of risk so that the decision maker knows what is at stake in his decisions (Ogilvy, 1996).

ii. Option regret: Regret could assist in identifying vulnerability to challenges which may be countered if the available information is used differently. A focus on vulnerability is linked to the finding that only negative outcomes stimulate the search for causes and criticism of choices (Peeters and Czapinski, 1990; Taylor, 1991), while good outcomes tend to elicit little cognitive activity. Despite the criticism that regret may reinforce rather than question conventional choices, being explicit about anticipated regret seems to align with the resulting tendency to an extreme reluctance to take risks that is typical for decision makers who expect to have decisions scrutinised with hindsight, such as physicians, CEOs and politicians who work within performance cultures (Kahneman, 2011). Moreover, in deeply uncertain decision contexts, a reasonable objective is to find a solution with performances as close as possible to the optimal values under all scenarios. This amounts to setting a threshold ε and looking for a solution with ε as small as possible. This is equivalent to determining a minmax regret solution (Aissi et al., 2009).

Consequently, the proposed basis for choice is cost-equivalent regret. For a given option, this is defined as the degree of difference of an option's value, measured in terms of its cost-equivalent, from the maximum achievable performance across all options in a given scenario. The prescription for choice would be the option with a concentration of regret values near zero. Consequently, choice is guided by an investigation of option performance within and across scenarios, and should enable a decision maker to rehearse how he/she would deal with the consequences of action and inaction.

4. Measuring effectiveness of the method

From the MCDA perspective, effectiveness of a method can be measured through process effectiveness (quality of the analysis process), output effectiveness (quality of the immediate output of the analysis), and outcome effectiveness (intended or unintended consequences of the analysis in the long run) (Schilling et al., 2007). In this thesis, the focus is on process and output effectiveness, recognising that it is difficult to claim outcome effectiveness of a strategic decision, which is ultimately a function of novelty of decision task, irreversibility of response, significance of outcomes, accountability, time and money constraints (Payne et al., 1993).

Similarly, the most effective scenario method will satisfy process as well as outcome criteria (Hulme and Dessai, 2008). From a process perspective, scenario building should link into the planning process and gain the support of top management early on (Schoemaker, 1998). Scenarios should be engaging and enable learning (Chermack et al., 2007), prompting uptake or usage of the scenarios amongst decision makers (Hulme and Dessai, 2008). From an output perspective, scenarios should capture a broad range of uncertainties, challenge implicit assumptions about what will not change, and capture one's imagination about how the future might develop (Ringland et al., 2010, O'Brien et al., 2007). They should therefore contain a sufficient representation of knowable uncertainties to offer the prospect that decisions taken in light of the scenarios will be robust (Hulme and Dessai, 2008). Collectively, these suggest that the benefit of the extensions proposed must be assessed with a view to addressing multiple aspects. This motivates a multi-method investigation of these issues, which is discussed next.

4.1 Research methods for assessing strategic decision making

The literature on the evaluation of judgment and decision making highlights different modes for assessing the effectiveness of decision making. For instance, decision making can be assessed intuitively (subjective measures of satisfaction) or objectively (weak and strong effectiveness); process or outcome can be compared against another set of rules; or the method can be evaluated in terms of logical reasoning from axioms (Hastie, 2001). As such, simulations (Durbach and Stewart, 2012), experiments (Payne and Bettman, 2004) or real world decision making (Morton and Phillips, 2009) can be used.

Experiments and simulations make assumptions about the decision making behaviour and their interaction with the environment. An experiment makes assumptions about the environment as a control strategy, but measures behaviour. An examination of real-world behaviour arguably makes the fewest assumptions about the environment and individual behaviour (Harries, 2003). Examination of real world behaviour in social science is particularly amenable to qualitative research as complex social processes often exist, and the aim is to understand the "black box" of practice, programs, and interventions which quantitative research cannot easily detect (Scholz and Tietje, 2002). On the other hand, quantitative research provides a stable, risk-free and efficient environment within which to rigorously test theoretical implications of particular strategies. A review of how scenario planning and MCDA have been assessed using each of these techniques can provide insights on how the extensions proposed in this thesis might be most effectively assessed.

Case study

The distinction between intended purposes and potential usefulness is less than clear in strategic decision making methods (Harries, 2003). This makes the case study approach a particularly appropriate tool in the early phases of new theory, when relationships between variables are being explored (Gibbert et al., 2008). It enables one to follow a thought process sequentially under successively unfolding social situations, and so is better placed than quantitative methods to grasp the important aspects of social phenomena (Numagami, 1998). While the number of cases one can include in the research design is limited by time and resources available, a cross-case analysis involving four to ten case studies has been suggested as providing a good basis for generalising from empirical observations to theory (Eisenhardt, 1989). However, single in-depth cases have also been shown to be powerful examples of management practice (Siggelkow, 2007). These may take the form of multiple case studies in different organisations, or different case studies within one organisation (a nested approach, e.g., Yin, 1994). A key criticism of the case study approach is its lack of reliability (i.e. enabling subsequent researchers to arrive at the same insights if they conduct the study along the same steps again) and internal validity (i.e. engenders confidence in the research conclusions) due to biased sampling and difficulty in distinguishing between the effects of organisation, method and environment. Triangulation, production of a case study protocol and a case study database of all data gathered may help achieve a satisfactory outcome on these criteria (Gibbert et al., 2008).

The case study approach has been manifest in the scenario planning literature often through reports of individual successes and the factors affecting them (Clark et al., 2006; Ogilvy and Smith, 2004; Ringland, 1998; Moyer, 1996). Increasingly, longitudinal studies are being used to address the question of how scenarios correlate with organisational performance (Bowman et al., forthcoming; Wright et al., 2009; O'Brien, 2004; Burt, 2010; Hodgkinson and Wright, 2002; Roubelat, 2000). Even so, the structure of these studies have ranged from pre-defined propositions (Bowman et al., forthcoming) to exploratory approaches that aim to understand the impact of the intervention on participants through an action research paradigm (Burt, 2007; Cairns et al., 2004; Burt and van der Heijden 2003; Roubelat, 2000) and supported by comparison with patterns established in previous studies (Wright et al., 2008). Ethnographic studies have followed a similar approach in examining how scenarios are used within organisations (van't Klooster and van Asselt, 2006). Techniques for data collection have often included interviews with several members of the senior management team prior to and following an intervention (Bowman et al., forthcoming; Wright et al., 2008; Hodgkinson et al., 1999) or with practitioners to find out what contributed to a successful intervention (Light, 2005; Glenn and Gordon, 2001), followed by coding of the qualitative data.

Within the MCDA literature, case studies have also featured quite prominently in the assessment of impacts from practical application (Stewart et al., 2010; Schilling et al., 2007; Hodgkin et al., 2005; Bana e Costa, 2001; Phillips, 1986). Quality criteria such as implementation cost and time, stakeholder participation, support for problem structuring and learning, as well as promotion of transparency and broader communication have been proposed (De Montis et al., 2000). It has also been suggested that these ought not to be compared only with respect to the status quo, but also in terms of distance from the perceived ideal (Schilling et al., 2007). Action research, which aims to support practical problem solving as well as engage decision makers in collaborative research to extract lessons for future interventions, has been an increasingly common methodology. The decision contexts in which action research has been applied for assessing the impacts of MCDA have been characterised by diverse stakeholder groups in the public sector and choices with high strategic impact leading to a desire to explore alternatives in a systematic manner (Franco and Lord, 2011; Stewart et al., 2010; Petkov et al., 2007; Belton et al., 1997). Several such studies have involved the use of multi-methodology approaches involving MCDA, particularly soft approaches such as cognitive mapping (Belton et al., 1997); soft systems thinking (Petkov et al., 2007) and scenario planning (Montibeller et al., 2006).

Experiment

Controlled experimental evaluations of scenario-based decision making have been elusive (Harries, 2003). They tend to follow a quasi-experimental pre-test/post-test design, and generally measure the effects of scenarios on beliefs, confidence or problem perception (Groves et al., 2008; Schoemaker, 1993; Kuhn and Sniezek, 1996) or improvements to specific aspects relating to the quality of the decision making process (Chermack and Nimon, 2008; Chermack, 2007). A quasi-experimental approach represents a compromise between carrying out a design that allows a clear causal inference (i.e. internal validity) of a test method, and fully engaging with workshop participants to address their real-time concerns about planning under uncertainty (i.e. external validity), but with a similar aim of learning from the experience to subsequently refine the method (Groves et al., 2008).

In the case of measuring scenario effects on beliefs, one quasi-experimental design presented scenarios over three workshop sessions in a sequence of decreasing order of familiarity and increasing order of complexity. Participants were asked to rate on a 5-point Likert scale the extent to which they agreed or disagreed with the credibility of the method, ease in interpreting results, effects of the methods on their confidence in the current management plan, and perceptions of vulnerability of the system to a negative outcome before, during and after a particular process (Groves et al., 2008). A sample size of between 15 and 30 was used for each group. Variance among pre-and post-test responses were compared, and a t-test conducted. While a significant effect was detected, sample size, lack of a control group and lack of a valid instrument for measuring impacts were cited as major limitations (Chermack et al., 2007).

Experimental studies are more common when one examines scenario presentation within the context of the broader literature on the impacts of uncertainty representation (Kreye et al., 2012; Durbach and Stewart, 2011; Gottlieb et al., 2007; Hodgkinson et al., 1999; Shanteau et al., 1992). Analysis has typically involved ANOVA based on a two-stage between-subject design based on analysis of mean confidence levels (Schoemaker, 1993) or allocation of a fixed sum of money (Kreye et al., 2012; Hodgkinson et al., 1999); but with varying levels of engagement in scenario construction from participants. For instance pre-defined scenarios were used (Durbach and Stewart, 2011; Kuhn and Sniezek, 1996), but there is evidence that participants have also been asked to develop scenarios (Schoemaker, 1993). Experiments have also formed the basis for theoretical explanations of the scenario planning process through classification and interpretation of the literature through Jungian's cognitive styles (Franco et al., forthcoming), or Dubin's eight-step theory building methodology (Chermack, 2005).

Within MCDA, the main advancements in recent times have been in terms of practical applications and documented reflections on the craft of modelling, as well as a deeper psychological understanding of the processes by which people can be helped to construct beliefs and make probabilistic assessments (Morton and Phillips, 2009). Experiments have been much less common, but studies do reflect attempts to investigate the existence of asserted benefits such as reduction in the complexity of a decision problem and increased confidence in evaluation results (Kasanen et al., 2000). For instance, role playing experiments with two groups of students have been used to provide an idea of how a proposed approach to interactively identify Pareto-optimal solutions worked in practice. Criteria were time to completion, ease of completing tasks and overall satisfaction (Hämäläinen et al., 2001). Similar criteria have been used to compare multi-criteria decision making methods (Bell et al., 2001; Zapatero et al., 1997). Crucially, both studies in scenarios and MCDA involving experiments have examined decisions as single events or over a short period of time.

Simulation

Simulations involving scenario-based decision making are even less common. Given the difficulties of mapping actions taken under a particular scenario to consequences on multiple criteria, a modelling approach based on assumptions such as knowledge of the full scenario space must be adopted (Stewart, 1996; Durbach and Stewart, 2009; Durbach and Stewart, 2012; Hall et al., 2012). One possible reason for the dearth of simulation techniques in analysing the effects of scenario planning is that effectiveness of scenario planning lies in the ability to engage organisational members in genuine conversation about the possibilities of the future (Schwartz, 1991).

Monte Carlo simulation has typically been used in MCDA in order to investigate the effects of various practical variables in a controlled environment, for example the effect of using piecewise utility functions, missing attributes, weight assessment difficulties, and violations of preferential independence (Durbach and Stewart, 2009). Another example has been to compare the similarities and differences in the option ranking yielded by different methods as the number of alternatives, criteria and their distribution vary (Zanakis et al., 1998). Option rankings for different multi-criteria approaches for aggregating conflicting criteria (e.g. benefit and cost) across different methods have also been compared. Although the simulation could not provide an answer on which option ranking was 'correct', it could highlight which approach was immune to ranking inconsistencies (Triantaphyllou, 2005). From a decision aid perspective, simulation has been used to quantify impact through measures such as incremental return on profit (Lilien et al., 2004).

Assessments of the combined use of scenario planning and MCDA have largely been based on case studies (Montibeller et al., 2006; Phillips, 1986). While experiments have been used in scenarios and MCDA separately, there is no known evidence of experimental evaluations involving the combined approach. Although the impact of different scenario selections on measures of performance within MCDA using a simulation approach has been cited as an area for further research (Durbach and Stewart, 2012), it remains unexplored.

4.2 Methodological choices

In this thesis, the impact of the proposed extensions is assessed in three ways:

- Practical: To what extent do the proposed extensions provide a transparent (i.e. relationships between model inputs and decision recommendations can be readily understood) and meaningful evaluation process?
- Effort implied by scenario selection: What is the time/quality trade-off from using different levels of scenario detail in the MCDA process?
- Relative accuracy of different robustness measures: To what extent do scenario selection techniques affect the accuracy of different robustness measures?

Investigating the latter two seeks to provide insights on the accuracy-effort trade-off implied by the proposed scenario selection procedure and the use of regret for assessing robustness. Practical evaluation aims to provide insights on the coherence of the proposed extensions in a real-world setting.

In order to evaluate the effectiveness of the individual extensions and the method as a whole, neither a purely positivist nor a purely interpretivist approach is sufficient to fit the complexity of the intervention (Eden, 1995). This suggests that a multi-research method approach is more appropriate. Controlled experiment can overcome the weakness of an interpretivist approach to identify exactly what works and to demonstrate how interventions could be improved (White, 2006). The practical assessment in turn could address the weakness of the controlled approach to provide insights on the coherence of the extensions, and the adequacy of the method in a practical setting. Conclusions on the areas for improvement of the method could then be made by preserving the tension and holding the contrast between methods in order to theorise in new ways (White, 2006). Triangulation therefore could be used not only to examine the same phenomenon from multiple perspectives but also to enrich one's understanding by allowing for new or deeper dimensions to emerge (Jick, 1979). The next section provides a rationale for the research methods used to assess impact in this thesis.

4.2.1 The Assessment of Practical Impacts

From the above review of the evaluative scenario planning and MCDA literature, four areas of qualitative inquiry could be considered to assess practical impacts of the method: ethnographic study, longitudinal study, grounded theory and action research.

The ethnographic approach has been used to gain a fuller understanding of whether and to what extent the scenario-axes technique provides a means for structurally and coherently developing images of the future (van't Klooster and van Asselt, 2006). While the idea of participant observation was relevant to the objectives of this thesis, ethnography would be more suitable if the aim was to develop an early understanding of the relevant domain, audience(s), processes, goals and context(s) of use as a precursor to design of the extensions.

A longitudinal approach would be most appropriate if the aim was to gain insights into the extent to which closure was achieved (i.e. extent to which problems that stimulated a decision were solved). Its key strength is that it provides a more representative assessment of the strategic decision making process than cross-sectional studies which provide a snapshot of the organisation at a particular point in time. Its key shortcoming is the time investment required. Given that this was a method in-development, it seemed reasonable that practical assessment should be limited to a period of learning about the impacts of the extensions in a less resource-intensive manner.

A grounded theory approach allows the systematic identification of a set of conceptual categories and their interrelations, which develop as the analysis continues. These emerging "grounded" concepts, derived from the data, are then used as the basic building blocks of the growing theoretical understanding of the phenomenon under study (Franco and Lord, 2011). This bottom-up process is based on constant comparison of similarities and differences among cases, with each subsequent case being chosen on the basis of what the researcher wants to investigate next. Given that the proposals to be assessed were based on pre-existing theoretical ideas and assumptions, this conflicted with the essence of grounded theory to inductively derive a general, abstract theory of process, action, or interaction grounded in the views of participants in a study.

Action research (AR), defined here as a research strategy and not a data collection technique, focusses on practical problem-solving while performing the research collaboratively with select subjects (Hult and Lennung, 1980). In so doing, AR provides potential for understanding the subjective meanings participants attribute to their experience of using the method, and places that understanding in the larger patterns of interaction within which the intervention is embedded. The significance of action research as a methodology is consequently its capacity to generate and test theory to learn in order to improve practice (McNiff and Whitehead, 2011; Checkland and Holwell, 1998), thereby making it an appropriate methodology for examining the practical impact of the method.

However, design of the AR intervention calls for two key criticisms to be addressed. The first is that its outcomes are essentially large body of knowledge which is not theory, not real practice, but is related to both. This is exacerbated by published reports of action research projects that tend to accentuate the positive and eliminate the negative whenever possible (Hodgkinson, 1957), and that focus on "pure action", lack clear research objectives or a clear research design. In order to mitigate the effect of this, results are compared and contrasted with the knowledge available in the literature, accompanied by a search for evidence that discredits it. This strategy cannot guarantee that the causal explanation is actually occurring (a dilemma shared by experimental design), but can increase the confidence that it is more plausible (Montibeller, 2007).

The second key criticism of AR is that it ignores the scientific frame of reference (Cohen and Manion, 1989; Hodgkinson, 1957). In other words, it precludes precise definition, measurement, and control of the variables, and relies on a sample size that is not representative, meaning that generalisations are limited. This weakness might be addressed through triangulation (Flick, 1992). In addition, recommendations that one should enact a process based on a declared-in-advance method in such a way that the process is recoverable by anyone interested in subjecting the research to critical scrutiny are followed (Checkland and Holwell, 1998).

Consequently, the following was employed to guide the interventions and analysis of decision maker responses:

i.*Definition of the Area of Application*. Three public sector projects in Trinidad and Tobago involving option assessment were used. This particular context was chosen as different areas were being reviewed to meet objectives of a 2020 development plan for the country. Cases were selected on the basis of suitability for application of the method (meaning there was uncertainty about which actions will yield most benefit; inability to envisage the full range of complex interactions; and a degree of difference in preferences regarding the relative importance of objectives); a belief that the current decision strategy was insufficient as well as a desire to pursue an analytical approach in the search for a better decision strategy. A number of different cases were chosen to enable a degree of generality through cross-case patterns. In each case the diversity of opinion was surveyed through interviews with those who would typically provide information inputs to the decision process (as identified by the decision maker) to canvas plausible uncertainties and objectives. Subsequently, a single decision maker was used to gain an understanding of the decision support method in its lowest common denominator of involvement. Given the visibility of decision-maker positions and institutions, various steps were taken to safeguard their rights, including articulation of research objectives verbally and in writing; written permission to proceed with the study as articulated; and full disclosure on all data collection devices and activities.

ii.*Definition of the Framework of Ideas.* The proposed method combining scenarios and MCDA as described in the previous section.

iii.*Derivation of Evaluation Criteria for the interventions*. The criteria chosen were grounded in the literature on benefits and cost criteria used to evaluate scenario planning and MCDA interventions, and are equally applicable to the integrated method:

a.Perceived transparency: Comprehensibility of each stage of the process, with limitations of the method clearly identified (Schilling et al., 2007). This criterion is akin to ease of use, and ease of understanding the relationships between model inputs and decision recommendations (Salo and Hämäläinen, 2010; Bell et al., 2001; Zapatero et al., 1997; Payne et al., 1993) and credibility of the process (Postma and Liebl, 2005).

b.Adaptive approach to change: Prompted to consider a range of possible challenges in the external environment when selecting strategic options (Schoemaker, 1993; Wack, 1985).

c.Rational: Supported the decision-maker in using meaningful and reliable information to make clear value trade-offs and use logically correct reasoning (Schilling et al., 2007; Bell et al., 2001; Matheson and Matheson, 1998).

d.Challenge current strategic priorities: Active questioning of the way strategic choices are currently made (Schilling et al., 2007; Schoemaker, 2002; van der Heijden, 1996).

e.Stimulate creation of options: Generation of additional options/improvements (Montibeller et al., 2006; Goodwin and Wright, 2001).

f.Confidence in the results and the procedure used to obtain results (Bell et al., 2001; Zapatero et al., 1997).

g.Time taken to complete the intervention, from problem structuring to option selection (Payne et al., 1993).

h.Emotional cost of considering trade-offs across multiple objectives.

iv.*Application of the proposed method.*

v.*Evaluation of the conducted application in relation to the pre-defined criteria.* The interviews were conducted in the form of a dialogue as opposed to a mere posing of questions followed by subject answers, and focussed on "what" and "how" questions (Sandberg, 2005).The consistent use of a pre-intervention and post-intervention questionnaire following this dialogue served to consistently gather feedback on the practical value of the process. For instance, the pre-intervention interview explored three main themes: inputs and strengths of the current process, how uncertainty and multiple objectives were handled within this process, and previous experience with scenarios or MCDA. The post-intervention interview explored perceptions on the suitability of the method for the decision; the importance of some of the defined benefits of the proposed method; how well the process met what they considered important in evaluating their decision and any other benefits or drawbacks they identified; and their suggestions on key areas for improvement (Dooley et al., 2009).

vi.*Derivation of conclusions; resulting in lessons learned and recommendations.* A high level analysis based on a process, information and outcome framework was first conducted. Pre- and post-intervention questionnaire ratings were then compared against the defined themes in terms of distance of proposed method from a stated ideal, and distance of the method from the status quo method. A small distance from these two values indicated an improvement attributed to the method; and a value near zero for the distance of proposed method from a stated ideal meant that the method brought about a more desirable change in evaluating strategic options under deep uncertainty. Codes were then used to capture feedback relating to each research theme, and colour codes to capture which stage in the process comments were made. This helped to weave a narrative of how perceptions changed throughout the process. These findings were then compared with those arising from practical applications of MCDA, scenario planning and more broadly, making judgments under uncertainty.

Findings are deemed generalizable only to decision contexts similar to those investigated, in keeping with action research principles (McKay and Marshall, 2001). In the course of analysing transcripts, the following guidelines are adhered to as a further check on validity:

a.Focus first on understanding what the decision maker is trying to convey, and look through the entire transcript without any pre-defined framework. This meant equal importance was assigned to feedback.

b.Deliberately search for differences and contradictions by assessing findings against alternative perspectives in the literature.
c.Acquire a general grasp of feedback based on several readings of transcripts. This is followed by a systematic search for concepts related to a particular dimension of quality, with a coding to represent the stage in the process the comments were made. This strategy supported an understanding of how perceptions evolved.

4.2.2 The Assessment of Effort and Impact

While AR provides insights on the practical impacts of the method, a theoretical assessment is required to examine the value of the method relative to its competitors in the literature. The benefits of a scenario narrative for learning under deep uncertainty are undisputed, but as discussed earlier, its relevance for option evaluation may be questionable. To assess this, a behavioural experiment is used to provide preliminary insights on the trade-off between the perceived benefit and the time requirement for MCDA evaluation for scenario snapshots versus narratives. This experiment, run as a pilot, is intended to gather some initial data about this rather unexplored issue in scenario planning.

In order to assess the impact of using the proposed scenario selection procedure with regret, it is compared to performance under a normative ideal. In the decision analytic framework, this refers to the maximisation of expected utility. Utility corresponding to the "true" best option can be compared to the utility corresponding to the best option implied by different scenario subsets for a given robustness measure, bearing in mind the influence of different elements of the decision problem such as risk attitude and problem size. This lends itself to simulation. This approach may be contentious among scenario planners, as an observable future space is defined, and may be detrimental to the process of learning through scenarios (Hulme and Dessai, 2008; van der Heijden et al. 2002; Masini and Vasquez, 2000). The impact on various aspects of learning in the evaluation process is addressed through experiment; while the simulation addresses a distinct gap in the literature on the evaluation of the relationship between scenario generation techniques and decision rules for robustness. The two analyses can together better inform the sequencing of steps in scenario-MCDA methods.

5. Outline of Thesis: The Three Papers

The substantive component of this submission comprises of three papers, both single and jointly-authored. Table 1 summarises these papers with respect to how they address the overall aims of the thesis as outlined above. Paper 1 investigates structural changes to the integrated scenario and MCDA method to facilitate exploration of a more diverse set of scenarios as well as comparison across scenarios given scenario-specific MCDA models. Paper 2 applies Action Research in three in-depth case studies to test the practical impacts of these proposals on pre-defined criteria for decision aid under deep uncertainty. Paper 3 assesses the benefit and cost of the individual extensions in more controlled settings.

Paper 1 proposes method for analysing options under multiple scenarios with multiple criteria. It consists of a technique for generating scenarios that seeks to attain the learning benefit derived from a small number of scenario narratives (that copes well with multiple qualitatively and quantitatively defined variables) versus the accuracy benefit derived from considering a large number of possibilities (that copes best with quantitative variables). To this end, a morphological analysis approach is used, due to its capability to select a larger number of uncertainties (five to seven compared to the typical two), each of which may take a small number (two to five) different levels (Ritchey, 2006). Paper 1 recommends the use of regret for assessing robustness, which benchmarks options against the best-performing option in a particular scenario. As a relative measure, regret focuses attention on the spread of performance among options and across scenarios (Lempert et al., 2006). This may serve to highlight the strengths and weaknesses of options in a more salient manner. Third, the construction of a separate additive MCDA model for each scenario can facilitate the process of exploring implications of scenarios and so can accommodate different value hierarchies across scenarios. However, the resulting option performance from these models is scenario-specific. Paper 1 proposes the concept of cost-equivalence for converting performances to a common metric for comparison across scenarios (Keeney, 1992).
Paper 2 aims to practically test the method proposed in Paper 1 by using action research to gauge the extent to which the extended method delivers what it is designed to do. Three independent case studies in the public policy context in a developing country are used. Action research is chosen as a suitable research methodology since its dual focus on practical problem solving as well as research through personal involvement means that it is well-placed to practically assist in developing and implementing actions to make the extended method more effective while simultaneously building up a body of scientific knowledge (Montibeller, 2007; Coughlan and Coghlan, 2002).

The cases consistently show that the main benefit of the method is a prompt to gather further information about options, and more systematically consider improvements to the existing option set. The scenarios, even in condensed form, provide sufficient information for the decision maker to engage in consequential reasoning about options. Structuring the problem in terms of paths that might plausibly lead to negative and positive consequences is crucial to the sufficiency of a snapshot.

The intent of Paper 3 is to develop a better understanding of the effort required by and impact resulting from differentiating aspects the method relative to different decision rules for robustness and different scenario generation techniques in the literature. Specifically, the impact of providing less information about the external environment for an evaluation task is assessed through a pilot experiment involving a career choice problem. Seventy-eight (78) students are randomly assigned no scenarios, scenario snapshots or narratives. They are asked to complete a MCDA evaluation exercise, and answer a short questionnaire regarding confidence in their choice, prompt to consider improvements in options, and consideration of relevant information through sensitivity to a broader set of outcomes in the external environment. These dimensions are consistent with criteria used in examining the cognitive impacts of scenarios (Kreye et al., 2012; Durbach and Stewart, 2011; Hodgkinson et al., 1999; Kuhn and Sniezek, 1996), but with criteria used to assess the quality of a decision analysis process (Schilling et al., 2007; Bell et al., 2001; Payne et al., 1993). The extent to which choice for different decision rules for robustness relative to choice recommended by an ideal procedure in a scenario-MCDA framework is evaluated through a simulation approach.

The results show that there is no detriment to using scenarios in the evaluation process. It may therefore be the case that scenarios increase the efficiency, but not necessarily the effectiveness, of the elicitation and option improvement process due to its capacity to provide a structure for clarifying preferences under deep uncertainty. The simulation highlights the need to consider the risk attitude of the decision maker in assessing robustness, with the threshold level for risk playing a key role. Scenario selection does influence the accuracy of robustness measures, but the loss incurred across robustness measures is similar, and practically immaterial. Nonetheless, the findings indicate that considering scenario clusters which highlight vulnerabilities of strategic options are superior to single point estimates of extremes.

	Paper	Methodological Issue Addressed	Research Objectives	Methodology/Approach	Main Findings
1	**Extending the Use of Scenario Planning and MCDA for the Evaluation of Strategic Options** ***Published in the Journal of the Operational Research Society***	Number and type of scenarios; use of MCDA performance measures to compare options across scenarios	Extend scenario planning and MCDA method to enable a more diverse set of scenarios to be developed quickly and to investigate how regret could be used to facilitate across scenario comparison of option performance.	Scenarios and MCDA with three key features: 1)Definition of uncertainties explicitly linked to values 2)Scenario snapshots developed using morphological analysis 3)Cost-equivalent regret for comparing option performance across scenarios	More diverse set of scenarios developed quickly through a morphological analysis approach; option comparison across scenarios when separate MCDA models for each scenario are developed is facilitated by the use of the concepts of cost equivalence and regret.
2	**Exploring the impact of evaluating strategic options in a scenario-based multi-criteria framework** ***Accepted for Publication in Journal of Technological Forecasting and Social Change***	Need for practical assessment of proposals made in Paper 1	To test the extent to which the proposed extensions (Paper 1) meet the intended aim of providing a time-efficient, understandable means of evaluation which prompts thinking about more effectively meeting the challenges of the decision problem.	Action research based on facilitated workshop with decision-makers in 3 independent public policy contexts in a developing country.	Decision maker found method useful for structuring problem and stimulating thinking about option improvement. Mixed reactions on number of scenarios, but outline format and focus on diverse scenarios well-received. However, greater support needed for supporting elicitation for inherently unfamiliar scenarios.
3	**Scenario presentation and scenario generation in multi-criteria assessments: an exploratory study**	Need for theoretical assessment of proposals made in Paper 1	To provide preliminary insights on the sequence of steps in a hybrid scenario-MCDA method through understanding the role of scenarios in option evaluation and choice of decision rule for robustness on outcome.	Experiment to examine the impact of using scenario information in varying levels for the evaluation of options using MCDA; simulation to examine the impact of robustness measures under different contexts.	Scenarios increase the efficiency of the elicitation and option improvement process, regardless of whether it is expressed as a narrative/snapshot. Larger scenario sets characterised by a cluster of extremes result in choice close to a normative ideal. Regret requires the consideration of a large set to address accuracy concerns.

Table 1- Key Findings of each Paper

6. Summary of Contribution

As a relatively new development, the integrated use of scenarios and MCDA has largely been limited to a few practical applications. However, a hybrid scenario-MCDA approach prompts several open research questions about the number and type of scenarios suitable for evaluating strategic options under deep uncertainty; the form and design of the MCDA model for evaluation; and how option robustness might be assessed and explored to motivate learning and creation of enhanced options. Various proposals exist in the literature for achieving an integrated approach, but there is a lack of systematic evaluation of their strengths and weaknesses.

This thesis explores how a larger, more diverse set of scenarios expressed as a snapshot of the future, and the use of cost-equivalent regret, could enhance the integration of scenarios and MCDA as a resourceful decision aiding tool. Results from practical and theoretical assessment of these elements can contribute to a deeper understanding of the factors that significantly impact effort, learning and accuracy. Secondly, the triangulated approach used provides a more coherent research framework for assessing the effectiveness of these elements than exists to date. This template can be easily adapted to researching impacts in other multi-methodology approaches involving scenarios or MCDA. Third, practically applying the method to public policy evaluation enable lessons from a broader contextual problem to be reported, so as to inform future decision support processes. These potential contributions might be relevant to decision analysts, scenario planners, and decision makers who wish to better address the challenges posed by deep uncertainty.

Prelude to Paper 1

Paper 1 suggests a new method for the combined use of MCDA and scenario planning. It reflects three areas of confluence for scenarios and MCDA:

i. Problem structuring and option generation in the context of deep uncertainty based on explicit definition of uncertainty boundaries as they relate to plausible positive and negative outcomes on key objectives;

ii. Preference elicitation based on scenario snapshots, rather than the traditional narrative of scenario planning (i.e. a chronology of events that explain how a hypothetical future might unfold from the present to an end state);

iii. Selection of robust option(s) given a scenario set characterised by a relatively larger scenario set than traditional configurations of extreme outcomes, and based on cost-equivalent regret.

Paper 1 makes no claim that this is a fully-developed method. A brief practical illustration is provided to examine the practical coherence of the proposals.

An earlier version of this paper was accepted for publication in May 2010 in the Journal of the Operational Research Society Special Issue on Strategy (http://www.palgrave-journals.com/jors/journal/vaop/ncurrent/abs/jors201090a.html).

Papers 2 and 3 further evaluate the proposals outlined in this paper through a multi-method research design.

EXTENDING THE USE OF SCENARIO PLANNING AND MCDA FOR THE EVALUATION OF STRATEGIC OPTIONS

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Abstract

Multi-Criteria Decision Analysis (MCDA) is well-equipped to deal with conflicting objectives when evaluating strategic options. Scenario Planning provides a framework for confronting uncertainty which MCDA lacks. Integration of these methods offers various advantages, yet its effective application in evaluating strategic options would benefit from scenarios that reflect a larger number of wide-ranging scenarios developed in a time-efficient manner, as well as incorporation of MCDA measures that inform within and across scenario comparison of options. The main contribution of this paper is to illustrate how a more diverse set of scenarios could be developed quickly, and to investigate how regret could be used to facilitate comparison of options. First, the reasons for these two areas of development are elaborated with respect to existing techniques. The impacts of applying the proposed method in practice are then assessed through a case study involving food security in Trinidad and Tobago. The paper concludes with a discussion of findings and areas for further research.

Keywords: Decision Analysis, Strategic Planning, Scenario

1. Introduction

Scenario Planning (SP) is an extensively employed method to support strategic decision making through the development of a set of narratives called scenarios. Scenarios are challenging descriptions of futures that are relevant to a strategic decision and representative of plausible developments in the external world (van der Heijden, 1996). They are an invaluable tool for managers or strategists who want to think through the future dimension of decisions and actions. When combined with option planning (where all options are put forward on a neutral mode) and a clear, structured view of what is desirable, scenarios provide a coherent framework for evaluating strategic options (Wack, 1985a; Wack, 1985b). They may also emphasise the importance of developing strategic options so that the final choice is robust (i.e. capable of responding to a variety of changes in uncontrollable factors) (Roy, 1998, 2010).

The literature has proposed several ways of integrating scenarios with a Multi-Criteria Decision Analysis (MCDA) framework (Phillips, 1986; Stewart, 1997, 2005; Goodwin and Wright, 2001; Belton and Stewart, 2002; Montibeller et al., 2006). The integrated methodology provides a range of contexts within which to systematically consider the implications of trade-offs among multiple objectives. However, there is scope for further development of the methodology with respect to developing scenarios that reflect a larger number of wide-ranging scenarios in a time efficient manner (Godet and Roubelat, 1996), and MCDA measures that inform within and across scenario comparison of options (Roy, 2005; Durbach and Stewart, 2003). This paper explores the former by suggesting a method for developing scenarios using a combinatorial set of key uncertainties, each of which may take a small number of different levels. It addresses the latter by proposing the use of cost-equivalent regret (Keeney, 1992; Lempert et al., 2006). The benefits and drawbacks of applying these in practice will be investigated through a case study involving food security in Trinidad and Tobago.

The paper is organized into three parts. First, the case for the proposed method in light of existing techniques is elaborated. This is followed by a practical illustration of the method using food security in Trinidad and Tobago. The paper then concludes with a discussion of findings and scope for further development of the method.

2. Application of Scenario Planning to the Evaluation of Strategic Options

Scenarios can be used to help the decision-maker develop a better understanding of the complex relationships between uncertainties, objectives, and strategic options, which are core components in the evaluation of strategic options (Stewart, 2005; Goodwin and Wright, 2001). They can direct attention to critical issues and uncertainties, and help define strategic priorities when multiple objectives exist. Scenarios also provide a platform for creating, testing, and refining strategic options. To this end, they may highlight potential strengths and weaknesses of options, or provide insights on how to increase the robustness of options.

The multiple uses of scenarios imply that evaluation techniques which seek to integrate them should be capable of:

- *Incorporating subjective judgments and dealing with multiple, conflicting objectives*- Scenarios are a combination of analysis and judgment about future possibilities (Schoemaker, 1991). An evaluation technique should therefore reflect this, while taking into account the existence of multiple preferences. The literature supports the use of quantitative analysis of how scenarios perform under a set of pre-defined strategic options (Leemhuis, 1985; Huss and Honton, 1987; Godet and Roubelat, 1996; Morgan et al., 1999; Wollenberg et al., 2000; Chermack, 2004; Stewart, 2005) over flexible qualitative descriptions (eg. Likert scales).

- *Achieving a diverse set of scenario themes quickly-* Robustness implies that it is meaningful to consider scenarios that cover a diversity of possibilities. The scenario narrative is typically developed by developing storylines of how the future might unfold from the present to four end states defined by the upper and lower bounds of two key uncertainties (Schwartz and Ogilvy, 1998). Development of the narrative is itself time-consuming, which is a disadvantage when this is only one constituent of the evaluation process.
- *Within and across scenario comparison-* In order to provide insights for the development and selection of a robust option, a scale that allows comparison must be developed, accompanied by informative visual displays.

MCDA and SP for the Evaluation of Strategic Options

The combined use of MCDA and SP provides a range of advantages with respect to the above implications. Firstly, MCDA is well-equipped to deal with objectives that are difficult to quantify, conflicting, and hard to compare. Scenarios provide a framework for confronting uncertainty which MCDA lacks. Secondly, it may provide a good balance between the analytic and intuitive components of decision-making, as well as between the roles of analyst and manager (Schoemaker, 1991). Finally, an integration of the methods that allows for within and across case comparison can provide a documented rationale for a particular choice, or a shortlist of options supported by an elaboration on the conditions in which they perform best (Roy, 1998).

Table 1 summarises the literature that involves integration of SP and MCDA to date. It assumes a set of scenarios S= s_k, k=1,..,t; a set of strategic options A= a_i, i=1,…,n and a set of criteria (measures by which the achievement of a particular objective is gauged) C= c_j, j=1,…,m. A MCDA analysis that incorporates scenarios involves elicitation of (a) v_{ijk} - how an option a_i will be perceived to perform in a given scenario s_k with respect to a criterion c_j (value) and (b) w_{jk} - how important a criterion c_j is relative to another criterion for a given scenario s_k (weight).

Examination of Table 1 highlights two areas for further development of the combined methodology. Firstly, SP and MCDA interventions have typically involved the use of optimistic, pessimistic and most-likely scenarios. Developing such scenarios goes against the generally accepted view in the scenario literature (Wack, 1985a; Wack, 1985b; Schoemaker, 1991; Ringland, 1997; Schwartz and Ogilvy, 1998; De Geus, 1999). Several other relevant possibilities are undermined due to a dominance of value-laden notions or assumptions of likelihood, both of which defeat the underlying philosophy of scenarios. Even so, one main disadvantage of scenario planning is the length of time taken to develop scenarios (Mietzner and Reger, 2005). One way to address the time-consuming nature of developing the narrative and difficulty in selecting two uncertainties is to apply a morphological analysis approach. This is based on a combinatorial set of uncertainties, each of which may take a small number (two to five) of different levels (Ritchey, 2006; Eden and Ackermann, 1998).

Secondly, MCDA measures resulting from each option-scenario combination should be compared within and across scenarios (Roy, 2005; Durbach and Stewart, 2003). Yet, Table 1 shows that some SP and MCDA interventions have employed the use of weights or probabilities to aggregate MCDA measures over all scenarios. This fails to achieve proper integration between the methods for two reasons. Firstly, scenarios are incomplete descriptions and cannot in general be expected to represent the same dimensions in probability space (Stewart, 2005). This is due to the focus of scenarios on interactions of uncertainties (Schoemaker, 2004), which means that the likelihood of two scenarios are not comparable. Secondly, aggregating MCDA measures runs the risk of diluting the rich information derived from the process. These include details on the differences between scenarios that favour one option over another, or scenarios that particular options may perform poorly in (Dias, 2006). Selecting options on those with stable performances close to the ideal, or assessing the spread of performances for each option in each scenario (Montibeller et al., 2006) provide better comparison.

Reference	Number of Scenarios	Approach to Scenario Construction	Method of Elicitation		Recommendations for Applying MCDA measure
			Weights (w_{jk})	Values (v_{ijk})	
Goodwin and Wright (2001)	2 'extreme world' scenarios; no probabilities attached.	Extreme World narratives created by putting all negatively and positively resolved uncertainties in separate scenarios and then checking for internal consistency.	-Compare 0-100 for each criterion c_j. -Assign 100 to the most important criterion and compare it with the relative importance of other swings on a 0-100 scale. -Normalise scores obtained.	-Allocate a score of 100 to the best strategy-scenario combination and 0 to the worst in terms of its performance under each criterion. -Allocate scores between 0 and 100 to represent the improvement in criterion c_j that the application of strategy a_i may be perceived to bring in scenario s_k for all s_k € S.	-Use scenario matrix to establish dominance of strategies across scenarios. -Perform sensitivity analysis. -Evaluate risk by including a risk criterion in the MCDA model.
Belton and Stewart (2002)	2 scenarios	Scenario narratives are external to the organization (i.e. arise from events outside the organisation's control) and are value-free.	Different weights assigned for each scenario using approach as in Goodwin and Wright (2001).	Best and worst performances against each criterion across all scenarios define upper and lower limits of the value scale. Allocate scores between 0 and 100 to represent the improvement in criterion c_j that the application of strategy a_i may be perceived to bring in scenario s_k.	-Select option that is robust against uncertainties (a direct holistic judgment). -Assign relative weights to scenarios and calculate a one-dimensional performance value for each alternative by multiplying the weight of each scenario by MCDA measure. -Select option which maximizes the worst aggregate performance given by the sum of all MCDA measures over all scenarios. This however ignores trade-offs between performances.
Montibeller et al. (2006)	2-3 scenarios	Narratives based on best; worst and extrapolation of present trends/themed according to one key uncertainty; no probabilities attached.	As in Goodwin and Wright (2001) but may assign a different set of weights for each scenario.	Focus on a single scenario when expressing preferences as in Belton and Stewart (2002).	-Identify options that are nearer to the ideal performance (100) and that have stable performances close to the ideal. -Evaluate risk by calculating inter-scenario risk, defined by assessing spread of performances for each option in each scenario. - Remove dominated strategies if uncertainty is low; otherwise perform sensitivity analysis.
Stewart (2005)	Suggests 3-5 scenarios may be sufficient.	Unspecified	Treat all criteria-scenario combinations as 'meta-criteria'.	Assumes intensity of preference for different increments in performance on any one criterion may differ from scenario to scenario. Guidance not explicitly provided on elicitation.	-Outranking to generate classification into preferences classes. -Goal programming to measure achievement in terms of distance from a goal or reference level.
Phillips (1986)	3 scenarios	High, medium and low based on demand uncertainty, which corresponds to optimistic and pessimistic considerations; probabilities attached.	Relative weights elicited which reflect the importance of moving from 0 to 100 on each criterion scale. Weights can also represent the probability of each scenario.	As in Belton and Stewart (2002).	-Find differences among best strategies in each scenario and find ways of managing them through further analysis or information.

Table 1- Summary of MCDA and Scenario Planning Interventions to date.

These can be contrasted with the concept of regret, which compares the performance of an option with the maximum achievable performance across all strategic options in that scenario (Lempert et al., 2006). Regret therefore makes explicit use of the information provided by the decision-maker to enable comparison, rather than the possible illusion of an ideal world which may never be achievable. However, the concept of regret has not been applied to SP and MCDA interventions.

3. Method and Illustration

This section proposes a Morphological Analysis approach for creating a more diverse cohort of scenarios for evaluating strategic options under the MCDA framework (see Figure 1). It also proposes the use of cost equivalent regret to facilitate within and across scenario comparisons. The method will then be applied practically to identify benefits and challenges of the proposed method. For the practical application, a case study will be used. The case study has been selected as an appropriate research strategy because many uncontrollable variables are involved, and the aim of the research is to explore how the method behaves in a practical setting (Yin, 2008). The case study will be based on the issue of the future of food security in Trinidad and Tobago. A policy context has been chosen because it represents a unique but equally critical and relevant application of the scenario planning and MCDA method compared to traditional business applications. This issue also reflects characteristics of a problem to which the proposed method would be suited, namely:

- The issue implies the existence of long-term consequences that are not known deterministically, but for which provisions must be made in the present to achieve core objectives or mitigate adverse effects.
- The cost criterion is an important consideration in the decision-making process.
- Factors affecting the decision are difficult to quantify, and involve conflicting objectives.

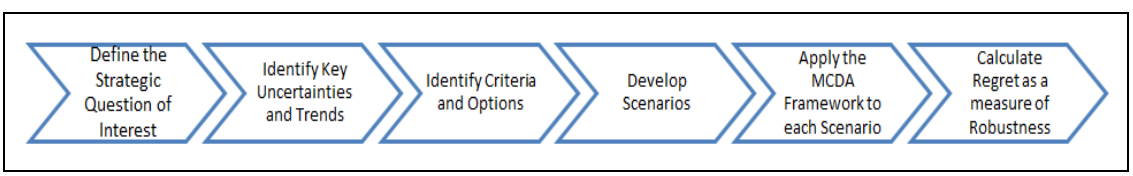

Figure 1- The Six Steps in the Proposed Method

In what follows, the theoretical description of each step is presented together with a rationale for it. This is followed by the corresponding practical implementation of each step.

Step One-Define the Strategic Question of Interest

An appreciation of the context helps define the issue and the time frame within which it is to be considered. In 2002, in pursuance of the Vision 2020 development goals, the government of Trinidad and Tobago outlined the promotion and enhancement of agriculture as a pillar of the national development and diversification of an economy traditionally based on oil and gas (Vision 2020 Operational Plan 2007-2010).

The majority of the country's agricultural resources have traditionally focused on producing export commodities such as sugar, cocoa, coffee and citrus. Under favourable marketing arrangements that assured a ready market and relatively stable prices, export agriculture was profitable (Sector Policy for Food Production and Marine Resources, 2001). However, as international trade regulations (e.g. food safety standards) became increasingly unfavourable, the contribution of agriculture to national GDP showed a declining trend over time. Local production of staple food items (e.g. wheat, corn) became increasingly uncompetitive. This meant that average incomes in the agricultural sector were the lowest in the country, and the share of the labour force in agriculture, particularly among younger age groups, was on the decline. However, the motivation to pursue agricultural initiatives weakened as steadily increasing oil revenues post-2002 were used to fuel a high level of food imports. Thus, growth in the oil and gas sectors resulted in the majority of arable land being traded off for infrastructure development and manufacturing industries. However, the unforeseen fall of oil prices in late 2008 and the steady rise of food prices emphasised the significance of developing an agricultural sector that could consistently provide nutritionally adequate food to its citizens on a sustainable basis. These circumstances provoke the question of which investments are likely to be the most favourable for the country in terms of food security given changes in the regulatory, economic, technological and social environment.

A time frame of eight years was chosen. This coincided with the election due to take place in 2017. Although the goal of food security does not have to be met by 2020, significant progress towards the goal must be shown by the election year. The current context also stresses the political and economic imperative to make provisions in the present to mitigate further adverse effects. An expert in the field of agriculture was deemed a suitable interviewee.

Step Two- Identify Key Uncertainties and Trends

Key uncertainties are events whose outcomes are uncertain but will significantly affect the issue of concern (Schoemaker, 1995). Trends that can plausibly affect the issue under consideration in constructing scenarios were also included since this is consistent with standard scenario planning formats (van der Heijden, 1996; De Geus, 1999; Schoemaker, 1991).

In the case study, the traditional approach of brainstorming and then plotting uncertainties on a two-dimensional grid to highlight the most uncertain and most critical uncertainties was used (see Appendix 1.1 for further details of the scenario selection technique). The most critical uncertainties selected for the development of scenarios were:

- Severity of natural disasters (flood, earthquake, hurricane, drought)
- Regulation in supplier countries
- State of global economy
- Consumer demand for safe foods
- Cost of farming inputs (e.g. fertilizer, pesticide, land)

Trends expected to continue were:

- High imports from other countries in the Caribbean region of produce such as bananas and ground provisions.
- Competition from other sectors (e.g. manufacturing and tourism).
- Traditional small farming as a means of livelihood in rural areas.
- Population will increase to 1.5m by 2017.

Step Three- Identify criteria and strategic options

In keeping with the philosophy of MCDA, the criteria pertinent to end objectives were considered. To derive this, several iterations of the question 'Why is this measure of success important?' were made. The criteria corresponding to the objective deemed important in absolute terms (i.e. its achievement did not imply/aid achievement of some other objective) were listed. This mode of questioning embodied the spirit of the SODA (Strategic Options Development and Analysis) methodology (Eden and Ackermann, 1998).

For the case study, the expert defined food security as the ability of the country to consistently provide nutritionally adequate food to its citizens on a sustainable basis. This implied the following key criteria:

- Quantity of food available − A good proxy for this is the balance of payments account for food (indicates whether net exports exceed net imports). This is influenced by per capita income, cost of food, consumption of home-grown foods, and the protection of the agro ecosystem for future generations.
- Quality of food− This refers to the extent to which food available contains basic nutritional value.
- Cost of implementing strategic option− The importance of this criterion is highlighted in the case where two options yield the same quantity and quality of food.

The set of options was obtained by considering the option currently being used as well as the main ones under consideration for the future. The discussion about options with the interviewee yielded the following set of strategic options:

A- Reduce cost of farming to subsistence farmers (greater access to loans, subsidies, and modern technology).

B- Provide basic infrastructure for farming (e.g. land tenure, road access, water access).

C- Exclude valuable agricultural land from areas identified as development areas, and exclude areas of high bio-diversity from being used for agricultural purposes.

D- Promote a positive profile of the agricultural sector, especially towards youths.

E- Mega-farm production of higher value local commodities. This approach involves using natural means to grow multiple crops on a large scale. It aims to exploit niche export markets and increase the competitiveness of local alternatives to imported items. This is the option currently being pursued most vigorously by the government.

The ‘Do-Nothing’ option was not considered because it was felt that it was unrealistic and might destroy key implications of the scenarios for strategy. Due to budget constraints, only one option could be implemented.

Step Four- Develop Scenarios

The development of scenarios in this paper is supported by Morphological Analysis (MA). MA is a method for structuring and analyzing multi-dimensional technical, social and political problem complexes where quantification is difficult (Ritchey, 2006). It is based around representations of the objects of interest through sets of variables each of which can take a range of possible states, conventionally represented as a table. As a structuring tool, a key element of MA is checking the consistency (assessing relationships between variables; and that trends are compatible within the time frame (van der Heijden, 1996)) of these various states in order to avoid a combinatorial explosion in the number of possible configurations. Similar ideas have been invented independently multiple times in the OR literature – for example in Strategic Choice Approach (Friend, 1989) and in the strategy table of Howard (Howard, 1988).

MA is well-suited to scenario development for formal evaluation for three reasons. Firstly, MA can deal with a larger number of uncertainties that are qualitatively and quantitatively defined. Scenarios are best suited for highly complex, uncertain situations where many factors are unquantifiable and virtually every factor is variable, and so there are a large number of variables (Millett, 1988). Secondly, MA encourages the investigation of multiple combinations of extreme boundary values in an efficient manner (Ritchey, 2006). This is very much within the philosophy of scenario planning to provide challenging views of the future. Thirdly, MA can facilitate the description of scenarios to the level of detail that provides the decision-maker with enough information for preferences to be elicited (Eden and Ackermann, 2009; Stewart and Scott, 1995; Schoemaker, 1991). This is achieved through the coherent construction of parameter spaces linked by way of logical relationships (Ritchey, 2006).

The steps involved in this stage are:

- Define the limits of each uncertainty and then establish 2-3 intermediate conditions. In determining the limits, the following steps are useful:
    - Consider the best and worst possible achievement levels for the criteria that can be perceived.
    - Extend these further but keeping within plausible levels, and try to envisage what uncertainty levels might lead to that situation. These levels define the limits.

- Combinations of conditions (one condition from each uncertainty) represent different scenarios.

- *Test for consistency*- This mode of scenario construction assumes that scenarios are merely a snapshot in time. Consequently, testing for consistency was necessary. The authors support the view that only those relationships which the decision-maker is certain about should be included. Therefore, in testing for consistency, any well-established relationships among the set of uncertainties were noted.

In the context of the case study, a spectrum of discrete values or conditions which the uncertainty can take is shown in Table 2. The best case scenario is denoted by BBBBB (i.e. combination of best/most preferable level of each uncertainty) and represents low severity of natural disasters; supportive regulation in supplier countries; positive growth in the global economy; high consumer demand for safe foods and low cost of farming inputs. Similarly, the scenario denoted by WBBBB holds all conditions as in BBBBB except for the severity of natural disasters which is high.

	Severity of Natural Disasters	**Regulation in Supplier Countries**	**State of Global Economy**	**Consumer Demand for Safe Foods**	**Cost of farming inputs**
Most Preferable (Best)	Low	Supportive	Positive Growth	High	Low
↓	High	Neutral	Stagnation	Low	Moderate
Least Preferable (Worst)		Restrictive	Negative Growth		High

Table 2- Key Uncertainties and the spectrum of possible discrete values.

There are theoretically 108 possible scenario combinations (2x3x3x2x3=108). However, Table 3 only uses 12 of these combinations. Both sets of swings in uncertainties were considered (i.e. assume all uncertainties at their best (worst) level and observe a swing of each uncertainty in turn to its worst (best) level). Consideration of both swings helped achieve some balance to the extent that if a picture dominated by favourable states was considered, then the trade-offs to be made in bad times would be overlooked. Similarly, sole focus on unfavourable scenarios would not offer a good reference for seizing new opportunities.

This approach to reducing the number of scenarios has two justifications. Firstly, it does not violate the philosophy of scenario planning. Scenarios should be relevant to the concerns of the decision maker; describe generically different futures; and represent states in which the system might exist for some length of time (Schoemaker, 1995). Secondly, the idea of using swings in uncertainties is similar to the use of swing weights in the MCDA framework. Although the scenarios in the proposed method make use of best and worst-case notions, they were merely used to broaden the interviewee's thinking on a range of plausible uncertainty levels. The best and worst labels have been used in the paper in an illustrative manner to highlight the pattern in the combinations chosen. The interviewee was shown Table 2, but the scenario was outlined to him in a brief narrative format that included trends (see Figure 2) to give a more comprehensive picture.

It is 2017 and the elections are months away. The population has increased to 1.5 million. Trinidad and Tobago has continued to import produce from other countries in the Caribbean region. The agricultural sector has continued to face competition from the manufacturing and tourism sectors. Rural farming is still common. There has been no major natural disaster; and regulation in supplier countries is supportive. This is supported by positive growth in the global economy. Consumer demand for safe foods is high, and the cost of farming inputs is low.

Figure 2- Sample Scenario Narrative for BBBBB.

Step Five- Apply the MCDA framework to each scenario

This step aims to measure how each strategic option performs under a given scenario. The performance of option i under scenario k using the MCDA framework is given as

$$\text{Performance } (a_i, s_k) = \sum_{j=1}^{m} v_{ijk} w_{jk}$$

where v_{ijk} is the value of option i in terms of helping to achieve a desired level of criterion j in scenario k and

w_{jk} is the weight assigned to criterion j in a given scenario k.

In order to calculate v_{ijk} two questions were posed to the decision-maker. Firstly, he was asked "Given scenario BBBBB, which strategic option do you think will perform best relative to the other options in terms of the extent to which it will help achieve a desirable level on C1 (quantity)?" Options were then ranked, with a value of 100 being assigned to the option ranked best and 0 to the option ranked worst. A value between 0 and 100 was assigned to other options in terms of the improvement in a particular criterion which implementation of the option is perceived to bring about. This prompted the second question- "How do you think option A will perform in scenario BBBBB relative to the other options in terms of the extent to which it will help achieve a desirable level on C1?" For example, in scenario BBBBB, rank 1 went to option B and rank 5 went to strategy A. B got a score of 100 and A, a score of 0. A value of 60 assigned to option C meant that the improvement in quantity from using option C over option A was roughly 60% as attractive as the improvement in quantity from using option B over A. Responses to these questions are shown in Table 3 below, with Table 4 providing an added illustration of what the values translate to on the scale for each criterion.

v_{ijk}	**SCENARIO**											
Quantity (C1)	**BBBBB**	**WBBBB**	**BWBBB**	**BBWBB**	**BBBWB**	**BBBBW**	**WWWWW**	**BWWWW**	**WBWWW**	**WWBWW**	**WWWBW**	**WWWWB**
A	0	100	70	25	100	100	40	100	90	0	100	0
B	100	75	100	100	75	90	60	90	80	50	75	80
C	60	50	60	40	0	50	80	80	0	70	50	60
D	80	0	70	50	85	60	100	40	75	100	0	70
E	95	70	0	0	80	0	0	0	100	80	90	100
Quality (C2)	**BBBBB**	**WBBBB**	**BWBBB**	**BBWBB**	**BBBWB**	**BBBBW**	**WWWWW**	**BWWWW**	**WBWWW**	**WWBWW**	**WWWBW**	**WWWWB**
A	0	100	100	60	100	100	80	90	100	75	80	0
B	85	95	70	100	80	90	60	75	60	70	100	70
C	100	90	60	60	70	70	100	100	25	75	0	100
D	60	0	75	70	80	0	95	0	30	0	75	65
E	90	80	0	0	0	80	0	60	90	100	65	75
Cost (C3)	**BBBBB**	**WBBBB**	**BWBBB**	**BBWBB**	**BBBWB**	**BBBBW**	**WWWWW**	**BWWWW**	**WBWWW**	**WWBWW**	**WWWBW**	**WWWWB**
A	75	100	60	30	100	25	15	0	25	100	10	25
B	90	60	0	100	0	0	30	65	40	65	30	40
C	100	10	100	70	95	100	90	90	85	90	95	85
D	95	50	80	75	90	70	100	100	100	85	100	100
E	0	0	50	0	60	40	0	40	0	0	0	0

Table 3- Elicited value for how strategies are perceived to perform with respect to each criterion in various scenarios.

	BBBBB			WWWWW		
	Quantity* (in US$)	Quality	Cost (in US$)	Quantity (in US$)	Quality	Cost (in US$)
A	-550 m	45% of RDI	330m	-400 m	35% of RDI	250m
B	200 m	65% of RDI**	25m	-480 m	27% of RDI	20m
C	-300 m	85% of RDI	1 m	-550 m	50% of RDI	1.5 m
D	-200 m	57% of RDI	3 m	-300 m	40% of RDI	2 m
E	150 m	75% of RDI	1bn	-700 m	25% of RDI	950m

* Balance of Payments for Food= Total Imports- Total Exports. The negative (positive) value represents the amount of reduction (increase) in the Balance of Payments from its current value.
** RDI- Recommended Daily Intake of Basic Nutrients Per capita

Table 4- Estimation of what elicited values translate to on respective criteria scales.

Eliciting w_{jk} involved the use of swing weighting. Swing weighting explicitly requires the decision maker to consider the relative value between the most and least preferred levels of two criteria (Goodwin and Wright, 2001). The question asked to elicit weights was- 'If you were in scenario A, and one criterion could be moved to its best level, which would you choose?' The criterion ranked first received a score of 100, and the other criteria were given a weight relative to this score. Weights were then normalized (Table 5).

w_{jk}	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
Quality	.255	.097	.385	.156	.217	.269	.204	.296	.264	.143	.275	.235
Quantity	.426	.645	.288	.4	.435	.346	.388	.334	.358	.476	.333	.373
Cost	.319	.258	.327	.444	.348	.385	.408	.370	.377	.381	.392	.392

Table 5- Normalised criterion weights for scenarios.

The approach to weighting which uses a standard set of weights across scenarios (Goodwin and Wright, 2001) was not adopted because it was felt that eliciting swing weights given a specific scenario was more compatible with examining implications of a scenario for strategy (Montibeller et al., 2006; Durbach and Stewart, 2003; Belton and Stewart, 2002; Parnell et al., 1999). The performance of each strategic option under each scenario is shown in Table 6, with the best performance for each scenario highlighted in bold.

The direct elicitation approach in this intervention offers two main advantages when compared with indirect assessment techniques. Firstly, it is consistent with value elicitation in other scenario planning and MCDA interventions to date (see Table 1). Secondly, it facilitates greater integration between the methods since it reinforces the concept of separate evaluations under each scenario while encouraging discussion about the impact of future events on choices in a useful and engaging manner (Belton and Stewart, 2002).

Performance	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A	23.9	**100**	**78.3**	32.7	**100**	**71.1**	38	60	68	48.8	59.2	9.8
B	**93**	73.1	55.8	**100**	50	55.4	47.8	76.3	59.6	58.6	**64.2**	62
C	83	43.6	73.1	56.4	48.3	74.6	88.2	**89.6**	38.7	78.3	53.9	79.2
D	79.7	12.9	75.2	64.2	85.7	47.7	**99**	50.4	**72.5**	**80**	59.8	**80.6**
E	63.4	52.9	16.4	0	55.7	36.9	0	32.6	59.6	52.4	47.9	54.9

Table 6- Overall Performance of how strategies perform under various scenarios.

Step Six- Calculate Regret as a measure of Robustness

The *regret* of a strategic option is defined as the difference between the performance of an option in some future state of the world, given some performance function, and that of what would be the best-performing option in that same future state (Lempert et al., 2006). In other words, if A is the set of options and Y is the set of scenarios, the regret of option a_i, $a_i \in A$, in scenario $s_k \in S$, using value v is given as

$$\text{Regret}_v\,(a_i, s_k) = \text{Max}_{a'}[\text{Performance}\,(a'_i, s_k)] - \text{Performance}\,(a_i, s_k) \quad \forall\, a_i \in A$$

A robust option can be defined as one with relatively small regret compared to the alternatives across a wide range of plausible futures considered (Lempert et al., 2006). A regret-based definition of robustness is used for three main reasons:

- Regret focuses attention on those states of the world in which alternative options have significantly different outcomes (Lempert et al., 2006). The architecture of the set of scenarios, Y, targets a range of these significantly different states.
- The measure explicitly anticipates the emotion of regret when evaluating different options in an effort to make the consequences of choice more salient. This can serve to induce greater deliberation among choices.
- It complements the philosophy of the proposed method since it does not employ the use of probabilities, nor does it recommend the elimination of strategic options through dominance.

Regret thus represents the loss in value relative to the best option, measured on a scenario specific scale, defined by the joint lower and joint upper levels of performance of the options under that scenario. In order to properly gauge the robustness of an option, the regret values had to be converted to a comparable scale. To achieve this, a cost-equivalent model was proposed (Keeney, 1992).

In the case study, scenario BBBBB for example had a cost range of US$949m (US$950m-US$1m), and the range of evaluation units was (100 x 0.319= 31.9), each evaluation unit was equivalent to US$29.75m. In other words, the marginal monetary worth for the overall scale was US$29.75m. To achieve a worthiness equivalent value for option B under this scenario, the overall performance/evaluation figure was multiplied by the marginal monetary worth coefficient before applying the regret calculation. This procedure was repeated for each option-scenario combination, and the results shown in Table 7, with details of its calculation presented in Appendix 1.2.

Cost Equivalent Regret (US$m)	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A	2054.5	0	0	1438.9	0	86.4	1419.3	758.7	111.4	776.1	121.4	1713.6
B	0	990.6	653.9	0	1363.9	475.2	1191.4	341.4	325.0	533.3	0	450.7
C	298.2	2076	150.9	931	1411.2	0	251.7	0	851.5	41.1	250.4	33.5
D	395.7	3203.8	89.5	764.8	391.2	663.6	0	1007	0	0	106.8	0.0
E	879.5	1732.1	1797.3	2137.4	1208.6	929.5	2302.3	1463.5	325.0	687.6	396.8	621.2

Table 7- Worth-Equivalent Regret Values for each Strategy-Scenario Combination.

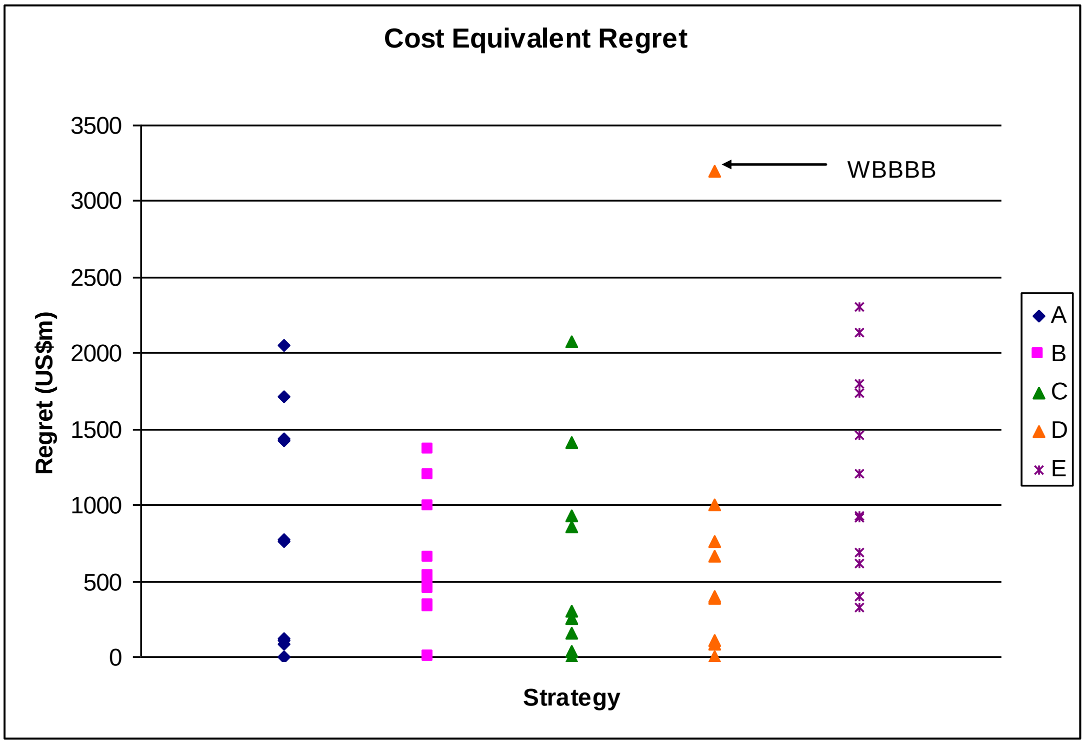

Figure 3- Plot of Cost Equivalent Regret Values.

The worth equivalent regret values for each strategic option across each scenario are plotted in Figure 3. The most robust option would ideally have a high frequency of low or zero regrets, and have a low spread of values relative to this point. At a first glance, option E always incurs some regret, and has the highest spread of regret values across scenarios. It can be concluded therefore that this option is not robust. Further examination of regret values under this option highlights that this could be due to the heavy dependence of its success on supportive regulation in supplier countries. Options B (provide basic infrastructure for farming) and D (promote a positive profile of the agricultural sector, especially towards youths) appear more worthy candidates. Option B has the lowest overall spread of regret values. Option D would perform better if mechanisms could be included that minimise its highest regret, which occurs in scenario WBBBB, when the severity of natural disaster is high. Such a mechanism might include the development of a comprehensive disaster preparedness plan. This is particularly interesting as it highlights the importance of building capabilities for food security should a sudden disruption in food supply occur, which is precisely what has not been pursued in the status quo. One similarity between options B and D that makes them more successful than other options is their orientation towards empowerment and self-sufficiency. These findings can provide a basis for further discussion of options that are compatible with this theme. Regret values may then be recalculated, but it must be borne in mind that regret depends on a given set of strategic options, and so the regret value may change as new options are added or existing ones deleted (French, 1986).

A number of assumptions underpin the approach outlined here:

- There are generally preferred directions of movement for criterion that hold no matter what other criteria values are (e.g. higher quality of food) (Keeney and Raiffa, 1993).
- The set of criteria are preferentially independent (Keeney, 1992).
- The decision-maker is able to provide the judgments required by the method.
- The regret measure is valid as a means of assessing robustness.
- Examining best-worst (worst-best) swings in uncertainties help provide meaningful information on how changes in the environment affect preferences.
- Attribute functions are linear and cost is a significant attribute in the value model (Keeney and von Winterfeldt, 2007).

4.Discussion

The proposed method explores ways to achieve a diverse set of scenario themes quickly and facilitate within and across scenario comparison of options, while being able to handle subjective judgments for multiple objectives under uncertainty. The implementation of the proposed method also highlights scope for improvement in these areas.

The proposed method developed scenarios based on swings in extreme possibilities of a set of five uncertainties. The interviewee felt that this approach tried to capture many factors that should be considered in making a decision and helped him to focus on prioritizing items to achieve ends objectives with limited financial resources. The proposed method of achieving a diverse set of scenarios to form a basis for measuring robustness can be contrasted with scenario narratives constructed around the impacts of decisions (Schoemaker, 1991; Stewart and Scott, 1995); variations of parameters of a system model, which are mathematically defined (Tietje, 2005); varying perspectives of a desirable future (Gordon, 2008); or minor variations to one or more emergent conditions such that evaluation in accordance with stakeholder concerns is permitted (Karvetski et al., forthcoming).

The interviewee found that the level of detail was sufficient for eliciting the required answers, even though the scenario presented was an outline of a future point in time (Schoemaker, 1991), and not a storyline of how the future might unfold from the present to an end state (van der Heijden, 1996; De Geus, 1999). In making value and weight judgments, he was prompted to consider how choosing an option now might plausibly behave in a particular scenario with respect to each criterion. He therefore acknowledged that in-depth knowledge of both the technical aspects of the problem and the decision making instrument were required in providing judgments.

He felt that applying the method in a group decision-making process would have been more useful, as it would have provided a basis for debate and validation of opinions with respect to criteria. However, the repetition of weight and value elicitation questions was perceived by the interviewee as time-consuming and inconvenient, especially after about the seventh scenario. One way of addressing this issue is based on adapting the framework of the swing weighting method for recalibration of a baseline value function, following incremental adjustment of the baseline (Karvetski et al., forthcoming). While this may reduce the time and effort needed for elicitation, an anchor and adjust strategy may fail to encourage the decision-maker to explore generically different futures that challenge the status quo, which lies at the heart of scenario planning philosophy. In addition, this method would not be applicable in cases like the one presented here, where scenarios alter not only how the decision-maker forms his/her preferences across criteria, but also how he/she perceives each option will perform.

With respect to within and across scenario comparison of options, the interviewee felt that visualization of regret measures helped to crystallize the purpose of the exercise. He thought that cost-equivalent measures were also useful given a circumstance of financial constraints. The main advantage of the illustrative display used in this paper is that it allows the decision-maker to see how much better/worse an option performs compared to another. Since a single MCDA model is created for each scenario (Montibeller et al., 2006), within-scenario value functions are not commensurable. Comparison of performance across scenarios is therefore facilitated only through the use of cost-equivalent figures. This can be contrasted with ranking (Karvetski et al., 2009), which does not provide such visualization; and box plot displays (Lempert et al., 2006) with cumulative frequency percentage charts (Bertsch, 2008), which provide information concerning how often each performance measure occurs. Stacked bar charts, cobweb diagrams (Karvetski et al., 2009) and value paths (Schilling et al., 1983) would also provide practical displays to identify the most important and sensitive criteria across scenarios; as well as those criteria with the largest potential for relative improvement.

Application of the proposed method highlights three main challenges. The first is reducing the demand on decision-makers for elicitation of weights and values. The second relates to extending the method to formally incorporate group decision-making, which would imply consideration of a range of values and weights that reflect multiple perspectives. The development of a common model may also be possible, assuming communication among stakeholders is desirable (Belton and Stewart, 2002). Applying the method in a group situation would inevitably be very time-consuming and likely to require software support (Wollenberg et al., 2000). The third challenge relates to the incorporation of new options that may develop as a result of the evaluation process. Given that direct elicitation was used, including any new options to test whether they do improve robustness may necessitate the redefinition of scales (Belton and Stewart, 2002).

5. Conclusions and Directions for Further Research

The main contribution of this paper was to illustrate how a more diverse set of scenarios that copes well with qualitative and quantitatively defined variables could be developed quickly; and to investigate how regret could be applied to MCDA measures facilitate within and across scenario comparisons.

The structure of the method was influenced by three main assumptions adopted by the authors, but arising from examination of the relevant literature. The first assumption is that the combined use of SP and MCDA is beneficial when considering the evaluation of strategic options. The second is that scenarios are intended to be challenging descriptions of futures that are relevant to a strategic decision and representative of plausible developments in the external world (van der Heijden, 1996). However, the use of scenarios for the evaluation of options has often involved the consideration of optimistic, pessimistic and most-likely scenarios. These are limited in their capacity to provide a representative range of variation that could occur and also goes against the generally accepted view in the scenario planning literature. The third is that MCDA measures should not be aggregated over scenarios through the use of weights or probabilities since it contravenes the philosophies of both methods.

Practical benefits from applying the method included a greater awareness by the interviewee of interactions among key components of a strategic decision; a purposeful display of measures to facilitate comparison of options anchored in cost considerations; and an interest in applying the method to a group-decision making process. The findings in this paper are nonetheless tentative. They have only been based on a single case, and more will be needed to confirm them. From a theoretical perspective, the method sought to stimulate investigation of how many scenarios are sufficient for use in evaluating options, and on the level of detail appropriate for using scenarios to evaluate strategic options, about which there remains a lack of literature and evidence from practice.

The paper suggests various directions for further research. Firstly, there is scope for investigating whether a more diverse set of scenarios with its increased elicitation burden justifies the loss of detail in the traditional narrative format in terms of quality and time taken. This prompts questions on how the demand on decision-makers for elicitation of weights and values can be reduced, and on how effective best-worst swings are in scenario selection. It may be possible to achieve this by using incomplete information about preferences with software support. Secondly, how this method may be adapted to accommodate multiple perspectives in an interactive group decision-making process remains an open question. Thirdly, the use of regret as a meaningful measure of robustness in such interventions also deserves further exploration. Finally, this paper has focused on the selection of robust options. However, assessments on whether options are flexible (i.e. option can easily transform to accommodate new conditions) (Rosenhead, 2001) and diversified (i.e. facilitates investment in a range of different areas relative to the organisation's current major offering(s)) (Wright and Goodwin, 2009) may improve the quality of options entering the evaluation process.

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Appendix 1.1: Explanation of Scenario Selection Technique

Step 1: Define key uncertainties and levels

From a practical perspective, the following ‘trigger’ questions were used to elicit the key uncertainties and levels:

A. *Establish problem boundaries*

- Define the space within which the organisation operates (CATWOE)
- What have been the most important changes in the last ten years, and how did the organisation anticipate these changes?
- What important upcoming decisions do you face?

B. *Identify factors in the external environment affecting these key decisions*

- What are the most important trends over the next decade (STEEP categories)?
- What is the biggest threat/opportunity arising from these trends?
- If you could see intro a crystal ball, what would you most want to know about the future of your organisation?
- Paint the most optimistic (most pessimistic) future for your organisation.

C. *Repeat (A) and (B) with others in the organisation who influence the decision making process.*

D. *Define objectives and options using methods outlined in (Keeney, 1992) and (Kirkwood, 1997).*

E. *Define boundaries for each uncertainty*

- What is a best-case (worst-case) outcome for each criterion?
- If you had no internal constraints, what outcome on each of the key uncertainties could further enhance best-case outcomes? Explain how this might happen.
- If you had no internal constraints, what outcome on each of the key uncertainties could reinforce worst-case outcomes? Explain how this might happen.

F. *Summarise uncertainties and ask the decision maker to rate uncertainties in terms of their level of importance to achieving outcomes and level of uncertainty regarding their influence on outcomes*

Step 2: Define the set of scenarios

Assume that each of q uncertainties y_a, a = 1…q, has three levels, b=1,..,3 with:

y_a^1 representing the best possible outcome for y_a (i.e. enabling conditions in the external environment for ideal outcomes).

y_a^3 representing the worst possible outcome for y_a (i.e. conditions in the external environment that lead to feasible but highly undesirable outcomes).

y_a^2 representing the business-as-usual/status quo outcome for y_a (i.e. conditions that currently exist in the external environment, assuming these are not worst or best possible states).

This representation is not intended to account for all the possible outcomes of each uncertainty, but merely to describe a wide range (Schoemaker, 2004).

The set of scenarios is the set product S: y_1 x y_2 x … x y_q of all levels of all *q* uncertainties. A scenario S_k is a vector $S_k = (y_a^b, \dots, y_q^b)$, specifying one level b for each uncertainty. This results in 3^q scenarios. The scenarios in S are assumed mutually exclusive and collectively exhaustive, and that they meet basic scenario criteria of being internally consistent and plausible. Table 8 below for instance shows the scenario set for q=3 uncertainties.

1	y11	y21	y31
2	y11	y21	y32
3	y11	y21	y33
4	y11	y22	y31
5	y11	y22	y32
6	y11	y22	y33
7	y11	y23	y31
8	y11	y23	y32
9	y11	y23	y33
10	y12	y21	y31
11	y12	y21	y32
12	y12	y21	y33
13	y12	y22	y31
14	y12	y22	y32
15	y12	y22	y33
16	y12	y23	y31
17	y12	y23	y32
18	y12	y23	y33
19	y13	y21	y31
20	y13	y21	y32
21	y13	y21	y33
22	y13	y22	y31
23	y13	y22	y32
24	y13	y22	y33
25	y13	y23	y31
26	y13	y23	y32
27	y13	y23	y33

Table 8- Scenario Configurations based on Uncertainty Outcomes

Step 3: Identify scenarios that are most different from the status quo outcome

Define the status quo scenario as $S_m = (y_1^{\ 2}, \ldots , y_q^{\ 2})$.

Determine the distance of every other scenario in the set from the status quo scenario. Define the distance between two scenarios as the number of uncertainty levels that are different (Tietje, 2005):

$$d\,(S_m, S_k) = \sum_{a=1}^{q} \{1 \text{ if } y_a\,(S_m) \neq y_a\,(S_k), 0 \text{ otherwise}$$

The size of the difference between two levels is not taken into account, but such a difference could be defined through weights (Alspaugh et al, 1999).

Results are shown below in Table 9 for q=3 uncertainties, but the results are the same for any number of uncertainties considered.

y11	y21	y31	3
y11	y21	y33	3
y11	y23	y31	3
y11	y23	y33	3
y13	y21	y31	3
y13	y21	y33	3
y13	y23	y31	3
y13	y23	y33	3
y11	y21	y32	2
y11	y22	y31	2
y11	y22	y33	2
y11	y23	y32	2
y12	y21	y31	2
y12	y21	y33	2
y12	y23	y31	2
y12	y23	y33	2
y13	y21	y32	2
y13	y22	y31	2
y13	y22	y33	2
y13	y23	y32	2
y11	y22	y32	1
y12	y21	y32	1
y12	y22	y31	1
y12	y22	y33	1
y12	y23	y32	1
y13	y22	y32	1
y12	y22	y32	0

Table 9- Scenario Configurations Selected based on proposed technique

The pattern above highlights that this set is characterised by best-case outcomes on all uncertainties, worst-case outcomes on all uncertainties, and scenarios with the worst possible outcome for one uncertainty given best possible outcomes on all others (repeated for each uncertainty); and vice versa.

Appendix 1.2: Explanation of Cost Equivalent Regret Calculation

Step 1: Calculate performance under MCDA

The performance of an option i (i=1,..,n) under scenario k (k=1,..,r) is defined as

$U_i = \sum_{j=1}^{m} u_{ijk} w_{jk}$

where u_{ijk} is the value assigned to option i for criterion j (j=1,…,m) under scenario k and w_{jk} is the weight assigned to criterion j under scenario k.

For instance, $U_{C,BBBBB}$ = (0.255* 100)+(0.426*60)+(0.319*100) = 82.96

W_{ij}	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
Quality	.255	.097	.385	.156	.217	.269	.204	.296	.264	.143	.275	.235
Quantity	.426	.645	.288	.4	.435	.346	.388	.334	.358	.476	.333	.373
Cost	.319	.258	.327	.444	.348	.385	.408	.370	.377	.381	.392	.392

V_{ijk}	SCENARIO											
Quantity (C1)	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A	0	100	70	25	100	100	40	100	90	0	100	0
B	100	75	100	100	75	90	60	90	80	50	75	80
C	60	50	60	40	0	50	80	80	0	70	50	60
D	80	0	70	50	85	60	100	40	75	100	0	70
E	95	70	0	0	80	0	0	0	100	80	90	100
Quality (C2)	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A	0	100	100	60	100	100	80	90	100	75	80	0
B	85	95	70	100	80	90	60	75	60	70	100	70
C	100	90	60	60	70	70	100	100	25	75	0	100
D	60	0	75	70	80	0	95	0	30	0	75	65
E	90	80	0	0	0	80	0	60	90	100	65	75
Cost (C3)	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A	75	100	60	30	100	25	15	0	25	100	10	25
B	90	60	0	100	0	0	30	65	40	65	30	40
C	100	10	100	70	95	100	90	90	85	90	95	85
D	95	50	80	75	90	70	100	100	100	85	100	100
E	0	0	50	0	60	40	0	40	0	0	0	0

Table 10- Elicited values and weights from intervention

Step 2: Determine cost equivalent value per unit of performance for each scenario

A.Determine the minimum and maximum possible cost across the set of option-scenario combinations (Right-hand side of figure below).

B.Determine the units of performance attributed to cost for a given scenario (Left-hand side of figure below).

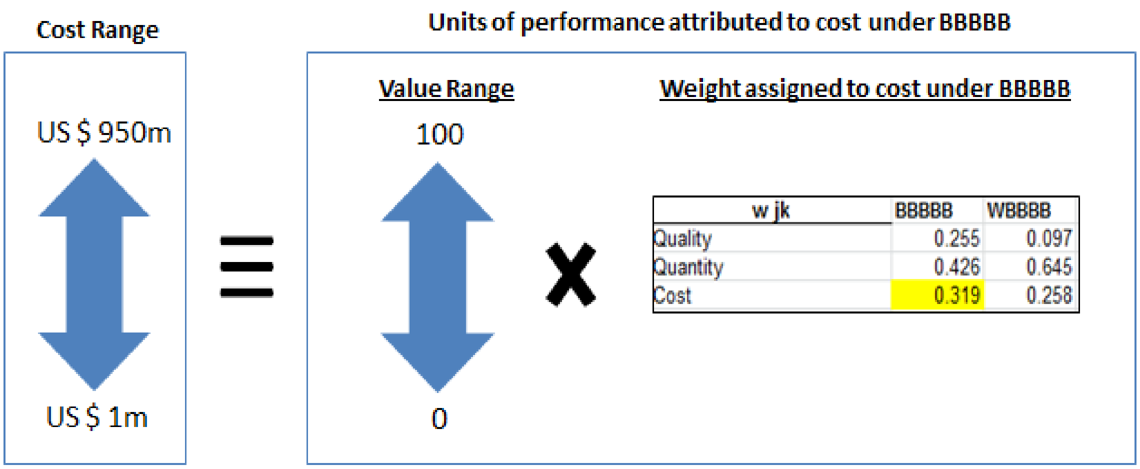

Figure 4- Illustration of Cost-Equivalent Calculation

The above calculation shows that US$949m ≡ 31.9 units of performance. In other words, one unit of performance under scenario BBBBB is valued at US$949m/31.9= US$29.75m.

Step 3: Calculate cost-equivalent performance

The cost equivalent performance of Option C under scenario BBBBB is therefore:

$U_{C,BBBBB}$ * US$29.75m = 82.96* US$29.75m = US$2467.995m

Repeating this calculation for each scenario yields the table below.

	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
Max_i	2766.38	3678.295	2271.796	2137.387	2727.011	1839.581	2302.255	2298.632	1824.245	1992.402	1555.198	1951.018
A	711.8987	3678.295	2271.796	698.4982	2727.011	1753.308	875.499	1539.945	1712.983	1216.264	1433.668	237.25
B	2766.38	2687.73	1617.943	2137.387	1363.233	1364.342	1110.888	1957.248	1499.269	1459.119	1555.198	1500.243
C	2467.995	1602.265	2120.884	1206.341	1315.783	1839.581	2050.584	2298.632	972.9138	1951.303	1304.633	1917.367
D	2370.715	474.5	2182.41	1372.63	2335.958	1176.021	2302.255	1291.666	1824.245	1992.402	1448.435	1951.018
E	1848.616	1946.186	474.5	0	1518.4	910.054	0	835.12	1499.269	1304.688	1158.409	1329.81

Table 11- Cost equivalent results

Step 4: Calculate cost-equivalent regret

$\text{Regret}_{ik} = \text{Max}_{i'} (U_{ik}) - U_{ik}$

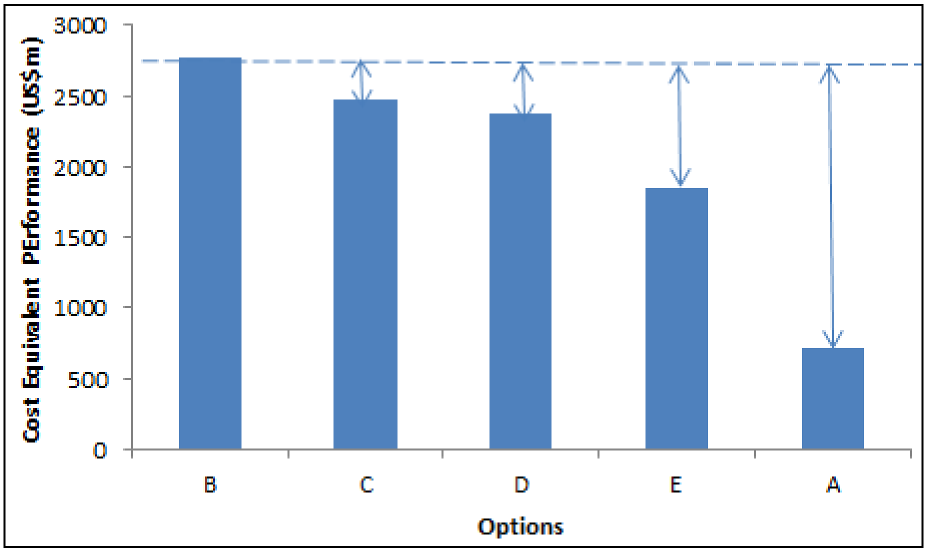

Figure 5- Illustration of Regret calculation. In the graph above, the arrows indicate the degree of regret incurred for each option.

Repeat for every option scenario combination and plot cost-equivalent regret for each option as in Figure 3.

A robust option is defined as one with low regret across scenarios. The figure above indicates that options B and D are candidates for meeting this criterion. Option C may also be considered if strategies can be found to reduce the spread of regret.

Prelude to Paper 2

The preceding paper proposed a method for generating a diverse scenario set and comparing options within and across scenarios. The main finding was that the scenario selection technique proposed was perceived as repetitive, but the snapshot format of presentation was sufficient for eliciting the required responses for an MCDA model. Representing performance through cost-equivalent regret stimulated questions on why options performed well or poorly under different circumstances.

Nonetheless, these findings have been based on a single case, and more evidence is needed to confirm them. Paper 2 thus undertakes a more detailed assessment of the practical impact of the proposed method. Three separate real-world public policy projects in a developing country are used to report lessons learned from applying the method.

The interventions represent decision areas that cascade from the overarching Vision 2020 plan for development in Trinidad and Tobago, which was developed in 2000. The timing of the intervention coincided with the need to present a mid-way review of initiatives implemented to date to achieve objectives outlined in the plan, and outline a rationale for strategic initiatives going forward to close the gap between current and desired achievement. Government bodies were given autonomy to develop these reports, with the expectation that the evaluation process used would provide an audit trail of the steps used to reach decision recommendations. The cases were chosen after discussion with a range of candidates based on their willingness to participate, and an opportunity to learn about the impacts of the method in different contexts. For instance, the chairman of a regional corporation was selected due to his desire to improve the rigour of tools used to assess strategic options. An adviser to the Minister of Agriculture was interested in finding a means to better address complex uncertainties in option evaluation. The chairman of a port services company perceived the method of potential benefit for helping him to address the impacts of different stakeholder responses.

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EXPLORING THE IMPACT OF EVALUATING STRATEGIC OPTIONS IN A SCENARIO-BASED MULTI-CRITERIA FRAMEWORK

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Abstract

One of the least explored aspects of scenario planning is how to assess systematically the value and robustness of strategic options after scenario development. In this context, there is growing research interest on the use of multi-criteria decision analysis (MCDA) to evaluate such options, but with very limited evidence about its performance in practice. This paper examines effects of applying in practice one of those recently proposed scenario-based MCDA methods for identifying robust options. Three public sector decision-making instances in Trinidad and Tobago are examined within an action research framework to provide insights on differences in decision-making behaviour and areas for improvement of the method. Findings from these in-depth case studies indicate that the method's main benefit was that it stimulated curiosity on how options might be improved in order to mitigate negative consequences and capitalise on opportunities across scenarios. We conclude the paper discussing these findings and their implications to the development of the method and the evaluation of strategic options under deep uncertainty.

Keywords: scenario planning, decisions under uncertainty, robustness, conflicting objectives.

1. Introduction

Deep uncertainty is characterised by unavailability of well-validated, trustworthy risk models giving the probabilities of future outcomes; disagreement about the likely impacts of alternative options; and uncertainty about available alternatives, resulting in a premature focus on salient options, which are not necessarily the best that could be devised (Cox, 2012; Lempert et al., 2003; Greenberger et al., 1976). Decision-making tools under deep uncertainty fall into two main areas: finding robust decisions that work acceptably well for many models in the uncertainty set; or learning what to do by well-designed and analysed trial and error (Cox, 2012).

Scenario planning, a systematic process for defining the plausible boundaries of future states of the world, is particularly useful in environments where deep uncertainty prevails, and aims to identify and create robust strategic options (i.e. reasonable performance across a range of scenarios) (Roy, 1998; Wilson, 2000; Harries, 2003; O'Brien, 2004; Roubelat, 2006; de Vries and Petersen, 2009; Bodwell and Chermack, 2010). Multiple, conflicting objectives also exist in such contexts. This has led to a growing interest in using scenario planning with multi-criteria decision analysis (MCDA[4]) (Phillips, 1986; Stewart, 1997; Stewart, 2005; Goodwin and Wright, 2001; Belton and Stewart, 2002; Montibeller et al., 2006; Karvetski et al., 2009; Wright and Goodwin, 2009; van der Pas et al., 2010; Montibeller and Franco, 2011; Comes et al., 2011; Durbach and Stewart, 2012). Some approaches have employed best-case, worst-case and most-likely outcomes; while traditional scenario planning supports the presentation of hypothetical futures that plausibly evolve from the present, each influenced by different drivers/key events (Schoemaker, 1995; van der Heijden, 1996. Inter-scenario risk and robustness measures (Montibeller and Franco, 2011); or threshold levels for performance for all scenarios (Stewart, 2005; Comes et al., 2011) have been suggested as evaluation metrics across multiple scenarios, although it remains an open question whether performance should indeed be compared across scenarios.

In one of these methods, which we proposed recently (Ram et al., 2011), systematises the evaluation of options under (2*x*+2) scenarios defined by a combination of extreme levels of *x* key uncertainties, where *x* is a small integer number. Such scenarios are employed to trigger a different set or strength of preferences among multiple objectives (Rettinger and Hastie, 2001), important for developing an appreciation of the multiple constructions of the policy process (Parsons, 1995; Fink et al., 2005). We based our selection technique on the assertion that extremes help one to consider a large range of variability for key uncertainties identified (Masini and Vasquez, 2003), and a consistent finding about the characteristics of extreme scenarios in a broader set defined by combinations of uncertainty outcomes. While the benefits of developing a scenario narrative are not to be understated (Bowman et al., forthcoming; Beach, 2009), our method focussed on evaluating option robustness. We were cognizant of the heavy cost incurred in terms of time to develop narratives (Ram et al., 2011) in light of subsequent stages in the process. We instead created scenario snapshots/vignettes, consistent with findings that brief

[4] MCDA refers to Multi-Criteria Decision Analysis, a technique for managing multiple conflicting objectives.

scenarios do not impact the benefit of accepting a broad set of outcomes (Kuhn and Sniezek, 1996). We adopted regret (i.e. under-performance of an option in a given scenario relative to the best performing option in that scenario) as the operator to assess robustness as advocated by (Lempert at al., 2003). It has been asserted as one of the more credible criteria for selecting decisions when likelihoods are not known with sufficient precision, as exists under deep uncertainty (Loulou and Kanudia, 1999). We also employed a way of normalising different value scales under each scenario using cost equivalents as suggested by (Keeney, 1992).

This paper aims to understand the extent to which characteristics of this method prompt a coherent portrayal of option evaluation under deep uncertainty. We measure coherence in terms of the extent to which it provides a comprehensible process, uses meaningful and relevant information, encourages active questioning of strategic priorities, and stimulates option improvement. We do not claim that the method is fully developed, but offer potential causal explanations of how decision makers in similar contexts might improve the quality of their existing processes through this method. This investigative analysis suggests on how our own proposals might be improved, and our finding may help further develop such stream of research. This is informed by our learning with and from participants, and previously developed relevant scenario planning and MCDA theory.

Given the aim of the inquiry, an action research strategy of inquiry was applied. It has been suggested that such research design is aligned with the mode of inquiry suitable for understanding scenario planning (Burt and van der Heijden, 2003; List, 2006) and MCDA interventions (Belton, 2001; Montibeller, 2007; Stewart et al., 2010). Comparing our method to existing processes (as opposed to competing methods) also aligned with our aim, and with previous effectiveness studies (Chun, 1992). Quality dimensions selected were aligned with the literature (Schilling et al., 2007). Three public sector projects in Trinidad and Tobago, involving option assessment, were used. This particular context was chosen as different areas were being reviewed to meet objectives of a 2020 development plan for the country. In each case we initially surveyed the diversity of opinion insofar as interviewing those who would typically provide information inputs to the decision process (as identified by the decision maker) to establish agreement of uncertainties and objectives. Subsequently, a single decision maker was used as we wanted to gain an understanding of the decision support method in its lowest common denominator of involvement. However, we also engaged in discussions with others involved in the decision-making process to understand the critical aspects of the problem under consideration and so identify and understand some of the major distinctions that mark central actors or stakeholder groups (Edwards and von Winterfeldt, 1987).

The paper is divided into five sections. First, we provide the rationale for key features of our decision support method. Next, we describe the research methodology. Then we discuss application to three cases, examining possible reasons for discrepancies between current decision practice and our proposed method. Subsequently, we compare findings across cases to evaluate benefits of the method, acknowledging that our methodology is limited in its ability to provide generalizable contributions. We conclude the paper by identifying tentative contributions and scope for future research in this area.

2. A Decision Support Method for MCDA Evaluation under multiple scenarios

Several methods have been recently suggested in the literature for scenario generation and option selection with MCDA (Phillips, 1986; Stewart, 1997; Stewart, 2005; Goodwin and Wright, 2001; Belton and Stewart, 2002; Montibeller et al., 2006; Karvetski et al., 2009; Wright and Goodwin, 2009; van der Pas et al., 2010; Montibeller and Franco, 2011; Comes et al., 2011; Durbach and Stewart, 2012). Three features differentiate our decision support method: the scenario generation technique, the use of cost equivalents, the use of regret for measuring robustness, and cost equivalents for comparing results across scenarios (Kenney, 1992). The scenario set systematises evaluation of options under (2x+2) scenarios defined by a combination of extreme levels of *x* key uncertainties, where x is a small integer number (see Figure 1 for details). We wanted not only to achieve a scenario set that provided the sense of ownership created by the scenario planning framework through a small number of detailed narratives (van der Heijden, 1996), but also provide a representative sample to better support weighting of judgments as advocated by risk management frameworks (Fiedler, 2000). Given that extremes help one to consider a large range of variability for key uncertainties identified (Masini and Vasquez, 2003), we asked decision makers to consider most likely, worst possible and best possible outcomes for key objectives. Debate between the decision maker and analyst sought to construct inherently plausible arguments for why a more extreme outcome would be implausible in the time horizon considered (Wright and Goodwin, 2009; Hirschhorn, 1980). All possible combinations of outcomes then defined the scenario set. Assuming equal weight for each uncertainty, we then defined extreme scenarios as those that were significantly different from the most likely scenario. We measured distance from the most likely outcome in terms of the percentage of overlap of outcomes between that scenario and another in the set (Alspaugh et al., 1999). We then examined characteristics of those scenarios that were most different from the most likely scenario (i.e. low similarity to the most likely scenario). For any number of uncertainties, this set was characterised by the scenarios with best possible outcomes on all uncertainties; scenarios with worst possible outcomes on all uncertainties; and scenarios with the worst possible outcome for one uncertainty given best possible outcomes on all others (repeated for each uncertainty); and vice versa (see Figure 1).

While the benefits of developing a scenario narrative should not be understated (Bowman et al., forthcoming; Wack, 1985), we were cognizant of the heavy cost incurred in terms of time, which could eventually affect the benefit perceived from scenarios (Grant, 2003). Given that brief scenarios, not causally linked, do not impact the cognitive benefit of accepting a wider range of outcomes (Kuhn and Sniezek, 1996), we created scenario snapshots/vignettes, each composed of a common module (trends) and an experimental cues module (combinations of uncertainty outcomes selected). We presented these to the decision maker for feedback on their clarity before applying the MCDA framework (Rungtusanatham et al., 2011). We hoped that this provided sufficient information to aid judgment, supported by the finding that judgments of experts and non-experts are described by a small number of significant cues (Shanteau, 1992).

We adopted regret (i.e. under-performance of an option in a given scenario relative to the best performing option in that scenario) as the operator to assess robustness as advocated by (Lempert et al., 2003). Regret has been asserted as one of the more credible criteria for selecting decisions when likelihoods are not known with sufficient precision, as exists under deep uncertainty (Loulou and Kanudia, 1999). It may be criticised for a focus on vulnerability relative to a norm, thereby reinforcing conventional choices. However, considering the possibility of regret before deciding may lead to lower experienced regret (Kahenman, 2011), with scenarios seen as an appropriate mechanism for investigating the role of anticipated regret (Connolly et al., 1997). Anticipated regret can also prompt thinking about how an event could have happened, how one could change it, or prevent its future occurrence (van Dijk and Zeelenberg, 2003; Zeelenberg, 1999).

We also employ a way of normalising different value scales under each scenario using cost equivalents as suggested by (Keeney, 1992). Independent MCDA models per scenario may be not only cognitively easier, but also practically meaningful when consequences are very different depending on whether a particular event occurs or not (Montibeller et al., 2006). Nonetheless, it is instructive to compare performance across scenarios to better understand the risks involved in selecting a particular option (French et al., 1997), although no such mechanism exists among applications of scenario planning and MCDA. The main advantage of cost equivalence over a benefit-cost model is that it does not rely on market considerations and observed prices. Nonetheless, it is a measure to be used with caution, as it may lead to awkward and difficult interpretations (e.g. it implies a particular monetary value for intangibles such as lives and ecological worth).

3. The Research Methodology

As described in the Introduction section, we applied the method described above to support three real-world decisions. Our analysis of such interventions was grounded in a qualitative research paradigm (Lincoln and Guba, 1985; Merriam, 1988; Eisner, 1991). Action research was chosen as the strategy for inquiry. It requires personal involvement in practical problem solving as well as researching collaboratively with decision makers. It seeks to understand the impact of changes created via an intervention, with a view to extracting lessons for future interventions (Montibeller, 2007; Coughlan and Coughlan, 2002; McNiff and Whitehead, 2011). It also fits with the paradigm in which MCDA interventions have been researched (Stewart et al., 2010; Montibeller et al., 2006; Belton, 2001; Franco and Montibeller, 2011), as well as scenario planning (Burt and van der Heijden, 2003), and even multi-methodology techniques involving MCDA (Belton et al., 1997; Petkov et al., 2007; Franco and Lord, 2011). While AR cannot aspire to the same claim of validity as that associated with natural science criteria, we sought validity by first focussing on understanding the decision maker perspective without any pre-defined framework, then through the lens of our pre-defined criteria, and finally through the lens of alternative perspectives in the literature. Our cases were also aligned with quality criteria for action research that emphasises useful and enduring consequences for those involved (Reason and Bradbury, 2001).

1 Identify key uncertainties and trends

- Identify uncertainties relevant to the strategic question. Uncertainties are issues which the organisation has no control over but whose outcomes can have an impact on the organisation. Separately list trends that are expected to continue based on research.
- Create a matrix with labels 'Level of Importance' (Information that is most valuable to help achieve objectives) on the left hand side and 'Level of Uncertainty' (how variable are the possible outcomes for a particular factor) on the top of the matrix.
- Let the top left hand corner denote High for each dimension; the bottom left hand corner denote Low for Level of Importance; and the top right hand corner denote Low for Level of Uncertainty. Select uncertainties in the High/High quadrant for scenario development [24].

2 Identify criteria and options

- Elicit objectives through the use of a value hierarchy.
- Shortlist options under consideration and which appear to meet these objectives. Options must be independent.

3 Develop scenarios

- Discuss best and worst possible levels of achievement of objectives, then extend ranges of objectives already put forward and ask whether circumstances could exist that make these extended ranges plausible.
- Repeat till decision-maker perceives implausibility [18].
- The best-case scenario is denoted by BBB (best case state/level for each uncertainty). Swing Uncertainty 1 (U1) to its worst level, leaving U2 and U3 at their best levels. This, combined with trends identified, results in scenario WBB. Construct BWB and BBW in a similar manner.
- Define the worst-case scenario as WWW (worst-case state/level for each uncertainty). Repeat a similar process to achieve scenarios BWW, WBW and WWB.
- Check each scenario for consistency (i.e. whether relationships between uncertainties make sense).

4 Apply MCDA framework to each scenario

- Weights: The question asked to elicit weights was: 'If you were in scenario A, and one criterion could be moved to its best level, which would you choose?' The criterion ranked first received a score of 100, and the other criteria were given a weight relative to this score. Weights were then normalised.
- Values: The first question asked here was: 'If you were in scenario A, which option would perform best relative to the others in terms of its ability to help achieve criterion i? The option that is selected gets a score of 100, with the option least likely to achieve a desirable level on criterion i being allocated a score of 0. Say option 1 gets a score of 100, and option 4 gets a score of 0. The second question asked here was: 'Still assuming you are in scenario A, how would you rate option 2 in terms of its ability to achieve a desirable outcome on criterion i?' A score of 40 on option 2 for example would indicate that the improvement in criterion i from option 2 was 40% as good as the improvement resulting from option 1. Questions were asked to ensure such consistency in responses [45].
  - Given a set of scenarios $S= s_k$, $k=1,..,r$; a set of strategic options $A= a_i$, $i=1,\ldots,n$ and a set of criteria (measures by which the achievement of a particular objective is gauged) $C= c_j$, $j=1,\ldots,m$

$$\text{Performance } (a_i, s_k) = \sum_{j=1}^{m} v_{ijk} w_{jk}$$

where v_{ijk} is the is the value of option i in terms of helping to achieve a desired level of criterion j in scenario k and w_{jk} is the weight assigned to criterion j in a given scenario k.

5 Calculate cost equivalent regret

$$\text{Regret}_v\,(a_i, s_k) = \text{Max}_{a'}[\text{Cost-Equivalent Performance } (a'_i, s_k)] - \text{Cost Equivalent Performance } (a_i, s_k) \quad \forall\, a_i \in A$$

- Cost equivalent performance is calculated as follows:
  i. If the weight assigned to cost on the best case scenario is 0.4, the range of MCDA performance units with respect to cost is 100 x 0.4=40.
  ii. If the cost of implementing options ranges from £10m-£90m, then each unit of MCDA performance is equivalent to Range of Cost/ Range of MCDA units for Cost= £80m/40=£2m.
  iii. If an option has an MCDA performance of 55 in a given scenario, then its cost equivalent performance is MCDA Performance x Cost Equivalent per unit of MCDA performance= 55 x £2m = £110m
- Plot expected regret for each option across all scenarios.

Figure 1: Outline of and rationale for steps in the proposed method

We applied the decision support method in public sector decision making for two reasons. First, it extended the scope of analytical operational research (OR) tools to address the multiplicity of factors in the development context [64]. Second, our method seemed timely as a half-way review of a 2020 strategic development plan in Trinidad and Tobago had recently been completed (January 2010), and discussions across the public sector were

focussed on which options would achieve the objectives of the plan given a range of changes in the external environment in the next ten to fifteen years.
The interventions were carried out between January and March 2010. Participants were contacted in writing and interviews conducted to make a final selection. We chose three cases that reflected the following conditions:

i. The existence of deep uncertainty.
ii. Conflicting objectives that were not easily monetised.
iii. The decision was irreversible.

The common denominator for choosing decision makers was seasoned knowledge and experience of the decision context, as well as willingness to engage with the process. Given the visibility of decision-maker positions and institutions, various steps were taken to safeguard their rights, including articulation of research objectives verbally and in writing; written permission to proceed with the study as articulated; full disclosure on all data collection devices and activities; and anonymity.

An in-person pre-intervention interview explored three main themes: inputs and strengths of the current process, how uncertainty and multiple objectives were handled within this process, and previous experience with scenarios or MCDA (see Appendix 2.1 for the Interview Protocol). We also provided a questionnaire so the decision-maker could rate perception of the current process and an ideal process (Schilling et al., 2007):

i. Perceived transparency: Comprehensibility of each stage of the process, with limitations of the method clearly identified. This criterion is akin to ease of use, ease of understanding and justification (Bell et al., 2001; Zapatero et al., 1997; Payne et al., 1993).
ii. Adaptive approach to change: Prompted to consider a range of possible surprises in the external environment when selecting strategic options (Schoemaker, 1993; Wack, 1985).
iii. Rational: Supported the decision-maker in using meaningful and reliable information to make clear value trade-offs and use logically correct reasoning (Bell et al., 2001; Schilling et al., 2007).
iv. Challenge current strategic priorities: Active questioning of the way strategic choices are currently made (Schilling et al., 2007; Godet and Roubelat, 1996; van der Heijden, 1996).

v. Stimulate creation of options: Generation of additional options/improvements (Montibeller et al., 2006; Goodwin and Wright, 2001; Schoemaker, 1997).

The post-intervention interview explored three main themes: perceptions on the key strengths of the process, satisfaction with how uncertainty and multiple objectives were handled within this process, and key areas for improvement. The questionnaire was repeated at this stage with reference to the method. The intervention was tape-recorded to measure time spent on each phase as well as to provide a reference for creating the reflection log. Initial notes were made to capture key observations from the process shortly after each meeting. Data was also collected from discussions with those who provided inputs to the decision-making process, secondary documents (e.g. meeting minutes, annual reports/budget statements, and newspaper articles on local developments).

This interview took place a couple of weeks after the exercise. Ratings for our method were compared in terms of distance from the current decision process and the ideal situation, assuming equidistance of the seven different scale points and a single peaked preference function [schilling]. For example, if the current process was rated 1 on transparency, the ideal was 4, and our method given a rating of 3, the distance of our method from the ideal was |4 - 3|=1 whereas the distance of the status quo from the ideal was |4 - 1|=3. One would conclude from this that on the dimension of transparency, our method was perceived as being closer to the ideal than the existing process.

A transcript of the entire intervention (manifest content) and reflection logs (latent content) formed the unit of analysis. The first stage of analysis involved comparing ratings from the pre-and post-intervention questionnaire (resulting in the spider diagrams in Figures 3, 5 and 7). The second stage of analysis involved open coding, as in qualitative content analysis (Krippendorff, 2004), to capture feedback relating to each quality dimension identified. Colour coding was also used to classify statements corresponding to stages in our process (see Table 1 for an illustration). This enabled us to track how perceptions changed relative to these dimensions. The third stage of analysis conducted parallel to the second order analysis mapped the development of quality dimensions. These were supplemented by findings on practical applications of MCDA, scenario planning and more broadly, making judgments under uncertainty. The output of this iterative procedure was a better understanding of how and to what extent a decision maker could leverage insights from our particular method.

Statement	Open Code	Quality Dimension	Stage in Process
The method we would normally use would be based on experience and judgment over years.	Reliance on experience	Transparency	Current strategy
We do not consider the combinations of the hierarchy acting together, but the amount of combinations is where there are weaknesses.	Interconnection not considered	Transparency	
Vulnerability to competition is based on what you know now. Your whole investment could be thrown off if for example they find that coconut causes cholesterol.	Reliance on current knowledge	Rational	Uncertainty selection and definition
What makes it difficult is that when you make a decision, must factor in 6 variables plus all criteria for technical feasibility. Are we coming up with the right answer? Or do so many factors go into the decision-making process?	Interactions raise doubt	Rational	Reaction to elicitation
Is the decision-making process as complex as that? I would expect that people would use this method.	Interactions are realistic	Rational	Reaction to method
This model makes you factor in a lot more variables and so helps you think through how these might interact. In so doing, it helped me be somewhat more proactive.	Interactions improve proactivity	Adaptive	Reaction to method
It allowed me to really look at that whole range of criteria-factors that I would normally not focus on. This helped me focus on issues to make a decision.	Interactions help focus on relevant issues	Adaptive	Reaction to method

Table 1: Description of categories and codes

The next section provides an analysis of the findings from each of the three action research interventions. A summary of the decision-making context is provided (see Appendix 2.2 for further details), followed by an outline of the current decision making process (against which our method is compared) and analysis of decision maker feedback.

4.1 Case Study 1 — Land Use in a Regional Corporation: Priorities for Infrastructure Development

Context and current decision-making strategy

The corporation that formed the subject of this case had a responsibility to provide public services, including investments in physical infrastructure, recreation and local employment for eight geographical areas with a stable population of 90,000 residents. However, it had to navigate a complex system of resource allocation. First, the corporation would make an application for funds needed in the coming year, which would then be allocated by central government. Implementation plans had to be provided quarterly, following which resources would be released monthly and its use periodically monitored. This process meant that the pursuit of long term objectives was constantly impeded by short term concerns.

The current strategy was based on an ad-hoc judgment of the size of the potential communal benefit. Allocated funds were tentatively shared equally across all areas, and project approvals made following discussion facilitated by the chairman on the best uses of these funds.

The decision support intervention and findings

We worked with the chairman to identify priorities for land use in one geographical area, given a 10 year timeframe. Results from practical application are shown in Figure 2.

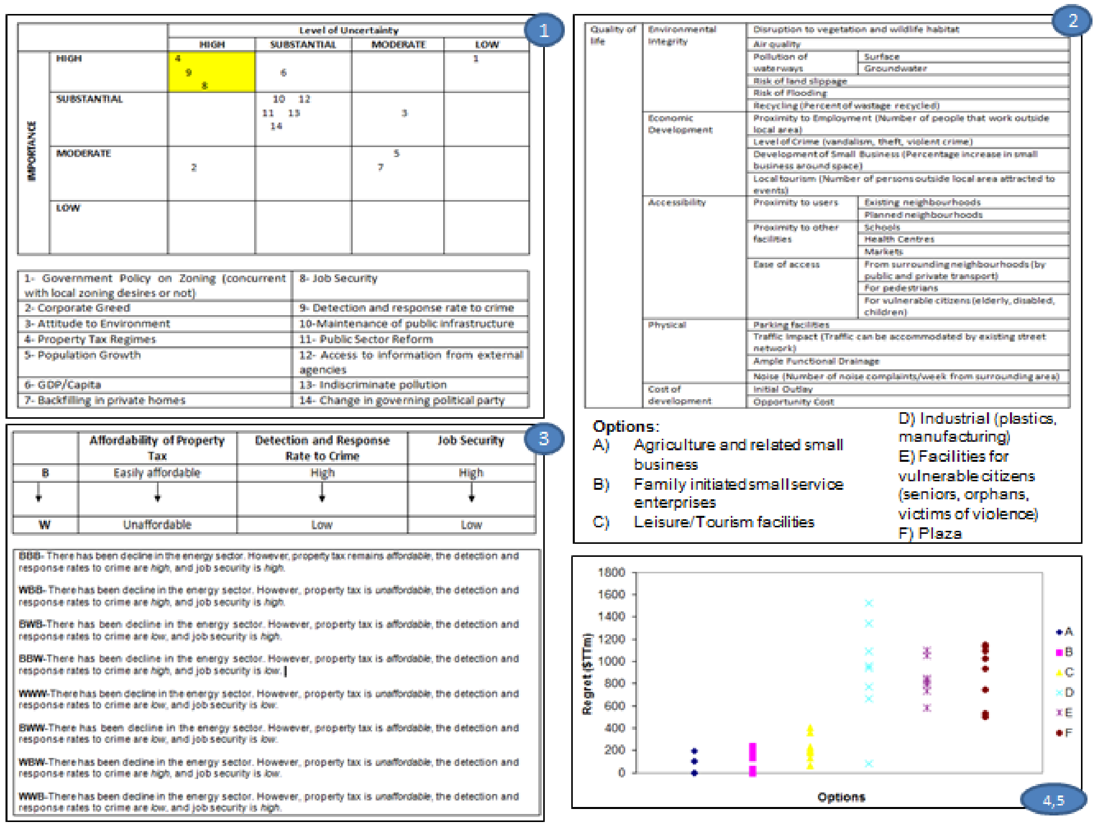

Figure 2: Outputs from practical application of method to priorities for infrastructure development. (1) represents the uncertainty/importance matrix, with the shaded box indicating the most critical uncertainties that form the basis of scenarios. (2) shows the value hierarchy which starts with end objectives on the left and cascades to criteria as well as options selected for evaluation; and (3) outlines the scenarios selected; and (4,5) represents the cost equivalent regret for each option across scenarios considered, with MCDA inputs detailed in Appendix 2.4

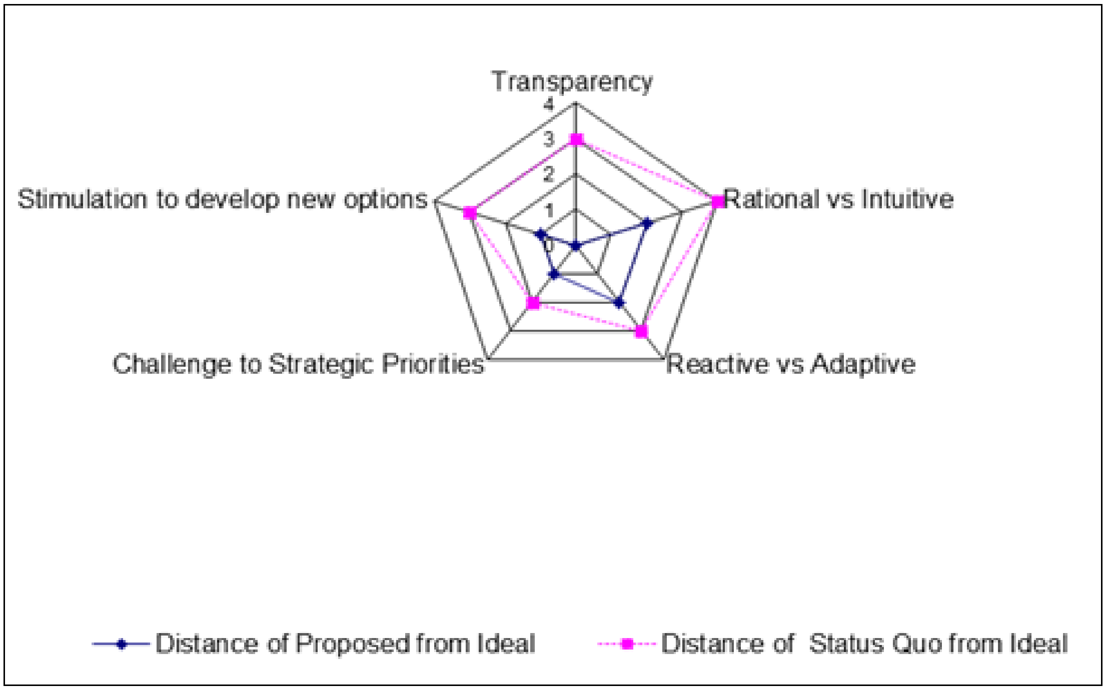

Figure 3: Decision-maker feedback on the intervention involving priorities for infrastructure development

Figure 3 shows that our method was perceived by the decision maker as more adaptive than the status quo. One main reason for this was that it made him "more aware of a rigorous way of decision making". The following quote summarises it well:

"It's the first time I have seen scenario planning applied like this. We would make decisions on feeling, emotion, political dimensions rather than a rigorous methodology which you have used. This model divests itself of extraneous matter and focuses on the necessity of making decisions based on hard facts and your vision when there are scarce resources."

In terms of transparency (ease of understanding each stage of the process), our decision maker initially found the concept of elicitation difficult to grasp. Tape recordings highlighted that the elicitation process for the first three scenarios took on average twenty (20) minutes each due to the need to repeat the question and longer pauses before answers were provided, with the next three scenarios taking about twelve (12) minutes each. Of course, the additional length of time may have been attributed to lack of visual aids for elicitation. Subsequent elicitations were easy to understand because he had a better understanding of his priorities across scenarios, as captured in the following quotes, both made during the intervention:

- “As I become more comfortable with it [the method] I make decisions a bit more quickly because I tell myself how I make the decision.”
- “There are political reasons for keeping all values high as different stakeholders will ask, ‘What about me?’”.
- “My theory is that if the economy is doing well, it is easier to address other things. Crime is a deterrent to the stimulation of economic development. Decline in the energy sector would be complete in this time frame; our focus will have to turn to other areas to stimulate the economy. Therefore, our priority is still economic development. If we have that sorted, then cost of development is not such an issue.”

In terms of perceptions regarding rationality, there is evidence to support that MCDA influences this more so than the scenarios from the following statements:

- “Your model says this is what you should do with that land, and why. That is an important output.”
- “It (the process) is fun for me because it has set me thinking about how I make decisions-how I take decisions based on balancing different objectives.”
- “This brings back a discipline to thinking and makes me aware that you must always be looking at the big picture. This injection of outside ideas is useful to me. I can certainly introduce some of it in my organisation.”

Nonetheless, our method was rated as relatively distant from the ideal in terms of rationality. The decision maker felt that “there will always be uncertainty about how people will behave to achieve economic gain”, making it difficult to ensure that the right information was being used. In this case, a group context may have been more useful as our decision maker adhered to a certain rationale for prioritising objectives after a few scenarios.

Our proposed method was deemed superior to current processes for challenging priorities and stimulation to develop new options. Even though the decision-maker’s top three preferred options before the intervention corresponded to the rankings suggested by the proposed method (options A, B, and C), there is evidence that the method prompted thinking differently. This process was composed of three stages. The first was recognition of the need to think differently (“We all operate in our comfort zones but we have to break out otherwise we will be left behind”). The second stage was thinking about stakeholder reactions to scenarios in terms of what would be most important and feasible for them:

“If property tax is affordable and job security is high [due to employment outside the local economy], the plaza will not languish. You [citizens] could afford to pay rent and shop, so this option will get fairly high ranking. Although crime is bad, coping strategies [among residents] will be adopted.”

The third stage was thinking about which combinations of options would suit stakeholder groups:

"If I must stimulate the local economy [as the energy sector has declined], one [option] must occur at expense of another. Although vulnerable [citizens] would not provide a return on investment, in bad times they are most vulnerable and society has a responsibility to protect them. Our vulnerable population is growing. At the same time, you need to stimulate some sort of employment. The likely returns on options A, B and C together should help stimulate economy and jobs."

4.2 Case Study 2 — Agricultural Commodities for National Development: Robust options with flexible elements

Context and current decision-making strategy

The long term trend towards increased food prices led to a need for increasing consumption of local fruits and vegetables, and also provided an opportunity for developing the agri-business and agro-processing sub-sectors in Trinidad and Tobago (Ministry of Agriculture, Land and Marine Resources, 2010). We worked with an agricultural expert to make recommendations on fruit and vegetables that fit with the policy emphasis that commodities for local production should possess the capability to ramp up domestic production to mitigate food supply challenges, and also aid the marketing and development of new and innovative value-added products (Ministry of Agriculture, Land and Marine Resources, 2010). A time frame of 20 years was selected to reflect the lag time to bring the crop to market and seasonal patterns of supply and demand for the commodities considered.

A typical process would involve identifying the main value drivers of a prospective solution (e.g. inputs) and their sub-factors (e.g. fertiliser). A weighted average would then be calculated to assess the extent to which these factors contributed, positively or negatively, to the observed situation (da Silva and de Souza Filho, 2007). This would be conducted by a multi-disciplinary team of experts (agricultural economists, agronomists, statisticians, animal scientists, food engineers etc.). Time varying indicators (production, market-share, prices, and others) for the past five years would form inputs to an econometric model, which would be used to predict future scenarios and test the robustness of the proposed solution (da Silva and de Souza Filho, 2007).

The decision support intervention and findings

Results from the practical application are shown in Figure 4. Figure 5 shows that our method was perceived by this decision maker as significantly more transparent and rational than the current method. It “provided a framework for thinking differently about the key issues and for making a decision based on them”.

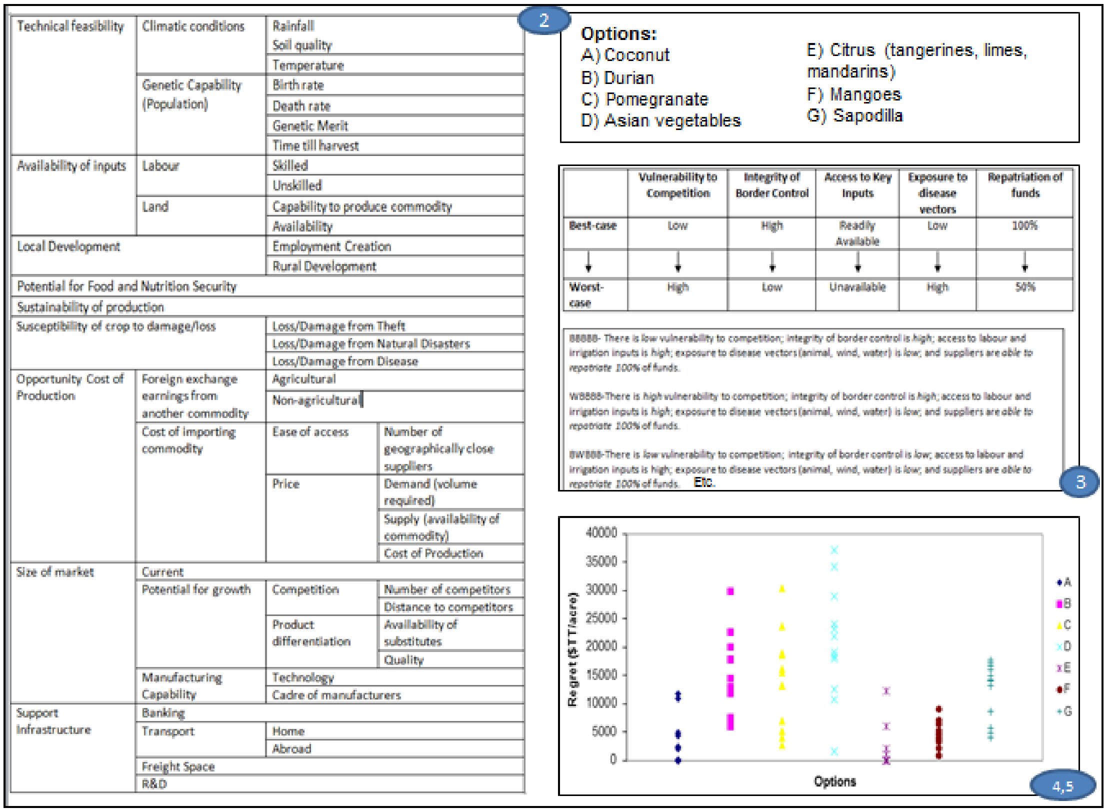

Figure 4: Outputs from practical application of method to selection of agricultural commodities. (1) represents value hierarchy; (2) outlines the scenarios selected; (3) lists the options selected for evaluation; and (4,5) represents the cost equivalent regret for each option across scenarios considered, with MCDA inputs detailed in Appendix 2.4

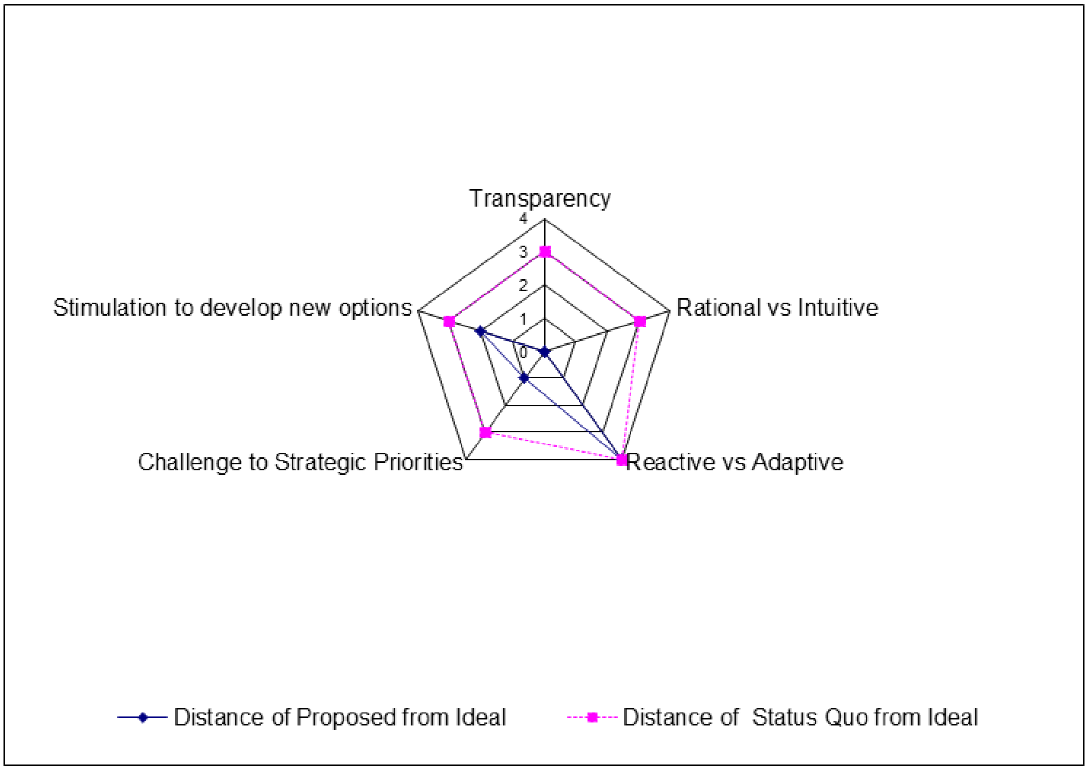

Figure 5: Decision-maker feedback on intervention involving selection of agricultural commodities

The value hierarchy was particularly helpful in assessing priorities, and was referred to throughout the process to support the rationale for values and weights:

- "We would normally use judgment and experience and not systematically consider a listing of criteria and how they interact"
- "It allowed me to really look at that whole range of criteria-factors that I would normally not focus on. This helped me focus on issues to make a decision."

Development of options was stimulated by a desire to "tweak the plan based on emerging opportunities or challenges", as illustrated in the following statement by him:

"Going into agriculture, you do not have full knowledge. So while one solution may have least regret now, one change in another country could throw these off completely that you would not normally be aware of. For example, if Mexico were to invest in coconut, this is not good for Trinidad. How does the model cope with that?"

Our response here was that the model could not automatically be updated to address this, but it provided an opportunity to develop improvements in a proactive manner. Examining the value hierarchy and implied trade-offs led to realisation of a new criterion and corresponding option generation:

"If you go into a market and it doesn't materialise, you could invest in alternate products. Diversification is particularly relevant to an economic/marketing point of view. So in the case of coconut for example, I could shift marketing efforts from the raw good to processed products such as coconut oil. This would be better than pomegranate. With high competition, processing pomegranate would need a lot of investment."

The value hierarchy was also at the heart of helping to challenge strategic priorities, more so than the scenarios, which largely received negative feedback on this dimension:

- "I would have come up with a weighting system for scenarios −those that would cause minor changes would be eliminated. Maybe choose top 3 critical ones from those combinations you developed. The scenarios should reflect states that are absolutely critical to success."
- I would suggest 3 scenarios because I fear that by adding more scenarios, we are moving away from being substantially different to making errors. I like the use of a swing, but you have to keep reflecting to base position."

The current and proposed methods were therefore perceived as equally weak in terms of adaptivity. Nonetheless, the perceived advantage of our method was that it made the decision-maker "factor in a lot more variables and so helped in thinking through how these might interact in a consistent manner". In so doing, it helped him "to be somewhat more proactive by looking at elements I would normally not focus on". Despite indications of fatigue during the process (request for breaks, complaints about the repetitive nature of the exercise), there was at the end an indication of intent to use elements of our method:

"We make decisions under uncertainty pretty often. I will tend to approach things in a more systematic way in future, or at least give people more options so the range of possibilities is not narrow."

4.2 Case Study 3 — To Divest or Not in the Port Services: Stakeholder Management

Context and current decision-making strategy

The subject of this study was the port services company responsible for one of three industrial ports in Trinidad and Tobago. The business was composed of two main parts — port and estate. The port's losses were significantly destroying shareholder value; whereas the estate was highly profitable. The financial health of the port was being reviewed to identify possible areas for cost reduction. If the port could not break even, divestment would have to be considered for the organisation's long-term survival. We worked with the CEO, who was very familiar with scenario planning, to explore the possible impacts of various strategic options on employment and the preservation of port services.

The decision support intervention and findings

The strategy being employed was to prepare for divestment by adopting a holding company structure to understand cost drivers and therefore derive efficiencies. Our proposed method was introduced as an additional layer of analysis to provide insights on the robustness of the divestment decision given the key stakeholder actions. Results from practical application are shown in Figure 6 below.

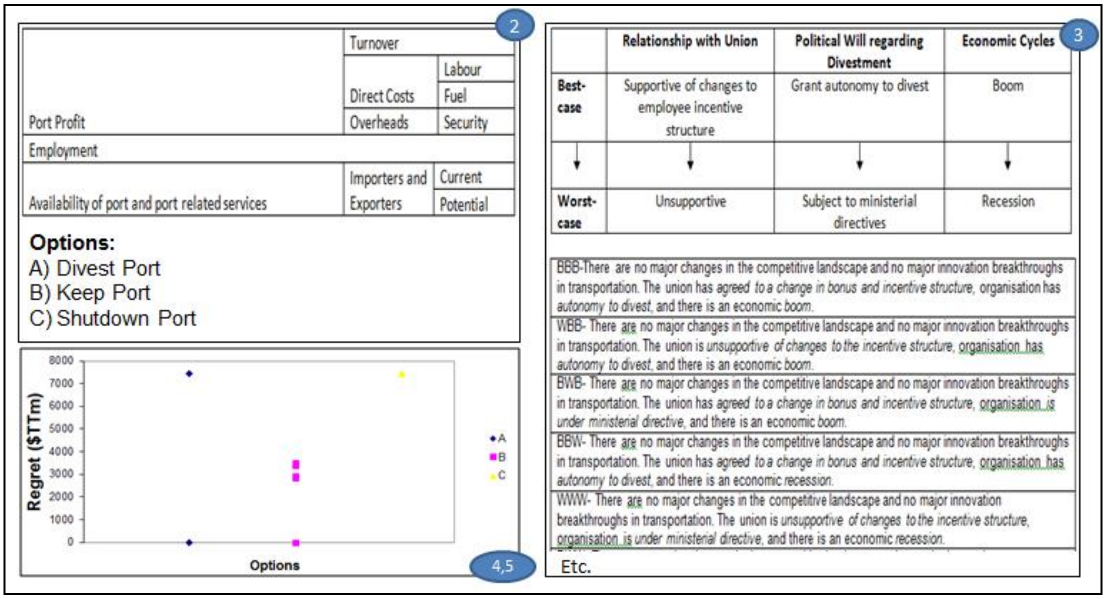

Figure 6: Outputs from practical application of method to port divestment decision. (1) value hierarchy; (2) outlines the key uncertainties and scenarios selected; (3) lists the options selected for evaluation; and (4,5) represents the cost equivalent regret for each option across scenarios considered, with MCDA inputs detailed in Appendix 2.4

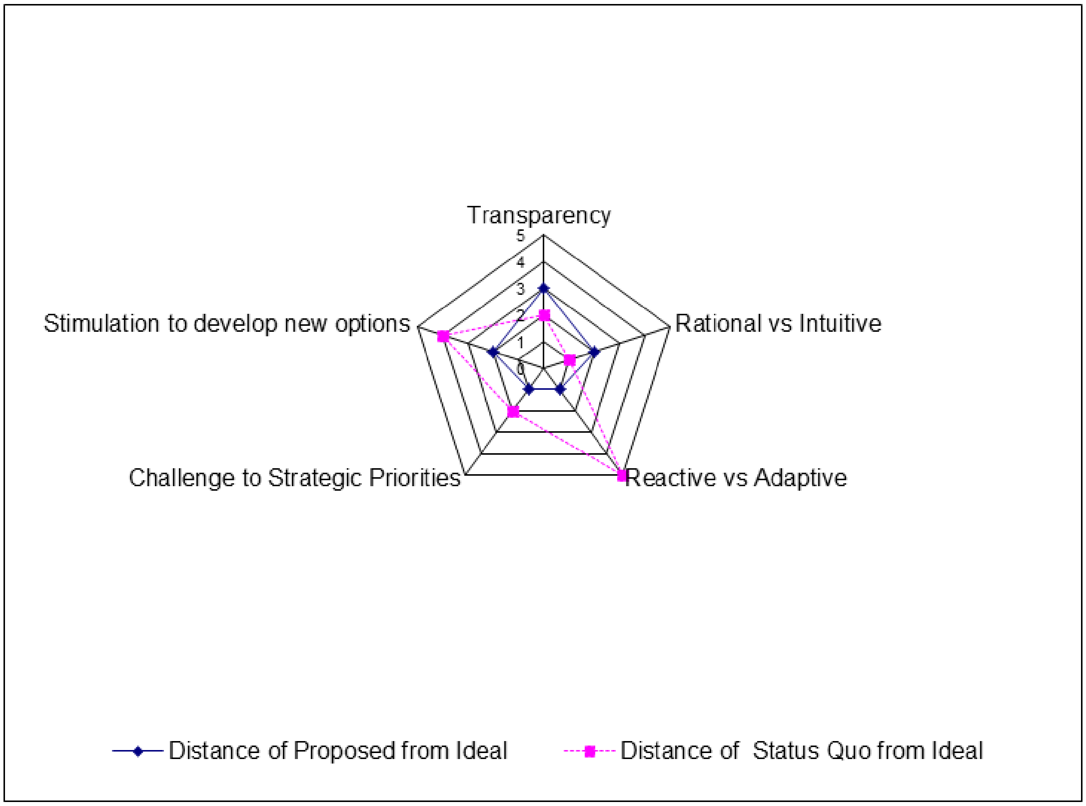

Figure 7: Decision-maker feedback on intervention involving port divestment decision

Figure 7 shows that our method was perceived as more adaptive than the current decision strategy. The decision-maker perceived scenarios as useful "because the action set could change quite considerably depending on how each of the [uncertainty] dimensions move". While the exploratory thrust of the exercise was "more valuable than a purely financial analysis", it was viewed as useful "only in non-crisis situations".

Conversely, the current strategy was seen as more transparent and rational. One reason for this was disagreement with the notion of trade-offs:

"A good executive team seeks an answer to the key strategic question: how do we get these bulls running in the same direction? Our present strategy aims to do this by trying to get the port to a place where we could sell if we wanted to, but if we didn't divest, it is profitable anyway".

The interest in finding intelligent ways of achieving good outcomes on all objectives resulted in high, relatively equal weights. Another possible reason for perceived lack of relative transparency was stated discomfort about the use of a quantitative approach

(MCDA) being combined with a qualitative paradigm (scenarios) in terms of providing meaningful output.

The greater benefit of scenarios was that of providing opportunities for exploring different options and identifying unintended consequences, which was in fact the original aim in using the proposed method. The scenarios presented different configurations for thinking about where the balance of power would lie, and options that would best address the needs of the dominant stakeholder. For example, if government mandated that the port be kept but the union was supportive of changes, then there would be greater scope for generating profit through implementing options to increase productivity. If the government and union were unsupportive, then the issue of employment would be of utmost importance, especially if economic downturn persisted. Unions in this case would be likely to exert greater power, and options would have to be implemented to gain support from them. The extremes also prompted the decision-maker to review his assumption that survival in a recession would guarantee survival in an economic upturn. While eliciting values for profitability under different scenarios, the decision-maker realised that an economic upswing could make the port significantly less profitable due to inherent inefficiencies. This prompted a shift in the strategic conversation from ‘What do we do with the port?’ to ‘How do we mitigate losses on the port?’ This reinforced the need to shift stakeholder mind set from one of “entitlement to a place where they are partnering with company to drive positive change”, with options then focussed in this direction.

5. Discussion

In this section, we compare findings across cases and against the literature to describe how the differentiating features of our method influenced decision-makers’ reactions.

We hoped that our scenario selection method would encourage consideration of a wider range of possible surprises when assessing options and prompt active questioning of the way strategic choices were currently made. In all cases, the MCDA process appeared to have a more significant role to play in achieving this than the scenarios. In the infrastructure case, the scenarios provided a strategic lens on decisions, but the MCDA process provided a “rigorous [approach] based on hard facts and your vision when there are scarce resources”. In the agricultural commodity case, considering more than three scenarios was seen as “moving away from being substantially different to making errors” and not reflective of states absolutely critical to success. This shortcoming was not due as much to the method, but because the factors critical to success of options were driven by inherent biological characteristics. In this case, the value hierarchy played a more dominant role in focussing on a broader range of interconnections as it was used as a reference point during elicitation and option improvement (see Appendix 2.3 for details on techniques used to support option improvement). In the port divestment case, it was not difficult for our decision maker to perceive the added value of scenarios given his familiarity with the technique. During the MCDA process he was able to perceive different interconnections, thereby prompting re-framing of the problem. While the ranking of options pre- versus post-intervention suggests that similar outcomes could have been achieved without scenarios, decision maker feedback indicated that without them there would not have been an understanding of the connections between the external environment (scenarios) and the internal environment (objectives, constraints). Whether another scenario selection would have yielded a better outcome is an open question that should be analysed in a controlled environment that is beyond the scope of this paper.

Our scenario selection technique also had a multiplicative effect on the elicitation burden, which meant that for the largest problem size (i.e. agricultural case with 9 objectives, 5 uncertainties and 7 options), the cognitive burden was heavy, due to the complexity of interactions/trade-offs that had to be considered. In contrast, neither the smallest problem size (i.e. port divestment case with 3 objectives, 3 uncertainties and 3 options) nor the infrastructure case (with nearly double the number of objectives and options: 5 objectives, 3 uncertainties and 6 options) resulted in issues regarding fatigue. The small variance across weights and the rationale provided for them further suggest that even with a relatively small number of uncertainties there was a tendency to use selection heuristics that focussed on a few key interactions as a way of managing complexity (Hilbig et al., 2012; Shah and Oppenheimer, 2011; Gigerenzer, 2008; Shanteau, 1992). The need to account for stakeholder perceptions in each scenario may also have resulted in relatively equal weights being assigned, as this was stated during the course of all interventions. These indicate that our scenario selection technique should be more sensitive to the resulting elicitation burden given the number of objectives being considered.

No decision maker raised concerns about the lack of narrative information contained within scenarios, although there was at least one scenario which was plausible but significantly different from anything experienced, making it very challenging to conceptualise priorities and/or impacts. As a result, the elicitation process for the first two or three scenarios took longer. However, the lack of a scenario narrative is not likely to be the driver of increased elicitation time as much as the lack of coherence (i.e. information that is inconsistent with experienced norms) (Glöckner and Betsch, 2012), indicating scope for improvement of the method. This observation may also be interpreted as a reluctance to think through the consequences of ambiguous situations, resulting in indecision about choice (Tversky and Shafir, 1992). While outputs were not directly usable in the sense that scenarios translated long term recommendations into a short term policy agenda (Greeuw et al., 2000), desire to engage in further investigation of options as a result of the exercise does not provide evidence scenarios were merely treated as extra information, or that they reinforced indecision.

We hoped that regret would enable an articulation of risk across scenarios such that the decision maker would be motivated to improve option robustness. Various displays were used (spider diagram, value profile, and scatter plot), a view supported by other applications of MCDA and scenarios (Karvetski et al., 2009; Montibeller et al., 2006; Belton, 1999). Each case indicated a range of prompts used to develop options, such as assessing the desirability for key stakeholders and examining shifts in potential consequences of one option relative to another, mainly aided by the ability to compare performance across scenarios. This aligns with studies which indicate that shifts in people's attention from one potential consequence to another, rather than likelihood judgments, determine choices (Busemeyer and Townsend, 1993; Diederich and Busemeyer, 1999). However, possible consequences were not necessarily considered with reference to minimising regret as improving outcomes on objectives within scenarios. This emphasises the ability of MCDA to support option development (Keller and Ho, 1988; Keeney, 1999) by helping one to explore why options perform better/worse in different scenarios.

This mode of option generation was also influenced by a desire to pursue options that were not simply robust (i.e. would yield reasonable value across a range of possibilities given significant upfront investment), but included flexible elements (i.e. can be manipulated to meet different needs over time). Decision-makers clearly felt that the degree of uncertainty was costly enough to consider flexibility (Stigler, 1939). The desire to pursue flexibility was indicative of a less risk averse attitude than would be expected for a decision context prone to the negative effects of the hindsight bias (Kahneman, 2011). Further evidence for a less risk averse attitude is provided by the low differential of weights. If weights differed significantly across upside and downside potential implied by scenarios, then we could conclude that risk attitude was context dependent, or that options with large downside potential seemed proportionately more risky for a naturally risk averse decision maker (Weber, 1999).

Placing this in the context of the risk management framework (Kaplan and Mikes, 2012), scenarios were focussed on addressing external risks (i.e. identification and mitigation of risks that an organisation cannot prevent from occurring) whereas comparing performance within the MCDA framework focussed on strategy risks (i.e. risk that an organisation may accept in order to generate superior returns from its strategy). Regret was therefore seen as emphasising the former at the expense of the latter, suggesting that it may not have been the most relevant robustness metric in these decision contexts. Nonetheless, this did not prohibit the use of techniques to improve flexibility such as examining conditions for success in individual scenarios (Walker et al., 2001), or diversification of options (Wright and Goodwin, 2009), considered in the port divestment and agricultural cases. We leveraged strategy tables for the infrastructure case (Howard, 1988).

Examination of the mean ratings of the hypothetical ideal (Table 2) highlights that transparency, an adaptive approach and development of new options were on average the most important among decision makers. Our method represented an improvement from the status quo processes on all these dimensions. In contrast, there was highest variance in our proposed method from the ideal on transparency, rationality (driven by lack of group involvement and lack of a suitable reference point for making judgments in some scenarios) and adaptive approach (driven by a focus on a few key interactions across scenarios).

	Case 1			Case 2			Case 3						
	Proposed	Ideal	Distance of Proposed from Ideal	Proposed	Ideal	Distance of Proposed from Ideal	Proposed	Ideal	Distance of Proposed from Ideal	Average of Ideal Ratings	Average of Proposed Ratings	Variance Proposed Ratings	Variance Proposed from ideal
Transparency	7	7	0	7	7	0	4	7	3	7.0	6.0	1.7	1.7
Rational vs Intuitive	4	6	2	7	7	0	4	6	2	6.3	5.0	1.7	1.2
Reactive vs Adaptive	4	6	2	3	7	4	6	7	1	6.7	4.3	1.5	1.5
Challenge to Strategic Priorities	5	6	1	6	7	1	4	5	1	6.0	5.0	1.0	0.0
Stimulation to develop new options	6	7	1	5	7	2	4	6	2	6.7	5.0	1.0	0.6

Table 2- Ratings for ideal method (pre-intervention) and proposed method (post-intervention) on dimensions of impact

6. Conclusions and Directions for Further Research

This paper explored how decision-makers in three different realistic contexts responded to a decision support method we recently proposed, which combines scenario planning and multi-criteria decision analysis. In each case study, we employed action research to learn about the decision support process and, at the same time, understand how a decision maker could use insights from our particular scenario selection and option selection procedure. As a method still in development, these insights were necessary before further improvements to the method were made. From these cases, we can now tentatively conclude the following for settings similar to the ones found in our interventions:

- Scenario snapshots were sufficient for direct elicitation within MCDA, and helped subjects to make different connections between the external environment (scenarios) and the internal environment (objectives and constraints). In this sense, MCDA supported the construction of a narrative around consequences that motivated option improvement, thereby playing a role in supporting a process of learning under deep uncertainty, even if the option ranking may not have changed significantly from pre-intervention rankings.
- Involvement in scenario development was an important step in helping decision makers define problem boundaries and further deliberate the critical interactions in

the system within which the decision was placed. This was aided by creating a mechanism to link objectives to the external factors that would critically affect them.

- While the use of extremes may have resulted in plausible scenarios, unfamiliarity with the context affected one's ability to make judgments. A systematised scenario generation technique must therefore be sensitive to the resulting elicitation burden.
- As a result of combinatorial dependency between criteria, options and scenarios, as well as the broader purpose of scenarios, there is no clear answer to the number of scenarios that is appropriate for the assessment of strategic options in this context. Our cases indicated a high degree of variation, with a desired maximum of three being cited in the agricultural case; whereas no indication of fatigue/boredom was indicated in the infrastructure case which involved a set of eight scenarios. Nonetheless, after the third scenario, there were diminishing returns to the scenarios as challenging priorities. In the port divestment case, there was an interest in examining the impacts of different shifts in stakeholder attitudes, so the set of eight scenarios considered was meaningful.
- There was perceived value in being able to compare performance across scenarios to understand why options differed in performance in different contexts.
- There was general agreement that regret was too restrictive given the decision context. While robustness was important, regret was not well-placed to evaluate options on the basis of flexibility. As such, regret did not prompt thinking about re-designing options as much as other stages in the process.

Collectively, these findings suggest that the main benefit to be derived from using the method is that it prompts one to gather further information about options and more systematically consider improvements to the existing option set. The scenarios, even in condensed form, provide sufficient information to enable the decision maker to engage in consequential reasoning about options. This is underpinned by a process of problem structuring that systematically defines negative and positive consequences and traces a path that might plausibly lead to such critical impacts. Of course, these findings are tentative and subject to the limitations of the small number of cases and the research methodology used. The first is that findings from a relatively tedious process are only relevant insofar as similar contexts exist. In political situations, changes in the power dynamic, demography of different areas and stakeholder perspectives may render findings invalid. The scale of action research interventions vary from single, as is common in educational settings, to as many as over eighty, as occurred in the case of soft systems methodology.

Secondly, action research may be framed as focussing on solutions to practical problems, and ignores the scientific frame of reference (i.e. large number of cases in a controlled setting, well-defined variables) (Cohen and Manion, 1989). While we have already asserted that action research cannot be judged by the same criteria required by traditional experimental research, the questions raised by the process lend themselves to such investigation.

For instance, there is scope for developing a strategy to address the elicitation burden. A systematic comparison of the benefits between using a smaller set of narratives and many (i.e. thousands of) scenarios (Bryant and Lempert, 2010) in single and group decision making should be conducted. Careful attention should be paid to the influence of the narrative to engage counterfactual thinking (Koriat et al., 1980) versus improvements in judgments due to a representative sample (Hilbig et al., 2011). Involvement in scenario development should not be underestimated, as reading or hearing scenarios generated by others may require less information processing, but might be less compelling and easier to discount (Hertwig et al., 2004; Weber et al., 2004). This would further inform research on systematising scenario selection by documenting the losses incurred by using certain scenario selection techniques.

Third, given uncertainty about the contribution of regret, simulation could be used to investigate the impacts of alternative robustness measures relative to a hypothetical ideal, as has been investigated in (Durbach and Stewart, 2012). Although strong assumptions will be required, they will enable one to test performance across a range of preference types. Insights on appropriate measures could then be used to develop portfolio management techniques within the scenario-MCDA framework. This is particularly relevant in the public sector context where options are not stand-alone investments. Further work should also consider techniques to practically manage the need to review decisions when more information is available if there is no clear robust option, bearing in mind that what can be changed over time varies with age of the organisation and industry within which it operates (Phillips and Bana e Costa, 2007).

The fourth key area for development relates to application of the method for group decision-making. This is closely aligned to findings that organisational dialogues are integral to learning and innovation through the exchange and testing ideas, beliefs and assumptions (Marx et al., 2007; Duncan and Weiss, 1979; Schön, 1983; van der Heijden and Eden, 1998). We acknowledge the limitation of involving only one person in every decision context, which was a way of simplifying the decision context and thus increase comparability between cases. However, group decision making applications with this method must clarify whether it is assumed that the group behaves as a single decision maker (sharing); individual preferences are aggregated (aggregating); or individual preferences are obtained using a common approach and used in decision or further discussion (comparing) (Belton and Pictet, 1997). Group decision making using our method must further account for differences in willingness to take risks to achieve potential rewards. It would also be desirable to automatically update parameters given additional information over time, and to develop aids for managing plausible but unfamiliar contexts. Indeed, these would be critical elements to strengthening the learning impact from scenarios (Bood and Postma, 1997).

Concluding, we believe that research on the multi-criteria assessment of options in scenario planning is a promising field, and hope that the tentative findings presented are relevant for other researchers investigating the combined use of scenario planning and MCDA to evaluate strategic options in real world settings.

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Appendix 2.1: Interview Protocol

Session 1 Questions (Problem Structuring):

1) Describe the current decision problem.
2) What are the strategic objectives for this decision?
3) What are the symptoms that a problem exists?/What is the impact of the problem?
4) How long has it existed?
5) What elements would be most detrimental to the achievement of your objectives?
6) What do you think is the best option and why?
7) How would you rank the other options based on your overall judgment of the best way forward?

Open Ended Questions Before Intervention:

1) Describe how you normally make a strategic decision involving a choice among various options.
2) In your opinion, what factors lead to consistently successful decisions?/ In your opinion, what aspects define a good decision-making process?
3) How do you cope with multiple objectives in making decisions?
4) How is uncertainty about the external environment considered in making decisions?
5) What difficulties do you have in this mode of decision-making?
6) Have you ever used scenarios? If so, what was your impression of using them?
7) Have you ever used multi-criteria decision analysis? If so, what was your general impression of the methodology?

Session 2 (MCDA Working Session)

Session 3 Questions (Open Ended Questions after Intervention):

1) Tell me what you thought about the session.
2) What was your overall impression of the proposed method?
3) What aspects did you find most useful?
4) What aspects of the method were you most dubious about?
5) How could it have been made stronger in your opinion?
6) What do you think is the best option and why?
7) How would you rank the other options based on your overall judgment of the best way forward?
8) Would you use this method again? If so, why and under what circumstances? If not, why?

Sample Questionnaire used before the intervention (Ideal and status quo) and after the intervention (Proposed):

A. Rating scale for status quo, hypothetical ideal state (answered before intervention) and intervention (answered after intervention) on the following dimensions of process:

a. Transparency and Comprehensibility

(i) **Proposed**: How do you rate the transparency and comprehensibility of the proposed method? **(P)**

(ii) **Status Quo**: How transparently and comprehensibly would the decision problem at hand or similar be solved with existing processes/methods? (**SQ**)

Complex, not very transparent and comprehensible	1 2 3 4 5 6 7	Highly transparent and comprehensible

b. Rational-based versus intuitive-based

(i) **Proposed**: How do you rate the proposed method in terms of rational analysis versus intuitive judgment? **(P)**

(ii) **Status Quo**: How rationally analysed versus intuitively judged would the decision problem at hand or similar problems be solved with existing processes/methods? (**SQ**)

Mostly based on intuitive decision making	1 2 3 4 5 6 7	Mostly based on rational analysis

c. Reactive versus Adaptive Approach to Change

i) **Proposed**: How do you rate the proposed method in terms of reactive versus adaptive approach to change? **(P)**

ii) **Status Quo**: How reactive or adaptive would the problem solving approach be in existing processes/methods given the decision problem at hand? (**SQ**)

Reactive	1 2 3 4 5 6 7	Adaptive

d. Extent to which strategic priorities are challenged

i) **Proposed**: How do you rate the proposed method in terms of the extent to which strategic priorities are challenged? **(P)**

ii) **Status Quo**: To what extent would existing processes/methods challenge strategic priorities for the decision problem at hand or similar problems be solved with? (**SQ**)

Strategic priorities not challenged, focus on an optimal solution	1 2 3 4 5 6 7	Strategic priorities challenged, focus on a robust solution

e. Extent to which creativity is stimulated with respect to developing new options

i) **Proposed**: How do you rate the proposed method in terms of rational analysis versus intuitive judgment? **(P)**

ii) **Status Quo**: How rationally analysed versus intuitively judged would the decision problem at hand or similar problems be solved with existing processes/methods? (**SQ**)

Less creativity-stimulating, more based on "established" ideas	1	2	3	4	5	6	7	Highly creativity stimulating, less based on "established" ideas

Appendix 2.2: Decision Context of Case Studies

Decision Context	Case Study 1 - Land Use in a Regional Corporation	Case Study 2 - Agricultural Commodities for National Development	Case Study 3 - To Divest or Not in the Port Services
Need to justify and legitimise the recommendation	High-Must be justified to Minister of Public Services	High-Must be justified to Minister of Agriculture	High-Must be justified to Minister of Works and Public Infrastructure
Degree of interconnectivity of decision (i.e. whether decision is taken in isolation or in connection with other decisions)	Decision is ultimately connected to infrastructure projects in other regional corporations, but due to budget constraints, the focus of the intervention is a decision taken in isolation	Value is ultimately judged relative to competing value from other income generating initiatives (e.g. energy, tourism), but due to time constraints and lack of access to Cabinet ministers, the decision was considered in isolation	Decision is connected to the value added by two other national ports, but given that the aim was to provide insights on stakeholder reactions for this port, the decision was considered in isolation
Possibilities for hastening or postponing decision	Decision can be postponed for 6 months if necessary	Decision cannot be postponed	Decision cannot be postponed
Possibility to organize iterative decision support processes where the results from the early phases inform later ones	Low-Decision cannot be revoked once made	High- Small scale investments can be made in promising options	Low- Decision cannot be revoked once made
Possibility to re-use earlier models since a similar decision has been made before	Previous model based on discussion with representatives of various geographical areas in the corporation	Value Chain Analysis	Financial Analysis

Stakeholder Engagement	Case Study 1 - Land Use in a Regional Corporation	Case Study 2 - Agricultural Commodities for National Development	Case Study 3 - To Divest or Not in the Port Services
Key Stakeholders Interviewed (selected on the basis of degree to which they are known to be affected by the decision, and familiarity with the decision problem)	• Representatives of the different geographic areas • Residents	• Advisor to Minister of Agriculture • Agri-business expert • Large scale farmer	• Due to the sensitive nature of the decision, interviewing other stakeholders was not permitted
Knowledge of key stakeholders interviewed	• Representatives provided insights on the nature of the conflicts that arise in making such decisions within the corporation and in the broader context, the uncertainties they grapple with and different opinions on options and how they should be implemented • Residents provide insights on key objectives	• Advisor provided information on political considerations, budget constraints and past failures • Agri-business expert provided insights on market developments and consequences of different choices from a national and international context • Farmer provided insights on objectives and constraints	

Appendix 2.3: Option Improvement Techniques

The techniques below are first described procedurally, followed by a brief illustration of how they were investigated in the context of the case studies.

1. Identify criteria that drive good performance and those that potentially require monitoring.

i.Highlight criteria that appear to consistently receive high weights across scenarios. Examine the impact of changes in such weights across pre-defined percentage changes or across the entire spectrum of possible weights. Highest weights are assigned to criteria that the decision-maker wishes to prioritise first across scenarios, based on his understanding of the decision problem. They play a significant role in determining overall performance, so examining the impact of changes in these weights is useful. It may be necessary if the decision must be justified to others who may disagree about the relative importance of criteria. Little or no change in overall performance would confirm the relative worth of strategic options. Significant negative impacts to performance may highlight the need for a decision-maker to maintain consistent effort to achieve desirable levels on these criteria (see example below).

ii.Similarly, examine the impact of changes in the lowest weights. If an increase (decrease) in these weights leads to a considerable improvement (decline) in overall performance, increased focus on these criteria would be recommended.

For example, in Case 1, economic development generally achieved the highest weight across scenarios (Figure 8). Sensitivity analysis on this criterion revealed that options D and F were most sensitive to changes (Figure 9), yet they consistently performed poorly. This indicated that economic development was not necessarily a driver of performance in options D and F, but a decision-maker should not overlook its relative importance. Environmental integrity and physical considerations had the lowest weights across scenarios (Figure 8). As the weight on environmental integrity increased, option A (Agriculture and related small business) still performed well, but B (Family initiated small service enterprises) and C (Leisure/Tourism facilities) slightly less so (Figure 9). Options A, B and C were nonetheless relatively resilient to changes in both criteria, implying that efforts at improving performance in these options need not focus on these criteria.

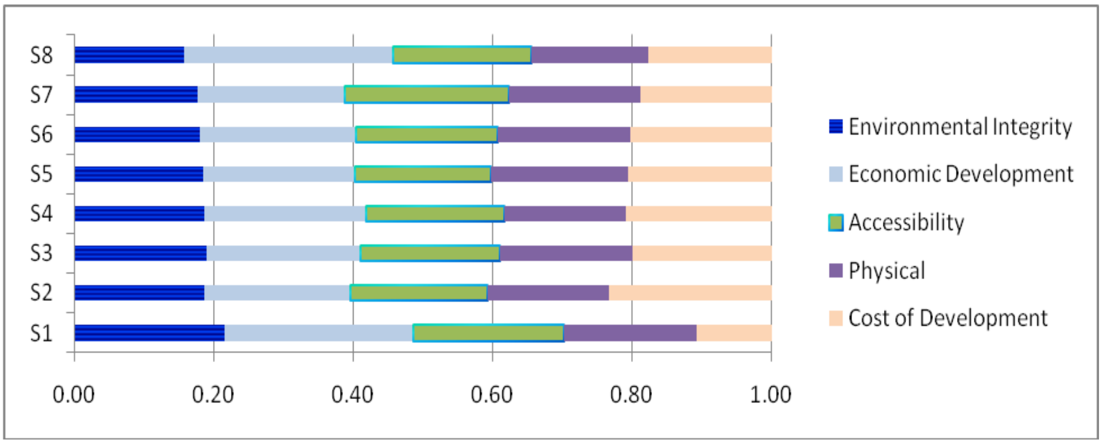

Figure 8 - Profile of average weights across scenarios for Case Study 1.

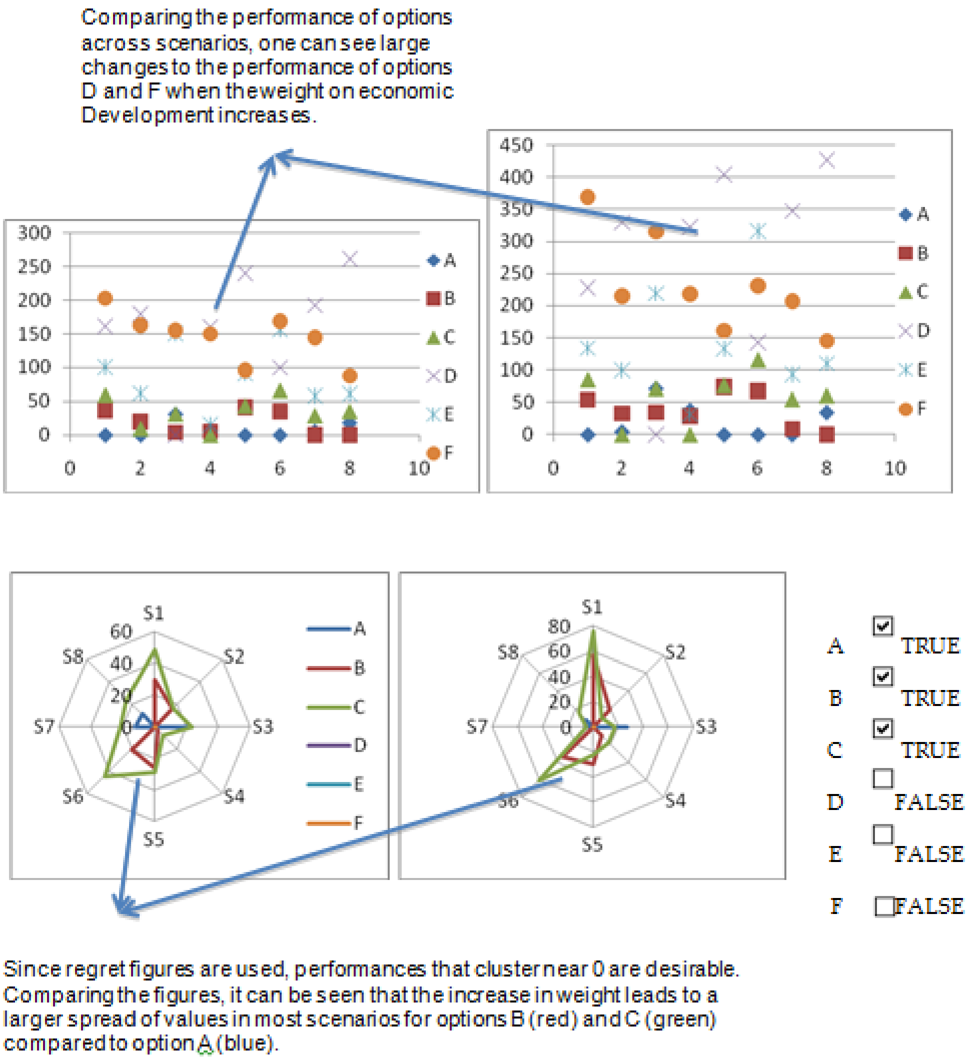

Figure 9- Sensitivity analysis for Case Study 1. *Top***:** Scatter plot showing impact of increase in weight by 20 percentage points on economic development (right) from its original value (left) across all scenarios. *Bottom*: Spider diagram showing impact of increase in weight by 20 percentage points on environmental integrity (right) from its original value (left) on candidate robust options.

2. Shortlist options that demonstrate consistently good performance across scenarios.

i. *Shortlist options that appear to be robust following initial results. These options would typically have a reasonable level of performance across scenarios.*

ii. *In order to confirm that options are robust to changes in weights, examine the impact of changes in criteria with highest weights across scenarios.*

iii. *Collate values (i.e. decision-maker perception of options' performance in criteria) that correspond to these criteria. Within scenarios, explore why certain options may have attained higher values than others on the selected criterion. Examine values across scenarios to identify environments in which an option is consistently achieving high (low) cost equivalent values. This could highlight conditions that help/hinder good performance.*

Figure 10 shows that for the relatively most important criterion across scenarios in Case 1 (C2-economic development), Option A (agriculture and related small business) remains a good option when job security is low (S5 - WWW, S6- BWW, S7- WBW), except for when combined with a scenario characterised by high response rates to crime and affordable property taxes (S4- BBW). In this case, tourism ventures (Option C) perform better, indicating a possible link between response rates to crime and the success of tourism ventures with respect to economic development. Examining values across scenarios highlights that options A, B and C demonstrate consistently good performance across scenarios, and can therefore be shortlisted.

	Options	S1-BBB	S1-WBB	S3-BWB	S4-BBW	S5-WWW	S6-BWW	S7-WBW	S8-WWB
C2	A	100	90	75	80	100	100	100	90
	B	90	85	80	85	80	80	90	100
	C	85	100	75	100	80	70	80	85
	D	60	0	100	0	0	75	0	0
	E	80	70	60	90	75	0	75	70
	F	0	65	0	60	60	65	60	65

C3	C4
100	100

Figure 10- Value Profile for Performance of Options across Scenarios on Economic Development Criterion (Case Study 1)

3. Search for resource efficiencies

Such investigation is particularly meaningful in contexts where financial resources are strained, and the most robust option is also the most expensive option. The following steps were used:

1.Select options that generally perform well across scenarios but are particularly expensive and/or whose final acceptance is likely to be strongly affected by cost considerations.

2.Identify strengths of other options that also perform well but are of lower cost.

3.(i) Note the different traits of options that appear to help meet objectives consistently.

(ii) Determine important considerations for any option to succeed.

(iii) Classify traits using a matrix format and use these to explore new options.

Implementing these steps in Case 1, option A deserves further investigation as it is the most expensive option yet performs consistently well. Options B and C are strong candidates for Step 2. Comparing these three options highlights firstly different focus areas. For instance, tourism is geared towards cultural development; whereas agriculture and small service businesses are focused on developing manufacturing and professional services. Option A focuses on expanding into limited niches, whereas Option C’s strength lies in downstream opportunities. Human resource requirements and regulation are other important aspects to consider in selecting an option. These can be organised in a matrix form as shown in Figure 11.

Important consideration				Important consideration
Human Resources	**Brand Focus**	**Expansion Thrust**	**Partnership Opportunities**	**Regulation**
Portfolio of skills in specific, existing areas	Cultural (Focus of Option C)	Expand into a variety of areas (Focus of Option B)	Government Ministries	**Sufficient power to regulate**
Attention to training and development	**Manufacturing Services**	**Expand into limited niches**	**Community Groups**	Mixture of regulation and persuasion
Portfolio of skills in a variety of new and existing areas	**Professional Services**	Concentrate on creating downstream opportunities for established expertise (Focus of Option C)	**Private Sector**	Strong influence with regulators
	Eco-friendly services (Not considered in current options)		Other Corporations (Not considered in current options)	

Figure 11- Matrix to support the development of options that potentially use fewer resources. The entries are not necessarily arranged in decreasing order of cost as combinations can lead to more/less expensive options.

There are various ways of using this matrix:

1) *Identify possibilities within columns that are not part of the current list of successful characteristics but may help to achieve better performance with fewer financial resources and are aligned to core values.* For example, in Case 1, further investigation of areas where there is influence with regulators could be explored, or partnering with other corporations may be a productive venture. Eco-tourism ventures and small business incentives for environmentally friendly practice could also be considered as they are cheaper and address a brand focus not currently covered by any option.

2) *Examine new combinations of characteristics across columns to identify how traits of the most promising options may be used to develop potentially better options that may use fewer resources*. *The decision-maker may also need to decide whether a short versus long-term investment of resources is feasible or desirable.* For example, in Figure 6, option A's characteristics are highlighted in bold. The following could be explored:

- Training an ageing workforce in specific skills which create downstream opportunities for established expertise. The interface could be used to further explore the trade-off between this and a cultural brand focus.

- Working with community groups, private sector and government ministries to enhance professional service skills.
- Options A and B both emphasise entrepreneurial activities as the most productive uses of the available land, so other options with this focus could be investigated.
- Option A is the most expensive, but a large proportion of the cost goes towards establishing infrastructure to support business, and less so in terms of maintenance. Option C's costs are likely to be the converse.

3) *Explore ways of leveraging traits of successful options to bring about particular scenarios rather than reacting to it.* For instance, in Case 1, partnerships with community groups could be used to explore alternative ways of mitigating threats to job security. Collaboration with other regional corporations may also offer ideas for addressing detection and response rates to localised crime, either through sharing of successful initiatives or development of joint programs.

4. Investigate potential acceptability of options through engaging in negotiation/dialogue with key stakeholders.

Apply the value hierarchy as a basis for developing consensus/compromise through negotiation and dialogue with other parties affected by the decision.

For example, in case 2, the union is currently averse to a proposal of performance-related pay schemes. The decision-maker assumes this is because workers are averse to this, and further negotiations have reached a stalemate. One way forward would be for the decision-maker to collaborate with the union on what defines a satisfied employee (a key objective for both parties). The resulting value hierarchy could be used to understand assumptions being made, and prompt discussion on what could be done to overcome the barriers to achieving end objectives. For example, there might be a need to invest in training or non-monetary incentives which employees may be less averse to compared to the current proposal.

Appendix 2.4: MCDA Inputs for Case Studies

Case Study 1- Land Use in a Regional Corporation: Priorities for Infrastructure Development

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Environmental Integrity	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
Agriculture and Small business	100	90	85	100	90	100	85	90
Family initiated small service enterprises	60	85	90	90	85	80	75	85
Leisure/Tourism	60	100	100	85	100	75	100	100
Industrial- eg. plastics, manufacturing, construction material	0	0	60	0	0	70	0	0
Facilities for vulnerable citizens	55	70	65	70	75	60	70	70
Plaza	45	60	0	65	60	0	50	60

	Physical	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
A	Agriculture and Small business	100	100	80	90	100	100	80	80
B	Family initiated small service enterprises	80	90	100	100	85	90	100	100
C	Leisure/Tourism	75	80	75	85	75	80	75	75
D	Industrial- eg. plastics, manufacturing, construction material	60	70	80	70	0	70	65	0
E	Facilities for vulnerable citizens	60	75	0	75	80	75	70	65
F	Plaza	0	0	70	0	70	0	0	60

Economic Development	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
Agriculture and Small business	100	90	75	80	100	100	100	90
Family initiated small service enterprises	90	85	80	85	80	80	90	100
Leisure/Tourism	85	100	75	100	80	70	80	85
Industrial- eg. plastics, manufacturing, construction material	60	0	100	0	0	75	0	0
Facilities for vulnerable citizens	80	70	60	90	75	0	75	70
Plaza	0	65	0	60	60	65	60	65

	Cost of development	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
A	Agriculture and Small business	100	100	80	100	100	100	85	100
B	Family initiated small service enterprises	85	90	85	90	85	85	100	85
C	Leisure/Tourism	80	80	75	85	80	70	80	75
D	Industrial- eg. plastics, manufacturing, construction material	0	60	100	80	75	65	75	0
E	Facilities for vulnerable citizens	70	65	0	75	0	60	70	80
F	Plaza	50	0	75	0	70	0	0	60

Accessibility	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
Agriculture and Small business	90	100	75	80	100	85	85	80
Family initiated small service enterprises	100	90	100	75	90	100	100	100
Leisure/Tourism	65	80	70	70	85	80	80	75
Industrial- eg. plastics, manufacturing, construction material	50	60	85	65	0	0	0	0
Facilities for vulnerable citizens	0	85	0	100	80	90	65	85
Plaza	70	0	80	0	65	60	60	70

w jk	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
Environmental Integrity	0.216	0.186	0.189	0.186	0.185	0.180	0.176	0.180
Economic Development	0.270	0.209	0.222	0.233	0.217	0.225	0.212	0.202
Accessibility	0.216	0.198	0.200	0.198	0.196	0.202	0.235	0.225
Physical	0.189	0.174	0.189	0.174	0.196	0.191	0.188	0.191
Cost of development	0.108	0.233	0.200	0.209	0.207	0.202	0.188	0.202

Range of costs (US$m)	175	TT$75m-TT$250m	1.75

Performance (CE)	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
Max_Performance	1583.75	1554.75	1467.67	1451.23	1588.84	1569.64	1513.0551	1525.99
A	1583.75	1554.75	1276.11	1451.23	1588.84	1569.64	1412.1213	1422.317
B	1347.5	1424.88	1467.67	1418.29	1374.18	1407.77	1513.0551	1525.99
C	1179.06	1422.99	1274.32	1384.41	1354.82	1211.33	1336.8971	1319.554
D	621.25	615.501	1386.73	676.675	250.73	905.772	426.58824	0
E	848.75	719.967	414.58	869.608	741.634	469.256	704.63235	742.0787
F	490	400.923	715.847	421.628	1052.19	432.879	577.03676	1023.996
F								

Regret	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
A	0	0	191.552	0	0	0	100.93382	103.6728
B	236.25	129.876	0	32.9397	214.66	161.875	0	0
C	404.688	131.759	193.351	66.8205	234.015	358.308	176.15809	206.4361
D	962.5	939.251	80.9375	774.553	1338.11	663.869	1086.4669	1525.99
E	735	834.786	1053.09	581.621	847.204	1100.39	808.42279	783.9115
F	1093.75	1153.83	751.819	1029.6	536.651	1136.76	936.01838	501.9944

Case Study 2 - Agricultural Commodities for National Development: Robust options with flexible elements

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Technical Feasibility	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	95	95	95	65	100	100	100	100	35	30	80	80
B-Durian	40	40	60	60	75	50	60	60	30	40	70	70
C-Pomegranate	0	0	50	30	70	45	45	45	70	70	60	60
D-Asian Vegetables	60	65	0	0	0	0	0	0	100	100	0	0
E-Citrus (tangerines, limes, mandarins)	100	100	100	95	65	80	65	65	0	25	100	100
F-Mangoes	90	90	90	100	60	85	75	75	40	0	95	95
G-Sapodilla	75	75	70	75	45	75	70	70	65	35	65	65
Availability of inputs	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	95	95	100	100	100	100	100	100	100	30	70	70
B-Durian	40	65	50	65	70	60	60	60	60	35	65	65
C-Pomegranate	0	60	40	40	45	45	45	45	45	70	45	45
D-Asian Vegetables	60	0	0	0	0	0	0	0	0	100	0	0
E-Citrus (tangerines, limes, mandarins)	100	100	70	70	65	75	65	65	65	40	100	100
F-Mangoes	90	90	75	75	75	95	75	75	75	0	90	90
G-Sapodilla	75	75	65	80	50	65	70	70	70	25	60	60
Susceptibility to damage/loss	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	85	90	0	100	0	0	0	0	100	50	60	60
B-Durian	0	45	35	65	30	30	35	35	75	0	30	30
C-Pomegranate	40	30	70	40	65	75	70	70	35	75	70	70
D-Asian Vegetables	90	0	100	0	100	100	100	100	0	100	0	0
E-Citrus (tangerines, limes, mandarins)	100	100	20	85	45	45	60	60	30	70	100	100
F-Mangoes	95	95	10	75	25	35	30	30	40	60	95	95
G-Sapodilla	45	40	40	70	35	65	45	45	60	55	65	65

Potential for food and nutrition/security	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	70	100	95	80	70	80	80	80	70	70	70	75
B-Durian	0	35	0	45	0	0	0	0	60	0	60	0
C-Pomegranate	20	30	35	55	30	65	35	35	65	40	40	65
D-Asian Vegetables	80	70	85	0	100	75	100	100	0	100	0	100
E-Citrus (tangerines, limes, mandarins)	100	80	100	100	75	100	85	85	100	90	100	90
F-Mangoes	60	60	90	85	65	70	65	65	90	80	90	80
G-Sapodilla	30	0	70	65	45	30	45	45	45	35	65	55
Size of market	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	100	100	100	100	100	100	80	80	100	80	65	80
B-Durian	40	35	65	70	70	60	65	65	80	70	60	70
C-Pomegranate	50	30	60	65	45	45	45	45	40	60	40	65
D-Asian Vegetables	0	0	0	0	0	0	0	0	0	0	0	0
E-Citrus (tangerines, limes, mandarins)	95	95	95	90	85	80	100	100	75	100	100	100
F-Mangoes	90	90	90	95	80	90	85	85	70	90	70	90
G-Sapodilla	65	65	70	85	65	65	60	60	45	50	55	60

Sustainability of production	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	100	100	100	70	100	100	90	90	100	100	65	65
B-Durian	40	65	65	65	80	65	100	100	80	75	60	60
C-Pomegranate	50	60	55	40	45	45	40	40	45	60	40	40
D-Asian Vegetables	0	0	0	0	0	0	0	0	0	0	0	0
E-Citrus (tangerines, limes, mandarins)	95	95	95	100	75	70	50	50	65	90	100	100
F-Mangoes	90	90	90	95	70	90	75	75	60	80	70	70
G-Sapodilla	55	75	60	75	35	50	35	35	50	40	55	55
Support infrastructure	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	0	0	80	100	100	100	100	100	100	90	60	60
B-Durian	60	35	0	65	70	55	70	70	85	100	100	100
C-Pomegranate	40	65	30	40	65	25	60	60	45	55	40	40
D-Asian Vegetables	100	100	70	0	0	0	0	0	0	0	0	0
E-Citrus (tangerines, limes, mandarins)	20	20	100	30	45	30	30	30	25	70	70	70
F-Mangoes	30	25	65	45	40	40	45	45	35	65	65	65
G-Sapodilla	45	15	75	55	35	45	55	55	50	50	55	55
Opportunity cost of production	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	70	85	0	70	50	30	0	0	40	40	60	60
B-Durian	0	55	80	65	70	35	40	40	60	35	0	0
C-Pomegranate	40	60	100	45	75	55	75	75	45	65	55	55
D-Asian Vegetables	45	75	50	0	0	100	100	100	100	100	100	100
E-Citrus (tangerines, limes, mandarins)	100	100	40	100	100	65	70	70	70	80	70	70
F-Mangoes	60	80	70	90	95	60	65	65	65	70	65	65
G-Sapodilla	35	0	60	60	65	0	60	60	0	0	35	35

Local Development	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	95	85	60	40	35	0	30	30	30	55	55	55
B-Durian	40	0	45	0	50	30	0	0	35	0	0	0
C-Pomegranate	45	15	65	65	60	35	60	60	60	65	65	65
D-Asian Vegetables	0	60	100	90	70	75	100	100	100	100	100	100
E-Citrus (tangerines, limes, mandarins)	100	100	80	100	100	100	75	75	70	70	70	70
F-Mangoes	65	80	75	75	65	65	70	70	65	60	60	60
G-Sapodilla	35	75	0	70	0	20	20	20	0	30	30	30

Opportunity cost of production	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	70	85	0	70	50	30	0	0	40	40	60	60
B-Durian	0	55	80	65	70	35	40	40	60	35	0	0
C-Pomegranate	40	60	100	45	75	55	75	75	45	65	55	55
D-Asian Vegetables	45	75	50	0	0	100	100	100	100	100	100	100
E-Citrus (tangerines, limes, mandarins)	100	100	40	100	100	65	70	70	70	80	70	70
F-Mangoes	60	80	70	90	95	60	65	65	65	70	65	65
G-Sapodilla	35	0	60	60	65	0	60	60	0	0	35	35
Local Development	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	95	85	60	40	35	0	30	30	30	55	55	55
B-Durian	40	0	45	0	50	30	0	0	35	0	0	0
C-Pomegranate	45	15	65	65	60	35	60	60	60	65	65	65
D-Asian Vegetables	0	60	100	90	70	75	100	100	100	100	100	100
E-Citrus (tangerines, limes, mandarins)	100	100	80	100	100	100	75	75	70	70	70	70
F-Mangoes	65	80	75	75	65	65	70	70	65	60	60	60
G-Sapodilla	35	75	0	70	0	20	20	20	0	30	30	30

w jk	**BBBBB**	**WBBBB**	**BWBBB**	**BBWBB**	**BBBWB**	**BBBBW**	**WWWWW**	**BWWWW**	**WBWWW**	**WWBWW**	**WWWBW**	**WWWWB**
Technical Feasibility	0.172	0.213	0.171	0.152	0.150	0.168	0.146	0.165	0.146	0.136	0.142	0.153
Availability of inputs	0.146	0.149	0.128	0.190	0.142	0.150	0.138	0.157	0.139	0.129	0.135	0.137
Susceptibility to damage/loss	0.137	0.128	0.137	0.143	0.157	0.075	0.163	0.148	0.131	0.143	0.128	0.145
Potential for food and nutrition/security	0.129	0.064	0.085	0.095	0.126	0.065	0.065	0.070	0.088	0.100	0.092	0.099
Size of market	0.120	0.191	0.154	0.133	0.079	0.056	0.098	0.052	0.124	0.121	0.099	0.107
Sustainability of production	0.086	0.053	0.068	0.086	0.071	0.140	0.057	0.061	0.095	0.114	0.106	0.115
Support infrastructure	0.082	0.138	0.162	0.076	0.110	0.187	0.154	0.174	0.117	0.107	0.121	0.046
Opportunity cost of production	0.069	0.043	0.051	0.067	0.102	0.121	0.130	0.130	0.102	0.093	0.113	0.130
Local Development	0.060	0.021	0.043	0.057	0.063	0.037	0.049	0.043	0.058	0.057	0.064	0.069

Range of costs (TT$m)/acre	3200	TT$13000-TT$9800	32

Performance (CE)	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
Max_Performance	43088.00	40313.83	37391.73	39532.95	33235.59	36832.52	29747.22	30822.96	36222.60	32131.63	42472.17	42759.27
A-Coconut	38200.00	38304.34	34960.07	39532.95	33235.59	36832.52	29614.50	30822.96	36222.60	27850.74	30696.40	31846.93
B-Durian	13184.00	20293.36	19552.92	27650.86	25688.72	22273.87	23699.19	23948.63	29584.06	19105.74	24461.19	20008.92
C-Pomegranate	12636.00	16547.28	24256.79	20988.00	26221.23	21293.12	25689.92	25591.17	23013.61	29383.20	23617.70	26542.08
D-Asian Vegetables	24720.00	17068.26	18257.37	2398.63	15277.35	12749.72	18959.35	18250.43	14298.39	30649.14	8269.50	13885.19
E-Citrus (tangerines, limes, mandarins)	43088.00	40313.83	37391.73	39510.74	32170.58	30839.07	29747.22	28714.02	23949.81	32131.63	42472.17	42759.27
F-Mangoes	36532.00	36890.26	33305.74	38644.57	28553.23	32909.53	28837.17	28653.18	27183.97	24969.06	37063.91	38130.87
G-Sapodilla	25448.00	24411.57	28860.99	33958.36	20106.61	22840.52	25784.72	26037.29	22009.31	17273.46	25850.47	25598.60

Regret	BBBBB	WBBBB	BWBBB	BBWBB	BBBWB	BBBBW	WWWWW	BWWWW	WBWWW	WWBWW	WWWBW	WWWWB
A-Coconut	4888.00	2009.49	2431.66	0.00	0.00	0.00	132.72	0.00	0.00	4280.89	11775.77	10912.34
B-Durian	29904.00	20020.47	17838.80	11882.10	7546.87	14558.65	6048.03	6874.33	6638.54	13025.89	18010.98	22750.35
C-Pomegranate	30452.00	23766.55	13134.94	18544.95	7014.36	15539.40	4057.30	5231.79	13208.99	2748.43	18854.47	16217.19
D-Asian Vegetables	18368.00	23245.57	19134.36	37134.32	17958.24	24082.80	10787.87	12572.52	21924.20	1482.49	34202.67	28874.08
E-Citrus (tangerines, limes, mandarins)	0.00	0.00	0.00	22.21	1065.01	5993.46	0.00	2108.94	12272.79	0.00	0.00	0.00
F-Mangoes	6556.00	3423.57	4085.98	888.38	4682.36	3922.99	910.05	2169.77	9038.63	7162.57	5408.26	4628.40
G-Sapodilla	17640.00	15902.26	8530.74	5574.59	13128.98	13992.00	3962.50	4785.67	14213.28	14858.17	16621.70	17160.67

Case Study 3 - To Divest or Not in the Port Services: Stakeholder Management

v ijk								
Profit	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
A-Divest Port	100	100	0	100	0	0	100	0
B-Keep Port	40	55	100	40	100	100	65	100
C-Shut down Port	0	0	0	0	0	0	0	0
Employment	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
A-Divest Port	100	100	0	100	0	0	100	0
B-Keep Port	40	60	100	65	100	100	50	100
C-Shut down Port	0	0	0	0	0	0	0	0
Availability of service	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
A-Divest Port	100	100	0	100	0	0	100	0
B-Keep Port	80	50	100	80	100	100	70	100
C-Shut down Port	0	0	0	0	0	0	0	0

w jk	BBB	WBB	BWB	BBW	WWW	BWW	WBW	WWB
Profit	0.400	0.417	0.370	0.370	0.370	0.364	0.364	0.364
Employment	0.280	0.250	0.333	0.296	0.296	0.327	0.327	0.327
Availability of Service	0.320	0.333	0.296	0.333	0.333	0.309	0.309	0.309
Range of costs (US$m)	2970	TT$30m-TT$3bn		29.7				

Performance (CE)	**BBB**	**WBB**	**BWB**	**BBW**	**WWW**	**BWW**	**WBW**	**WWB**
Max_Performance	7425	7425	7425	7425	7425	7425	7425	7425
A-Divest Port	7425	7425	0	7425	0	0	7425	0
B-Keep Port	3920.4	4052.813	7425	4510	7425	7425	4576.5	7425
C-Shut down Port	0	0	0	0	0	0	0	0

Regret	**BBB**	**WBB**	**BWB**	**BBW**	**WWW**	**BWW**	**WBW**	**WWB**
A-Divest Port	0	0	7425	0	7425	7425	0	7425
B-Keep Port	3504.6	3372.188	0	2915	0	0	2848.5	0
C-Shut down Port	7425	7425	7425	7425	7425	7425	7425	7425

Prelude to Paper 3

Paper 2 highlighted that a key benefit of the proposed method was that it provided a framework for thinking about re-designing options aligned to long-term objectives. It confirmed the finding from Paper 1 that a scenario snapshot was sufficient for the decision-maker to think about future implications for strategic options. This was perhaps because examining the uncertainty boundaries as proposed served to stimulate a narrative based on consequences for objectives, rather than one based on a series of plausible events that could lead to a hypothetical future. The combinatorial dependency between criteria, options and scenarios meant there was no clear answer to the number of scenarios appropriate for the assessment of strategic options.

Mixed perceptions to the scenario generation technique and to the regret operator suggest the need for systematic assessment of the role of scenario presentation in option evaluation; the role of the level of scenario detail (i.e. snapshot versus narrative) in assessing consequences and developing robust options; and the impact on choice for different decision rules for robustness relative to choice recommended by an ideal procedure.

Paper 3 aims to provide further evidential support to improve the sequence of steps in development of the method. Analysis is performed in two stages. First, a more consistent examination of whether the level of detail in a scenario makes a difference to the perceived quality of the process is carried out through a behavioural experiment. Next, the loss in utility across different scenario set/robustness measure configurations, relative to a normative ideal is assessed using a computer simulation. This multi-method research design also suggests a template for the type of in-depth comparison that might help bring structure to the emerging field of scenarios and MCDA.

SCENARIO PRESENTATION AND SCENARIO GENERATION IN MULTI-CRITERIA ASSESSMENTS: AN EXPLORATORY STUDY

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Abstract

The lack of systematic option evaluation procedures involving scenarios, as well as the lack of a structured approach to consider deep uncertainty within the multi-criteria framework has offered scope for synergy in combining scenarios and multi-criteria decision analysis for assessing robustness. This paper uses a multi-method research design to provide insights on the role of scenario presentation in the evaluation process, and the extent to which choice is affected by decision rules for robustness when different scenario generation techniques are used in multi-criteria assessments. It concludes that the threshold level for risk proneness of utility functions and the degree of exposure/vulnerability are key factors to consider in choosing robustness measures and scenarios. Moreover, the use of a few scenarios, expressed simply as snapshots, may improve the efficiency with which preferences are elicited in the evaluation process.

Keywords: deep uncertainty, robustness, simulation, scenario narrative

1.Introduction

Deep uncertainty exists when there is disagreement on how to model inter-relationships between variables in the external/controllable and internal/controllable environment; how to specify probability distributions to represent threats; and/or how to value various consequences (Courtney, 2001; Walker et al., 2001). Option evaluation procedures under deep uncertainty increasingly involve the combined use of scenarios, defined as challenging descriptions of futures that are relevant to a strategic decision and representative of plausible developments in the external world (van der Heijden, 1996), and quantitative models (Wilkinson et al., 2013; van Vliet et al., 2012). One example is the complementary use of scenario planning and multi-criteria decision analysis (MCDA) (Stewart et al., 2013; Durbach and Stewart, 2012; Montibeller and Franco, 2011; Ram et al., 2011; van der Pas et al., 2010; Wright and Goodwin, 2009; Montibeller et al., 2006; Stewart, 1997, 2005; Belton and Stewart, 2002; Goodwin and Wright, 2001; Phillips, 1986). MCDA provides a systematic framework that helps synthesise subjective and objective information to inform what options drive the realisation of value (Wallenius et al., 2008), which scenario planning lacks. Conversely, scenarios provide a context for exploring potential consequences and identifying new strategic options under deep uncertainty (Bodwell and Chermack, 2010; de Vries and Petersen, 2009; Roubelat, 2006; O'Brien, 2004; Harries, 2003).

In the context of deep uncertainty, the concept of robustness is appropriate (Aissi et al., 2009; Lempert and Collins, 2007; Hites et al., 2006; Vincke, 1999). Robustness does not focus on finding an answer to what will happen, but on narrowing option selection to those actions available today that give reasonable indication of performing well given that one cannot predict the future. Static robustness focuses selection on options that work acceptably well or reduce vulnerability in the largest possible range of conditions (Rosenhead, 2001). A decision maker subscribing to this view is likely to assess the advantages and disadvantages of available decision strategies based on a priori information about the decision problem. On the other hand, adaptive risk management, or learning what to do as relevant data become available, is a more dynamic approach to robustness. Underlying this approach is the belief that option selection depends as much on knowledge developed during the course of solving the problem as on information extracted from the initial problem definition (Payne et al., 1993).

Regardless of whether static or dynamic robustness is explored, there is significant variation in how scenarios are presented and the decision rules deemed appropriate for measuring option robustness. The impact of scenario presentation (i.e. the level of scenario detail) in an option evaluation process remains relatively unexplored due to a paucity of assessments on the relationship between scenarios and strategy. A good process would ensure that the proper problem was being analysed, that the most relevant information was used, would pursue an adequate search for alternatives, integrate evaluation with logic, and lead to a clear commitment to action (Howard, 1988).

In addition, multiple mechanisms exist for operationalising the robustness concept, with very little insight on implications for an integrated scenario-MCDA framework. For example, from the perspective of scenario planning, robustness assumes that the uncertainty space can be bounded, either in terms of representing plausible models that are different from the prevailing view, or capturing a representative sample of the uncertainty space (Schoemaker, 2002). Within the multi-attribute utility framework, maximisation of expected utility is widely seen as the most accurate basis for choice (Payne et al., 1993). Robustness is operationalised through various perspectives on a good outcome, or a choice that, despite all (knowable) uncertainties, performs almost as well as the choice recommended by some ideal procedure, as assessed in hindsight by the difference in rewards that they generate (Cox, 2012).

This variation in approaches imposes the need for coherence in how to sequence steps within hybrid methods such as scenarios and MCDA given the purpose of the intervention (Wilkinson et al., 2013; Kowalski et al., 2009; Vincke, 1999). This paper seeks to examine the unique role of scenario presentation in the option evaluation process, and the impact of different decision rules for robustness relative to the choice recommended by an expected utility maximiser. It applies a multi-method research design to develop preliminary insights on how scenario presentation affects various aspects of the option evaluation process; and the implications of the relative difference between various decision rules for robustness and the choice recommended by utility maximisation in the context of different scenario sets. Simulation is used to explore how different scenario sets are affected by different decision rules for robustness; and controlled experiment is used to investigate the role of scenario presentation in the option evaluation process under MCDA. Collectively, insights can provide a better understanding of how to improve the sequence of steps in a hybrid method. This investigation may further contribute to the scenario planning literature through a better understanding of the role of the level of scenario detail in option evaluation. Within the MCDA framework, it can provide initial insight on the inter-relationship between scenario presentation and decision rules.

The subsequent section will explore the role of robustness and scenarios in option evaluation within scenario planning and MCDA as separate disciplines and in integrated approaches to date, followed by details on study design, results and implications.

1.1 Perspectives on robustness and role of scenarios in option evaluation within scenario planning and MCDA

The option evaluation process under multi-attribute utility (MAUT) involves information acquisition; time taken to consider all available cues; time taken to retrieve cue values based on current non-existent futures that can exist in the future; proper weighting of cues; integration of information for each option; and comparison of all options (Shah and Oppenheimer, 2008). Within this framework, maximisation of expected utility is widely seen as the most accurate basis for choice (Scholz et al., 2012; Payne et al., 1993). A robust option is a choice that, despite all (knowable) uncertainties, performs almost as well as the choice recommended by some ideal procedure, as assessed in hindsight by the difference in rewards that they generate (Cox, 2012). Within this framework, diverse techniques also exist for attaining a robust solution. For example, robustness may be seen as an additional criterion in the analysis process; or the result of sensitivity analysis to ascertain how much the uncertainty in the output of a model is influenced by the uncertainty in its input factors (Saltelli et al., 1999).

Outside the expected utility paradigm, multiple decision rules also exist for operationalising robust performance, such as the minimax criterion; minimax regret; and various forms of satisficing such as risk discounting, and certainty equivalents (Rosenhead et al., 1972). If an option scores well according to several decision rules, it could be considered as more robust even though these rules can be expected to be inferior to the expected value rule as they do not take into consideration all the outcomes and probabilities of occurrence (Montibeller et al., 2006).

From the perspective of scenario planning, comparison of options is often based on robustness. A robust choice is one that performs well under a range of plausible outcomes (van der Heijden, 1996). Assessments of robustness within scenario planning often form part of a broader process of enhancing judgment and enabling the development of more and better strategic options, in keeping with the orientation to shared inquiry and mutual learning (Ramirez, 2008; Chermack and van der Merwe, 2003; Wack, 1985). This has resulted in a diversity of approaches to making a robust choice, and in the scenarios that define appropriate conditions for evaluation. Scenario planning typically assumes that the uncertainty space can be bounded, either in terms of plausible models that represent a cognitive shift from the prevailing view, or that capture a representative sample of the uncertainty space. Techniques for ascertaining option robustness range from congruence and resource analysis (Coyle, 2004); to examining the extremity of scenarios that may be required to meet a minimum required level of performance, similar to a back-casting scenario approach (Lafley et al., 2012; Courtney, 2001); to selecting no-regret moves that help an organisation build the capabilities it needs to succeed (O'Brien and Meadows, 2013; Schoemaker, 2002).

Within hybrid scenario-MCDA methods, there is agreement on the need to facilitate further discussion on trade-offs and development of more robust options (Stewart et al., 2013). However, multiple robustness measures have been applied. For example, inter-scenario risk and robustness measures have been proposed to assess spread of performances for each option on each scenario and stability of performance relative to the ideal (Montibeller et al., 2006). An alternative approach is to rank all option–scenario combinations from best to worst for each objective and compute the sum-of-ranks for each option (Wright et al., 2013). The avoidance of extreme negative outcomes has been captured by the regret criterion (Ram et al., 2011; Linares, 2002). Scenario-MCDA methods to date also employ a range of techniques for scenario generation; from extreme factors that could cause changes in levels of achievement of an organisation's key objectives (Wright et al., 2013; Ram et al., 2011) to use of the scenario-axes approach (Montibeller et al., 2006).

This diversity of approaches raises two open questions for positioning various scenario generation techniques and decision rules for coherent application of an integrated scenario-MCDA method. The first relates to developing a better understanding of the impact of scenario presentation, and the level of detail in which they are presented, in the option evaluation process under the multi-criteria decision analysis framework. The second relates to investigating the impact on choice for different decision rules for robustness relative to choice recommended by an expected utility maximiser.

1.2 Research design

In order to design an appropriate means for addressing these issues, it is instructive to examine the literature on measuring the effectiveness of decision support methods. Such assessments take the form of case studies based on real-world problems, controlled experiment or simulation (Harries, 2003). Case studies have been most popular to date in terms of assessing the overall effectiveness of scenario-MCDA methods (Ram and Montibeller, 2013; French et al., 2011; Montibeller et al., 2006).

However, in order to systematically assess the role of scenario presentation in option evaluation using MCDA, controlled experiment has advantages. Its ability to hold assumptions about the environment constant enables consistent measurement of decision making behaviour (Gliner et al., 2009; Harries, 2003). Typical behavioural measures include time taken to complete elicitation tasks, and subjective measures on one's confidence in choice, support for considering improvements in options, and sensitivity to a broader set of outcomes in the external environment (see Appendix 1 for a summary of key studies to date on the representation of uncertainty). These dimensions are consistent with criteria used in examining the cognitive impacts of scenarios, as well as criteria used to assess the quality of a decision analysis process (Wilkinson et al., 2013; Schilling et al., 2007; Bell et al., 2001; Payne et al., 1993).

On the other hand, simulation makes assumptions about decision making behaviour and how it interacts with the environment, which allows one to better examine the effect of different decision rules for robustness (Harries, 2003). This makes it amenable to understanding the factors that influence option robustness. In this type of analysis, the ideal procedure can be defined as optimal decision making with perfect information (expected utility maximiser). This provides the utility corresponding to the ‘true’ best option against which the utility corresponding to the best option implied by different scenario subsets can be compared for a given robustness measure. In so doing, one is able to compare the degree of error incurred by various assertions of what defines an acceptable range of futures. The simulation approach is also aligned with the investigative mode applied in other studies that aim to assess the impacts of simplified models (Durbach and Stewart, 2012; Durbach and Stewart, 2009; Butler et al., 1997; Stewart, 1996), and comparison of robust decision methods (Hall et al., 2012; McInerney et al., 2012). While the simulation approach cannot model the qualitative strengths of scenario planning, the focus of the analysis here conducted is limited to examining how scenario selections influence the robustness of minmax and maximax measures given multiple parameters that characterise the decision process.

Nonetheless, the multi-methodological approach adopted here should provide a starting point for better understanding of hybrid scenario-MCDA approaches through comparing and contrasting process effects through controlled experiment; and hypothetical outcome impacts through simulation. Each of these is detailed next, with the results from both studies being used to inform recommendations for sequencing of steps in scenario-MCDA methods.

2. Simulation Study: Understanding factors that influence robust performance under deep uncertainty

Mechanisms for operationalising robust performance are affected by various factors, including formalisation of the problem (i.e. number of options and criteria; and representation of uncertainty, which is here explored through scenarios) and decision maker attitude to risk. To develop a better understanding of how these factors impact choice for different decision rules for robustness relative to choice recommended by an ideal procedure, the simulation study will investigate the following questions:

i. *To what extent are decision rules for robustness affected by scenario generation techniques?*

   A small set of scenarios is widely advocated in scenario planning, and the criteria for appropriate range is based on subjective measures such as plausibility, differentiation, consistency, decision-making utility and challenge (Wilson, 1998). The alternative view is that analysing a well-crafted handful of scenarios will miss most of the future's richness and provides no systematic means to examine their implications (Goodwin and Wright, 2010). As such, a case can be made for a large set of scenarios (i.e. greater representation/coverage of the (knowable) uncertainty space). While the simulation approach cannot model the qualitative strengths of scenario planning, the focus of this analysis is limited to examining how scenario selections influence the robustness of minmax and maximax measures given multiple parameters that characterise the decision process.

ii. *To what extent does scenario generation based on extreme possibilities help a decision maker choose an action that is likely to serve him best as recommended under an ideal procedure?*

   The concept of extremes in scenario planning is linked to the notion that bounding the range of plausible outcomes can support decision making under deep uncertainty (Schoemaker, 2002). Behavioural studies show that the more extreme the consequence (i.e. greater variability), the more decision makers who expect to have their decisions scrutinised with hindsight (e.g. politicians, doctors, CEOs) are inclined to select conventional/bureaucratic solutions as a result of anticipated regret (Kahneman, 2011; Gilovich and Medvec, 1994). The minmax criterion has been used in the multi-attribute framework to reflect decision maker desire to minimise variability of outcomes across scenarios and/or avoid extreme negative outcomes (Montibeller et al., 2006). Moreover, in the presence of uncertainty on prices and yields, the behaviour of some economical agents (farmers) could sometimes be better predicted using a minmax regret criterion, rather than a classical profit maximisation criterion (Kazakci et al., 2007).

On the other hand, it has been shown that anticipation of regret can cause people to negotiate ineffectively, to overvalue the ability to change their minds and to purchase emotional insurance that they do not really need (Gilbert et al., 2004). Mixed feedback on the use of regret in a proposed scenario-MCDA method echoes this spectrum of findings (Ram and Montibeller, 2013) but further analysis on the nuances that exist can further inform appropriate use of these measures.

iii. *To what extent does risk attitude affect perceptions of robust choice relative to the choice recommended under an ideal procedure?*

Different risk attitudes may exist among stakeholders; or among decision makers over the course of the decision-making process, as is typical in political contexts. Risk attitudes of future generations who will be affected by the decision may simply be unknown (Cox, 2012). Differing risk attitudes and corresponding robustness measures further reflect features of the decision context itself. For instance, the minmax criterion is arguably more appropriate for non-repetitive decisions (e.g. construction of a high voltage line, highway or other capital infrastructure) and for decision environments where precautionary measures are needed (e.g. nuclear accidents, public health), or when the decision maker must reach a pre-defined goal under any variation of the input data (Aissi et al., 2009). The maximax rule may be more appropriate when profits or revenue are a key incentive, or when there are one or more future opportunities to modify or further define choice. Regret has been perceived as too risk-averse a measure in at least one case study involving a scenario-MCDA approach (Ram and Montibeller, 2013). Understanding the role of risk attitude may help avoid unnecessary mitigation of risk or potentially significant opportunities from being overlooked in scenario-MCDA methods.

iv. *How consistent are these insights across problem size (i.e. number of criteria, uncertainties, and options)?*

Understanding how problem size affects each of the above is important to identify the extent of insights garnered.

2.1 Modelling decision maker values and responses

The areas to be investigated through simulation involve the extent to which various scenario generation techniques capture an appropriate range within a decision analytic framework; the validity of extreme possibilities; and the impact of risk attitude. To this end, the simulation model has been designed to capture optimal decision making with perfect information, so that alternatives can be compared to the normative approach of maximisation of expected utility (Durbach and Stewart, 2009). To this end, a model must be constructed that describes:

(i) Criteria that define a successful option and the options available;

(ii) Scenarios which represent configurations of events in the external environment;

(iii) Perceived or anticipated impacts of these scenarios on option-criteria combinations;

(iv) Translation of these impacts to utilities for option-criteria combinations for each scenario considered;

(v) Synthesis of option utility per scenario into a measure of robustness, bearing in mind diverse preference types.

Figure 1 below provides an overview of the model elements that capture these stages in the scenario-MCDA process, with details subsequently provided.

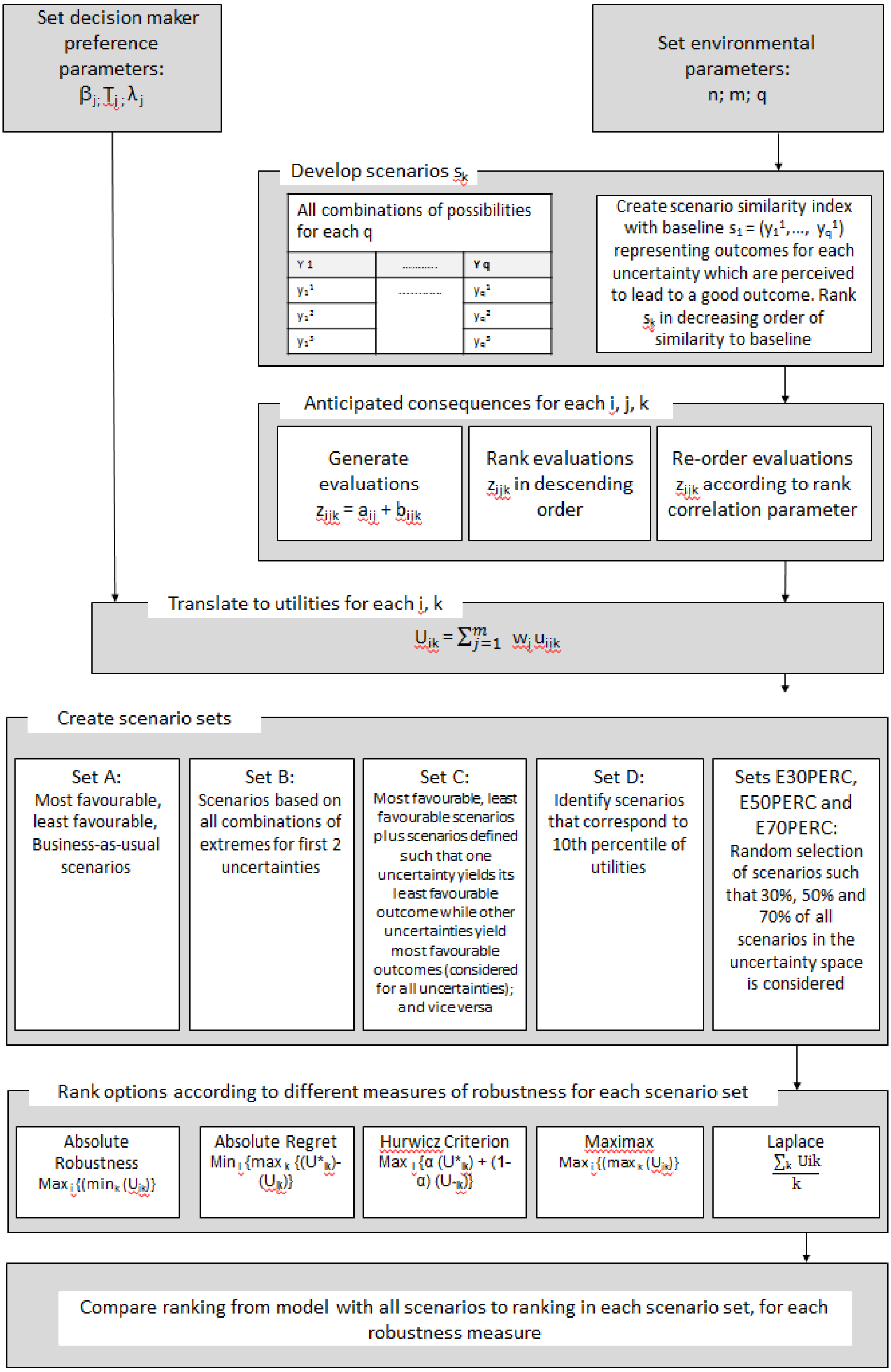


Figure 1: Outline of simulation model

Define criteria and option sets

The problem size is defined by three parameters: the number of uncertainties (i.e. factors in the external environment that drive change in the broader system (Schoemaker, 2002)) and their plausible outcomes; the number of options; and the number of criteria. The parameters for option and criteria numbers (Table 1) are considered reflective of the focus on a few salient options but several objectives as is typical under deep uncertainty (Cox, 2012). In reality, this may not be the complete set of options, but a simplifying assumption that the option set is well-defined is made here. It is also assumed that the option set remains constant from one scenario to another.

Case	**Number of options (i=1,2,..,n)**	**Number of criteria (j = 1,2,..,m)**
1	5 (Small)	9 (Small)
2	5 (Small)	19 (Large)
3	11 (Large)	9 (Small)
4	11 (Large)	19 (Large)

Table 1: Option and criteria combinations considered

Define scenarios

Scenario generation techniques reflect two approaches to bounding the uncertainty space: capturing the largest possible range of scenarios as advocated in the risk management literature; and choosing an option that is likely to serve one best in significant upside/downside, given that the largest possible range of scenarios will not guarantee knowledge of the future, as advocated in the scenario planning literature. The risk management literature advocates generation of several (i.e. thousands) scenarios based on the degree of vulnerability they expose a promising option to (Bryant and Lempert, 2010; Lempert et al., 2006). The underlying rationale for a large set is that an option that performs well for most scenarios is likely to also do so in reality, provided that reality is well-described by at least some scenarios in the uncertainty set, and this set is much more likely than the set of scenarios not considered (Cox, 2012). Estimates of likelihood can be based on subjective probability judgments elicited regarding willingness to bet on a particular scenario compared to other events with known probabilities (Hora, 2007).

Conversely, the scenario planning literature calls for generation of a few (i.e. 4-6) scenarios, with an emphasis on extreme yet plausible and consistent outcomes (Wilson, 1998). The underlying rationale for this approach is to help a decision maker explore options within a broader frame of reference and address confirmation and overconfidence biases (Schoemaker, 1993). A popular technique is the 2x2 matrix (van der Heijden, 1996; Ringland, 1998; Schoemaker, 2002). Others include Field Anomaly Relaxation (FAR) (Coyle, 2004) and a technique that focuses on the selection of extremes is that suggested by Ram et al. (2011), which derive from morphological analysis (Ritchey, 2006). Finally, the incremental method of scenario development uses the business-as-usual scenario as a starting point for exploring a broader set defined by best and worst case possibilities (van der Heijden, 1996).

In the simulation model, a maximum of seven has been chosen for the number of uncertainties, as this already provides a large number of scenario states to consider. All uncertainties are assumed to be equally relevant in terms of the extent to which they impact the decision. For each uncertainty, three plausible possibilities are assumed: best-case, intermediate and worst-case (labelled 1, 2 and 3 respectively). In reality, many additional possibilities will exist, but the purpose here is not to cover all possibilities, but to describe a wide range, through a characterisation that has been used in scenario planning (Schoemaker, 2004).

Scenarios are therefore defined by all possible combinations of uncertainty outcomes, as in morphological analysis. Each uncertainty y_a, a = 1…q, (q= 5, 7) has three levels, b = 1,..,3 with y_a^1 and y_a^3 representing plausible extreme outcomes for y_a. The set of scenarios is the set product S: $y_1 \times y_2 \times \ldots \times y_q$ of all levels of all *q* uncertainties. A scenario S_k is a vector $S_k = (y_1^b, \ldots, y_q^b)$, specifying one level b for each uncertainty. This results in 3^q scenarios. The scenarios in S are assumed mutually exclusive and collectively exhaustive, and that they meet basic scenario criteria of being internally consistent and plausible.

Various scenario sets were used, resulting in different numbers of scenarios. They are described later in the paper, but either reflect configurations of extreme possibilities or large samples that represent coverage of the uncertainty space.

Perceived or anticipated impacts of scenarios on option-criteria combinations

Outcomes for the performance of alternative i on criterion j when scenario k occurs must next be generated. The evaluations are generated according to the process $z_{ijk} = a_{ij} + b_{ijk}$ with a_{ij} being normally distributed with mean 0 and variance 1. The a_{ij} for each option i are standardised to ensure that the resulting options are non-dominated in the sense that no option will have a smaller criterion value than another option on every criterion (Durbach and Stewart, 2009). It is assumed that larger values for z_{ijk} are preferred, all other things being equal.

Uncertainty is introduced via the b_{ijk}, which cause the z_{ijk} to differ over scenarios. This captures the difficulty in detecting accurately the particular element of a scenario configuration that may trigger a highly impactful outcome. For a particular scenario k*, the resulting b_{ijk*} is modelled as a realisation of a random variable B_{ij} following a gamma distribution with shape parameter ε_{ij} and scale parameter ω_{ij} , so that the expectation, variance, and skewness of B_{ij} are given by the quantities $\varepsilon_{ij}\ \omega_{ij}$, $\varepsilon_{ij}\omega^2_{ij}$, and $2/\sqrt{\varepsilon_{ij}}$ respectively. With the desired variance and coefficient of skewness specified, one can easily solve for the two unknown parameters ε_{ij} and ω_{ij}. Two possibilities for skewness are assumed:

Case	**$2/\sqrt{\varepsilon_{ij}}$**	**Description**
1	U(0,1)	Small positive skewness
2	U(0,3)	Large positive skewness

Table 2: Skewness parameters considered in simulation

Moderate and high variability ($\sqrt{(\varepsilon_{ij}\omega^2_{ij})}$) are modelled by U(0.3,0.4) and U(0.5,0.6) respectively. This is intended to capture the variability in impacts, which can be expected to be higher as the level of environmental uncertainty increases (Ramirez, 2008). In so doing, this parameter aligns with the philosophy that examining assumptions and considering what major shifts in the business environment might occur implies consideration of a broad range of possible outcomes (Huss and Honton, 1987; Toffler, 1985).

Translation of impacts to utilities for option-criteria combinations for each scenario considered

In order to relate impacts to utilities for each scenario, the concept of a relatively favourable scenario is introduced. Scenarios cannot be ordered, but a favourable scenario can be defined as one whose configuration implies positive impacts, underpinned by the decision maker's mental model. These consequences may or may not materialise in reality, but represent perceptions basedon available information at the time of option evaluation. Other scenario configurations that lie in the neighbourhood of a favourable scenario may attain similar outcomes. The model contains two mechanisms to capture these concepts.

The first involves using $S_1 = (y_1^1, \ldots, y_q^1)$ as a reference point, which denotes a hypothetical most favourable scenario. Similarity is defined as the sum of the number of common uncertainty outcomes in a scenario-pair (S_1, S_k) divided by the sum of the sizes in each set:

$$\mathrm{Sim}(S_1, S_k) = \frac{2|S_1 \cap S_k|}{|S_1| + |S_k|}$$

A value of 0 indicates no similarity, whereas a value of 1 indicates complete overlap of the outcomes characterising the scenarios (Alspaugh et al., 1999). For instance, if one assumes that $S_1 = (y_1^1, y_2^1, y_3^1, y_4^1, y_5^1)$ and $S_2 = (y_1^1, y_2^1, y_3^2, y_4^1, y_5^1)$, the similarity between these two scenarios is $\mathrm{Sim}(S_1, S_2) = 8/10 = 0.8$.

Scenarios are then ordered in terms of similarity to s_1 and evaluations z_{ijk} sorted in descending order such that z_{ij1} denotes the most favourable consequence. There is of course no guarantee that the most favourable scenario (s_1) will always attain the highest level of performance across each option i and criterion j; or that scenarios similar to s_1 will yield similar outcomes. In order to capture the uncertainty in performance of option-criteria combinations even due to small deviations from a given scenario, a correlation parameter is introduced.

The correlation parameter is used to derive a second rank order that is correlated to the rank order of the sorted z_{ijk}. If the correlation is 1, the highest z_{ijk} is assigned to scenario s_1, the 2nd highest z_{ijk} to scenario s_2, and so on. For correlations less than one, the highest z_{ijk} will be assigned to a favourable scenario, but not necessarily s_1. Values of 0.1 and 0.9 are used as correlation parameters. An illustrative example is provided in Table 3.

Index	Original z_{ijk}	Sorted z_{ijk}	Rank of sorted z_{ijk}	Rank generated by correlation parameter	Rationale for new z_{ijk}	New z_{ijk}
z_{111}	3	6	1	3	1st ranked z_{ijk} (6) assigned to 3rd most favourable scenario (s_3)	4
z_{112}	4	4	2	1	2nd ranked z_{ijk} (4) assigned to most favourable scenario (s_1)	3
z_{113}	2	3	3	2	3rd ranked z_{ijk} (3) assigned to 2nd most favourable scenario (s_2)	6
z_{114}	6	2	4	5	4th ranked z_{ijk} (2) assigned to 5th most favourable scenario (s_5)	1
z_{115}	1	1	5	4	5th ranked z_{ijk} (1) assigned to 4th most favourable scenario (s_4)	2

Table 3: Correspondence between scenario and evaluation ranking (Assuming that i=1, j =1, and the scenario index represents scenarios ordered by similarity to the most favourable scenario)

The utility functions used in constructing the idealised preference structure are based on risk proneness for losses and risk aversion for gains relative to a reference level (Durbach and Stewart, 2009). It satisfies the assumptions of completeness, transitivity and additive independence.

$$u_j(s) = \begin{cases} \dfrac{\lambda_j\,(e^{\alpha_j s} - 1)}{(e^{\alpha_j \tau_j} - 1)} & \text{for } 0 \le s \le \tau_j \\[2ex] \lambda_j + \left(\dfrac{(1-\lambda_j)\,(1 - e^{-\beta_j (s - \tau_j)})}{(1 - e^{-\beta_j (1-\tau_j)})} \right) & \text{for } \tau_j \le s \le 1 \end{cases}$$

This function simulates diverse preference types. Each marginal utility function is concave above some threshold or reference level τ_j and convex below it (modelling perceptions of gain or loss). The value of the utility function at the reference level is λ_j, and indicates the strength of preference for avoiding outcomes below the threshold τ_j (Stewart, 1996). A high value of τ_j indicates that there is little to be gained in seeking improved trade-offs above the threshold level, relative to the potential (and usually quite sharp) loss due to dropping below the threshold. Parameters α_j and β_j indicate the degree of curvature below and above the reference level respectively. β_j will be generated by U(1,4) and U(2,8) for low and high respectively, whereas α_j will be generated by β_j + [1,4] and β_j + [2,8].

Case	τ_j	λ_j	**Description**
1	0.15-0.4 (Low)	0.6-0.9 (High)	Moderately risk seeking/ strong risk-averse.
2	0.6-0.9 (High)	0.15-0.4 (Low)	Moderately risk-averse/strong risk seeking

Table 4: Parameter combinations for τ_j and λ_j, modelled by a uniform distribution

Synthesis of option utility per scenario into a measure of robustness

To generate weights for m criteria, m-1 random numbers are independently drawn from a uniform distribution on (0,1). These are then sorted in descending order (i.e. $1 > r_{(j-1)} \geq \ldots \geq r_{(2)} \geq r_{(1)} \geq 0$). The criteria should have a minimum normalised value of 0.01, so the formula $Pr(h) = 0.01 + (1 - 0.01m)(r_{j-1} - r_j)$ for $j = 1, \ldots, m$, where $r_0 = 1$ and $r_m = 0$ is used. This will result in a set of numbers ($h_1, h_2, \ldots, h_m$) that will sum to one and be uniformly distributed (Durbach and Stewart, 2009; Butler et al., 1997). These are held constant across simulations. From a practical perspective, this reflects lack of knowledge about the relative importance of criteria.

The idealised outcome is modelled as $U_{ik} = \sum_{j=1}^{m} w_j u_{ijk}$ for the set of all scenarios. A similar calculation was used for all scenario sets considered following selection of scenarios as explained in Table 5.

Set	Description	Selection Rationale	Steps in scenario selection
A	Most favourable, least favourable, Business-as-usual scenarios	Corresponds to the incremental method of scenario development and used in practical interventions involving scenarios and MCDA (Phillips, 1986; Montibeller et al., 2006)	Assuming 5 uncertainties, select scenario-similarity indices corresponding to combinations: $(y_1^1, y_2^1, y_3^1, y_4^1, y_5^1)$; $(y_1^3, y_2^3, y_3^3, y_4^3, y_5^3)$; To select the business-as-usual scenario, probabilities were generated using a similar process for k scenarios as that for generating weights for m criteria. The scenario corresponding to the maximum of the generated numbers for k scenarios is assumed to represent a view of the future that has maximum similarity to the status quo. It can be viewed as the likelihood of a particular configuration of uncertainties occuring; as the evaluation distributions contain mechanisms to capture the likelihood of consequences. This procedure is only used to select the scenario.
B	Scenarios based on all combinations of extremes for first 2 uncertainties	Based on using a 2x2 matrix (extremes on two most critical uncertainties) to define boundaries of the uncertainty space (Schoemaker, 2002). Typically, four scenarios result, but here all possible combinations involving the extremes on the first two uncertainties are considered here since all scenarios in the set are plausible.	Assuming 5 uncertainties, select scenario-similarity indices corresponding to combinations: $(y_1^1, y_2^1, y_3^b, y_4^b, y_5^b)$ $(y_1^3, y_2^1, y_3^b, y_4^b, y_5^b)$ $(y_1^1, y_2^3, y_3^b, y_4^b, y_5^b)$ $(y_1^1, y_2^3, y_3^b, y_4^b, y_5^b)$; for b=1,2,3
C	Most favourable, least favourable scenarios plus scenarios defined such that one uncertainty yields its least favourable outcome while other uncertainties yield most favourable outcomes (considered for all uncertainties); and vice versa	Based on the pattern identified among scenarios that are least similar to business-as-usual levels of uncertainties (Ram et al., 2011)	Assuming 5 uncertainties, select scenario-similarity indices corresponding to: $(y_1^1, y_2^1, y_3^1, y_4^1, y_5^1)$ $(y_1^3, y_2^3, y_3^3, y_4^3, y_5^3)$ $(y_1^3, y_2^1, y_3^1, y_4^1, y_5^1)$ $(y_1^1, y_2^3, y_3^3, y_4^3, y_5^3)$ $(y_1^1, y_2^3, y_3^1, y_4^1, y_5^1)$ $(y_1^3, y_2^1, y_3^3, y_4^3, y_5^3)$ $(y_1^1, y_2^1, y_3^3, y_4^1, y_5^1)$ $(y_1^3, y_2^3, y_3^1, y_4^3, y_5^3)$ $(y_1^1, y_2^1, y_3^1, y_4^3, y_5^1)$ $(y_1^3, y_2^3, y_3^3, y_4^1, y_5^3)$ $(y_1^1, y_2^1, y_3^1, y_4^1, y_5^3)$ $(y_1^3, y_2^3, y_3^3, y_4^3, y_5^1)$
D	Identify scenarios that correspond to the lowest 10% of evaluations/impacts	Scenarios considered should be those that lead to greatest vulnerability for promising options (Lempert et al., 2006).	Sort impacts by scenario in descending order, and take those which correspond to the lowest 10%.
E30PERC	Coverage leads to higher accuracy than a small set of scenarios defined by extremes (Durbach and Stewart, 2012).		Random selection of scenarios such that 30% of all scenarios in the uncertainty space is considered
E50PERC			Random selection of scenarios such that 50% of all scenarios in the uncertainty space is considered
E70PERC			Random selection of scenarios such that 70% of all scenarios in the uncertainty space is considered

Table 5: Steps on how each scenario set was created

Within MCDA, robustness measures can be classified into minmax or maximax strategies. Assuming U_{ik} is the utility of option i (i= 1,…,n) under scenario s_k (s=1,…,k), the classical minmax criteria for decisions under uncertainty are (Roy, 2010):

- *Absolute robustness*- Maximise the value of the solution in the worst case scenario:

  $Max_i \{(min_k (U_{ik})\}$
- *Absolute regret*- Minimise the distance from the optimal solution in a given scenario:

  $Min_i \{max_k \{(U^*_{ik}) - (U_{ik})\}$ where U^*_{ik} is the value of the optimal solution in scenario s_k
- *Hurwicz pessimistic criterion*- Maximise the weighted average between an optimistic and pessimistic decision, with weight being determined through a coefficient of realism, α. An α value close to 0 represents decision maker who is pessimistic about the future:

  $Max_i \{\alpha (U^*_{ik}) + (1-\alpha) (U_{*ik})\}$ where (U_{*ik}) is the value of the worst solution in scenario s_k

Each of these minmax measures assigns a determining role to the worst scenario. Maximax rules explicitly recognise good performance, and so represent a less conservative robustness criterion:

- *Maximax*- Maximise the value of the solution in the best case scenario:

  $Max_i \{(max_k (U_{ik})\}$
- *Laplace criterion*- Average performance over all scenarios: $\frac{\sum k \ Uik}{k}$
- *Hurwicz optimistic criterion*- An α value close to 1 represents an optimistic decision maker:

  $Max_i \{\alpha (U^*_{ik}) + (1-\alpha) (U_{*ik})\}$

Table 6 below provides a summary of how the concerns of deep uncertainty have been captured in the model.

	Challenge of deep uncertainty (Cox, 2012)	How this is reflected in the model
1	Incomplete set of options due to a premature focus on salient options	A simplifying assumption that the set of options is a complete one is made.
2	Uncertainty about the full range of consequences (i.e. failure to correctly envision and account for all the important consequences that an act might make more probable, or lack of confidence that all such important consequences have been identified)	It is assumed that the full set of scenarios is defined by all combinations of outcomes of knowable uncertainties. This allows one to capture the loss arising from failure to correctly account for all important consequences for a range of problem configurations. Uncertainty about consequences is reflected through a gamma distribution, and uncertainty about how scenario consequences are related to options captured through a correlation parameter.
3	Probabilities for scenarios may not be well known either because: i)the state itself is not well-known, making subjective probabilities unreliable ii)different stakeholders have conflicting beliefs about consequences of taking a particular action	The simulation does not explicitly assign probabilities to scenarios as probabilities are accounted for in the gamma distribution which implicitly models the probability of a particular consequence. The probability derived from the technique used to select the business-as-usual scenario for Set A can be viewed as the likelihood of a particular configuration of uncertainties occuring.
4	Uncertainty about values and preferences (e.g. arising from differences in willingness to take risks to achieve potential rewards, or because the preferences of future generations for consequences of current decisions are not well known)	Uncertainty is introduced by parameters that define the shape of the utility function (τ_j , λ_j ,α_j , β_j). The distributions used to estimate z_{ijk} capture uncertainty about consequences by assigning probabilities to them.

Table 6: Summary of how deep uncertainty is considered in the model structure

In order to assess impact, the loss in utility of the most robust option based on a given scenario selection is compared to the utility corresponding to the idealised outcome implied by a particular robustness measure. This provides observable model output to examine the extent to which utility is over/under-stated through different scenario generation techniques and robustness measures.

The measure is aligned to criteria used in other scenario and MCDA assessments using simulation (Durbach and Stewart, 2009) and to the concept of examining conditions influencing relative option performance (Kwakkel et al., 2012).

Utility loss in the simulation is calculated as:

Utility Loss = $(U_i^* - U_i^{sel}) / (U_i^* - U_{i*})$ where

U_i^* represents the 'true' best option (i.e. option ranked first in the idealised ranking)

U_{i*} represents the 'true' worst option (i.e. option ranked last in the idealised ranking)

U_i^{sel} represents the model best option (i.e. option ranked first in the simplified model based on different scenario selections).

2.2 Hypotheses

Four hypotheses are formulated to reflect the aims described earlier in terms of measurable statements:

H1: The degree of coverage of the (knowable) uncertainty space has an impact on utility loss regardless of the robustness measure used.

This hypothesis is intended to address the lack of clarity on the extent to which various scenario generation techniques capture an appropriate range within a decision analytic framework.

H2: Utility loss for robustness measures increases as variability ($\sqrt{(\varepsilon_{ij} \omega^2_{ij})}$) in impacts increases.

This hypothesis is intended to assess how the degree of loss for robustness measures changes relative to an ideal, as uncertainty about consequences increases.

H3a: The threshold level above which the utility function is concave (τ_j), and the strength of preference for avoiding outcomes below the threshold level (λ_j) influences robustness measures.

H3b: Minmax robustness measures have lower utility losses for risk-averse attitudes (low τ_j and high λ_j), and maximax measures have lower utility losses for risk prone attitudes (high τ_j and low λ_j), regardless of scenario selection.

These hypotheses arise from the claim that maximax and minmax measures reflect different risk attitudes (Roy, 2010).

H4: Problem size (i.e. number of uncertainties, criteria and options considered) does not affect the degree of utility loss of robustness measures.

The purpose of this hypothesis is to cross check that findings remain consistent across problem sizes.

	Desired insight for development and validation of scenario-MCDA methods	Translation into observable model outputs (i.e. hypotheses)	Specific model runs to be undertaken
H1	Extent to which robustness measures are affected by scenario selection	The degree of coverage of the (knowable) uncertainty space has an impact on utility loss regardless of robustness measure used.	Combinations considered for each of the two parameters for number of criteria (m), number of uncertainties (q), skewness ($2/\sqrt{\varepsilon_{ij}}$), variability ($\sqrt{(\varepsilon_{ij}\omega^2_{ij})}$), τ_j, λ_j , α_j, β_j resulting in 256 different cases for each of which 100 iterations were conducted based on n=11 options. Utility loss was calculated for each combination of robustness measure (6) and scenario set (7). The process is repeated for random scenarios corresponding to percentage of uncertainty space captured by selections in sets A, B, C, D.
H2	Extent to which robustness measures are affected by variability in consequences, and the role of scenarios based on extreme possibilities in minimising error relative to choice defined by an ideal decision procedure	Utility loss for robustness measures increases as variability ($\sqrt{(\varepsilon_{ij}\omega^2_{ij})}$) in impacts increases	
H3	Extent to which robustness measures are affected by risk attitude of the decision maker	The threshold level above which the utility function is concave (τ_j), and the strength of preference for avoiding outcomes below the threshold level (λ_j) influences robustness measures. Minmax robustness measures have lower utility losses for risk-averse attitudes (low τ_j and high λ_j), and maximax measures have lower utility losses for risk prone attitudes (high τ_j and low λ_j), regardless of scenario selection.	As above, with additional runs for τ_j,= λ_j = 0 and 1
H4	Extent to which robustness measures are affected by problem size	Problem size (i.e. number of uncertainties, criteria and options considered) does not affect the degree of utility loss of robustness measures.	As above, with utility loss calculated based on each of the problem size parameter values in turn.

Table 7: Summary of how hypotheses will be tested through simulation

2.3 Results of the Simulation

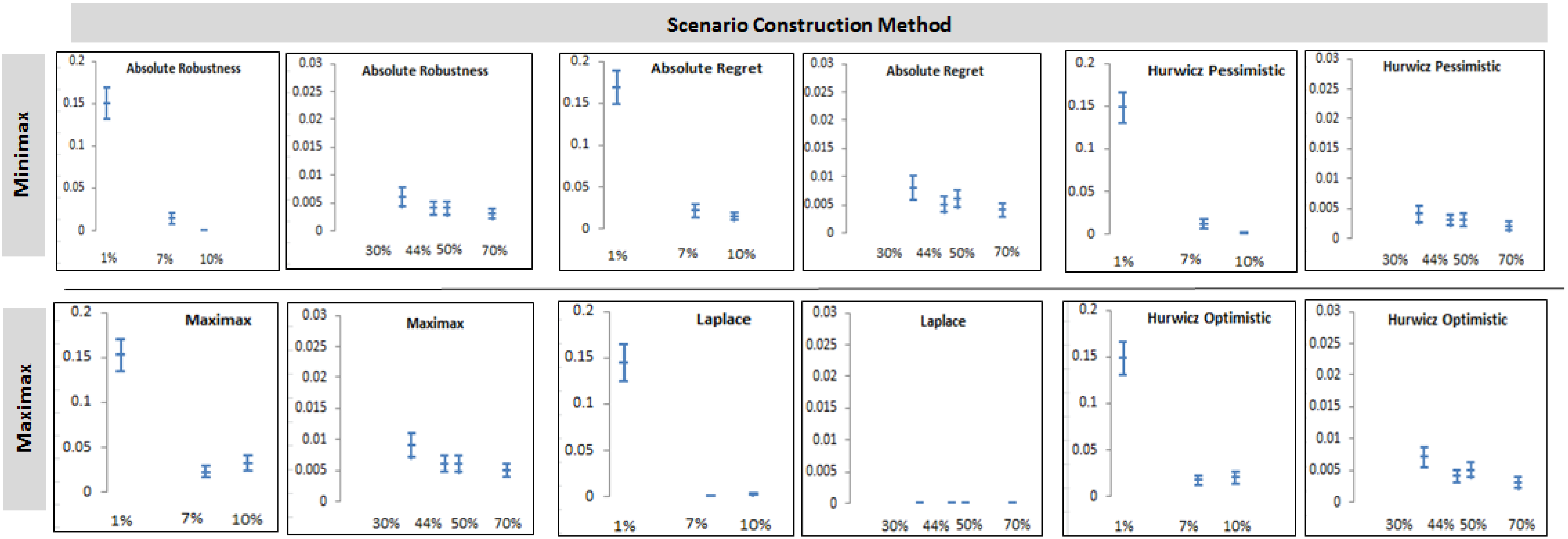
H1: The degree of coverage of the (knowable) uncertainty space has an impact on utility loss regardless of robustness measure used.

The mean utility loss and standard error were used to plot a confidence interval for each combination of scenario generation technique (expressed in terms of percentage of uncertainty space covered) and robustness measure following the simulation runs described in Table 7. Further analysis was conducted to examine whether scenario generation technique had any impact, and whether the same level of coverage through random selection had a similar impact on utility loss.

Figure 2 and Appendix 2 (which compares deliberate scenario selection in sets B, C and D to random scenario generation) confirm that coverage and scenario selection have different impacts on robustness measures. However, the relationship is not linear, as there is a not a consistent decrease in utility loss as coverage increases. The improvements in utility losses are negligible for coverage over 30% for all measures, even when random selection occurs. The largest drop in utility loss occurs when coverage increases from 1% to 7%.

The Laplace operator incurs the lowest average utility loss regardless of the degree of coverage. Laplace does not, however, mitigate the significant error from using a small scenario set such as set A. Higher utility loss for set A and D compared to the others under Laplace, especially when variability is high (Figure 3) hints at the importance of capturing the range of variability in a sufficient manner for this measure to be effective.

In order to assess whether deliberate scenario selection has positive impact, the utility loss in sets B, C and D is compared with random scenario generation (Appendix 2). Set B performs better than random selection for absolute regret, maximax and Hurwicz Optimistic operators. Set C consistently performs worse than any random selection, which raises doubts about its quality as a selection technique. Set D consistently incurs lower utility loss for minmax measures. The main difference of set D from C is that the former focuses on a set that captures highest vulnerability. The lesson for the proposed scenario methodology, which combines set C with regret (Ram et al., 2011), as well as other scenario-MCDA frameworks, is that the range of vulnerability must explicitly be considered, perhaps through scenario clusters (as in set D), particularly if minmax measures are used.



Set	Description	Coverage
A	Most favourable, least favourable, Business-as-usual scenarios	1%
B	Scenarios based on all combinations of extremes for first 2 uncertainties	44%
C	Most favourable, least favourable scenarios plus scenarios defined such that one uncertainty yields its least favourable outcome while other uncertainties yield most favourable outcomes (considered for all uncertainties); and vice versa	7%
D	Identify scenarios that correspond to 10th percentile of utilities	10%
E30	Random selection of scenarios such that 30% of all scenarios in the uncertainty space is considered	30%
E50	Random selection of scenarios such that 50% of all scenarios in the uncertainty space is considered	50%
E70	Random selection of scenarios such that 70% of all scenarios in the uncertainty space is considered	70%

Figure 2: Mean utility loss ± 1.96*standard error for different robustness measures across all configurations. The x-axis corresponds to coverage percentages as indicated in the table.

H2: Utility loss for robustness measures increases as variability ($\sqrt{(\varepsilon_{ij}\omega^{2}_{ij})}$) of impacts increases.

Following the simulation runs described in Table 7, the mean utility loss was captured by robustness measures and scenario generation techniques focussed on extremes (sets A, B, C,D) and coverage (sets E30PERC, E50PERC, E70PERC) for n=11. Analysis was also conducted for random selection of scenarios with the same coverage as techniques A, B, C, D to enable high-level analysis of the extent to which scenario sets based on extremes differed as variability increased. One-way ANOVA was then used to examine whether variability had a statistical impact on the utility loss derived from robustness measures.

Table 8 below shows that across the range of scenario sets considered, the difference in utility loss arising from variability is most significant for Hurwicz Optimistic, maximax and regret. However, these differences are very small (of the order of 0.01) (Figure 3). For the same reason of small differences, no scenario set necessarily results in differentiated improvement in utility loss, although higher coverage, even by random selection, alleviates this issue. Comparison of deliberate scenario generation techniques with random selection for high and low variability yields similar results as in H1, indicating that clusters of extreme possibilities appears more relevant when variability is high. The main implication for scenario-MCDA frameworks is that practical advantage is not attributed to any particular robustness measure when variability is high.

	Robustness Measure	**F-Statistic**	**Statistically significant impact on utility loss**
Minimax	Absolute Robustness	$F(1,1022)=3.23$, p=0.07	x
	Absolute Regret	$F(1,1022)=6.74$, p=0.01	√ (0.006)
	Hurwicz Pessimistic	$F(1,1022)=3.19$, p=0.07	x
Maximax	Maximax	$F(1,1022)=10.39$, p=0.001	√ (0.007)
	Laplace	$F(1,1022)=0.006$, p=0.937	x
	Hurwicz Optimistic	$F(1,1022)=7.13$, p=0.008	√ (0.005)

Table 8: One-way ANOVA results for the impact of variability on average utility loss

Minmax

Focus on Extremes

Variability U(0.3,0.4)	A	B	C	D
Abs Robust	0.142	0.004	0.016	0
Abs Regret	0.159	0.005	0.02	0.014
Hurwicz Pess	0.14	0.003	0.013	0.001

Variability U(0.5,0.6)	A	B	C	D
Abs Robust	0.149	0.005	0.025	0
Abs Regret	0.169	0.007	0.034	0.019
Hurwicz Pess	0.146	0.004	0.022	0.002

Variability U(0.3,0.4)	A	B	C	D
Maximax	0.14	0.004	0.019	0.03
Laplace	0.136	0	0	0.002
Hurwicz Opt	0.138	0.003	0.015	0.02

Variability U(0.5,0.6)	A	B	C	D
Maximax	0.15	0.007	0.031	0.042
Laplace	0.135	0	0	0.003
Hurwicz Opt	0.145	0.005	0.03	0.03

Focus on Coverage

Variability U(0.3,0.4)	E30%	E50%	E70%
Abs Robust	0.006	0.004	0.003
Abs Regret	0.008	0.005	0.004
Hurwicz Pess	0.005	0.003	0.002

Variability U(0.5,0.6)	E30%	E50%	E70%
Abs Robust	0.009	0.006	0.004
Abs Regret	0.012	0.008	0.006
Hurwicz Pess	0.007	0.004	0.003

Variability U(0.3,0.4)	E30%	E50%	E70%
Maximax	0.007	0.005	0.004
Laplace	0	0	0
Hurwicz Opt	0.005	0.004	0.003

Variability U(0.5,0.6)	E30%	E50%	E70%
Maximax	0.012	0.008	0.007
Laplace	0	0	0
Hurwicz Opt	0.009	0.006	0.005

Maximax

Figure 3: Average utility loss of different robustness measures and scenario sets for low and high variability in performance. The shaded cells indicate the lowest average utility loss for a given scenario set. Numbers rounded to 3 d.p.

H3a: The threshold level above which the utility function is concave (τ_j), and the strength of preference for avoiding outcomes below the threshold level (λ_j) influence utility loss across robustness measures.

H3b: Minmax robustness measures have lower utility losses for risk-averse attitudes (low τ_j and high λ_j), and maximax measures have lower utility losses for risk prone attitudes (high τ_j and low λ_j).

Following the simulation runs described in Table 7, ANOVA was used to examine whether τ_j and/or low λ_j had a statistically significant impact on the utility loss derived from each robustness measure.

Table 9 below shows that there is a main effect from τ_j, $F(1,1020)=14.22$, $p<0.05$, but not from λ_j, $F(1,1020)=0.037$, $p>0.05$, with respect to absolute robustness. There is no significant interaction between τ_j and λ_j. Utility loss is lowest for low levels of τ_j, confirming that absolute robustness is a reasonable robustness measure for risk-averse attitudes. Similar analysis for β_j (which captures the degree of curvature of the utility function) indicates that this variable does not have a significant impact on utility loss, on its own, or in its interaction with τ_j and λ_j.

Table 9 also confirms that the threshold level, τ_j, exerts a main effect for all measures except the maximax and Hurwicz Optimistic criteria. The lower average utility loss values for high τ_j on maximax measures shows that they are more robust to risk attitude, but remain somewhat worse in terms of utility loss compared to others. Similarly, the higher average utility loss values for low τ_j on minmax measures reflect that these measures are more robust to risk-averse attitudes, with regret performing worse in terms of utility loss compared to other minmax measures. Similar results are found for $\tau_j = \lambda_j = 0$ and $\tau_j = \lambda_j = 1$. The main implication for scenario-MCDA frameworks is that knowledge of the risk attitude of a decision maker may assist in the selection of an appropriate robustness measure. Maximax and regret are particularly sensitive to risk attitude. However, the size of the differences is not large, so one should not be guided by this criterion alone in selecting a measure of robustness.

<table>
<tr><th rowspan="2">Robustness Measure</th><th colspan="2">F-Statistic</th><th colspan="3">Statistically significant impact on utility loss (p<0.05)</th><th colspan="3" rowspan="2">Utility Loss Profile for τ_j and λ_j</th></tr>
<tr><th>τ_j</th><th>λ_j</th><th>τ_j</th><th>λ_j</th><th>β_j</th></tr>
<tr><td rowspan="5">Absolute Robustness</td><td rowspan="5">F(1,1020)=14.22</td><td rowspan="5">F(1,1020)=0.037</td><td rowspan="5">√</td><td rowspan="5">x</td><td rowspan="5">x</td><td>Tau</td><td>Lambda</td><td>Mean</td></tr>
<tr><td>1.00</td><td>1.00</td><td>.023</td></tr>
<tr><td></td><td>2.00</td><td>.023</td></tr>
<tr><td>2.00</td><td>1.00</td><td>.028</td></tr>
<tr><td></td><td>2.00</td><td>.028</td></tr>
<tr><td rowspan="5">Absolute Regret</td><td rowspan="5">F(1,1020)=6.032</td><td rowspan="5">F(1,1020)=0.004</td><td rowspan="5">√</td><td rowspan="5">x</td><td rowspan="5">x</td><td>Tau</td><td>Lambda</td><td>Mean</td></tr>
<tr><td>1.00</td><td>1.00</td><td>.031</td></tr>
<tr><td></td><td>2.00</td><td>.031</td></tr>
<tr><td>2.00</td><td>1.00</td><td>.036</td></tr>
<tr><td></td><td>2.00</td><td>.036</td></tr>
<tr><td rowspan="5">Hurwicz Pessimistic</td><td rowspan="5">F(1,1020)=11.09</td><td rowspan="5">F(1,1020)=0.029</td><td rowspan="5">√</td><td rowspan="5">x</td><td rowspan="5">x</td><td>Tau</td><td>Lambda</td><td>Mean</td></tr>
<tr><td>1.00</td><td>1.00</td><td>.023</td></tr>
<tr><td></td><td>2.00</td><td>.023</td></tr>
<tr><td>2.00</td><td>1.00</td><td>.028</td></tr>
<tr><td></td><td>2.00</td><td>.028</td></tr>
<tr><td rowspan="5">Maximax</td><td rowspan="5">F(1,1020)=0.07</td><td rowspan="5">F(1,1020)=0.61</td><td rowspan="5">x</td><td rowspan="5">x</td><td rowspan="5">x</td><td>Tau</td><td>Lambda</td><td>Mean</td></tr>
<tr><td>1.00</td><td>1.00</td><td>.035</td></tr>
<tr><td></td><td>2.00</td><td>.031</td></tr>
<tr><td>2.00</td><td>1.00</td><td>.033</td></tr>
<tr><td></td><td>2.00</td><td>.034</td></tr>
<tr><td rowspan="5">Laplace</td><td rowspan="5">F(1,1020)=5.612</td><td rowspan="5">F(1,1020)=0.078</td><td rowspan="5">√</td><td rowspan="5">x</td><td rowspan="5">x</td><td>Tau</td><td>Lambda</td><td>Mean</td></tr>
<tr><td>1.00</td><td>1.00</td><td>.018</td></tr>
<tr><td></td><td>2.00</td><td>.018</td></tr>
<tr><td>2.00</td><td>1.00</td><td>.021</td></tr>
<tr><td></td><td>2.00</td><td>.022</td></tr>
<tr><td rowspan="5">Hurwicz Optimistic</td><td rowspan="5">F(1,1020)=1.061</td><td rowspan="5">F(1,1020)=0.169</td><td rowspan="5">x</td><td rowspan="5">x</td><td rowspan="5">x</td><td>Tau</td><td>Lambda</td><td>Mean</td></tr>
<tr><td>1.00</td><td>1.00</td><td>.029</td></tr>
<tr><td></td><td>2.00</td><td>.027</td></tr>
<tr><td>2.00</td><td>1.00</td><td>.030</td></tr>
<tr><td></td><td>2.00</td><td>.030</td></tr>
</table>

Table 9: 2x2 ANOVA results for τ_j and λ_j for all robustness measures considered (based on average utility loss for all scenario sets). 1 represents low values of τ_j and λ_j ,and 2 represents high values of τ_j and λ_j.

H4: Problem size (i.e. number of uncertainties, criteria and options considered) does not affect the degree of utility loss of robustness measures.

Figure 4 shows that the difference in utility loss from changes in the number of options is at most 0.01. Increases in the numbers of uncertainties and criteria considered increase utility loss (Figures 5 and 6), with the highest utility loss being for scenario set A which is based on the selection of one scenario to capture extreme possibilities (regardless of robustness measure). One can further conclude from the figures that robustness measures are most sensitive to changes in uncertainties or criteria only when very small scenario sets are used, but are not sensitive to changes in the number of options. The implication for scenario-MCDA frameworks is that the scenario generation is likely to benefit from the use of scenario clusters to characterise extreme possibilities rather than point estimates.

Minmax

n=5	A	B	C	D
Abs Robust	0.142	0.005	0.027	0
Abs Regret	0.016	0.007	0.033	0.019
Hurwicz Pess	0.138	0.004	0.023	0.002

n=5	E30%	E50%	E70%
Abs Robust	0.009	0.006	0.004
Abs Regret	0.011	0.008	0.006
Hurwicz Pess	0.007	0.005	0.004

n=11	A	B	C	D
Abs Robust	0.15	0.004	0.014	0
Abs Regret	0.168	0.005	0.021	0.014
Hurwicz Pess	0.148	0.003	0.012	0.001

n=11	E30%	E50%	E70%
Abs Robust	0.006	0.004	0.003
Abs Regret	0.008	0.006	0.004
Hurwicz Pess	0.004	0.003	0.002

Focus on Extremes

Focus on Coverage

n=5	A	B	C	D
Maximax	0.14	0.006	0.03	0.04
Laplace	0.13	0	0	0.04
Hurwicz Opt	0.14	0.004	0.023	0.03

n=5	E30%	E50%	E70%
Maximax	0.01	0.007	0.005
Laplace	0	0	0
Hurwicz Opt	0.008	0.005	0.004

n=11	A	B	C	D
Maximax	0.152	0.006	0.022	0.032
Laplace	0.0144	0	0	0.002
Hurwicz Opt	0.148	0.004	0.017	0.02

n=11	E30%	E50%	E70%
Maximax	0.009	0.006	0.005
Laplace	0	0	0
Hurwicz Opt	0.007	0.005	0.003

Maximax

Figure 4: Average utility loss of different robustness measures and scenario sets for different numbers of options. The shaded cells indicate the lowest utility loss for a given scenario set. Numbers rounded to 3 d.p.

Minmax

m=9	A	B	C	D
Abs Robust	0.03	0.004	0.021	0
Abs Regret	0.045	0.006	0.028	0.016
Hurwicz Pess	0.03	0.003	0.018	0.002

m=9	E30%	E50%	E70%
Abs Robust	0.007	0.005	0.004
Abs Regret	0.009	0.007	0.005
Hurwicz Pess	0.005	0.004	0.003

m=19	A	B	C	D
Abs Robust	0.26	0.005	0.02	0
Abs Regret	0.28	0.006	0.03	0.02
Hurwicz Pess	0.26	0.004	0.02	0.001

m=19	E30%	E50%	E70%
Abs Robust	0.008	0.005	0.004
Abs Regret	0.01	0.007	0.005
Hurwicz Pess	0.006	0.004	0.003

Focus on Extremes

Focus on Coverage

m=9	A	B	C	D
Maximax	0.04	0.006	0.02	0.04
Laplace	0.009	0	0	0.002
Hurwicz Opt	0.03	0.004	0.02	0.02

m=9	E30%	E50%	E70%
Maximax	0.009	0.007	0.005
Laplace	0	0	0
Hurwicz Opt	0.007	0.005	0.004

m=19	A	B	C	D
Maximax	0.25	0.006	0.03	0.04
Laplace	0.26	0	0	0.002
Hurwicz Opt	0.25	0.004	0.02	0.02

m=19	E30%	E50%	E70%
Maximax	0.01	0.007	0.005
Laplace	0	0	0
Hurwicz Opt	0.007	0.005	0.004

Maximax

Figure 5: Average utility loss of different robustness measures and scenario sets for different numbers of criteria. The shaded cells indicate the lowest utility loss for a given scenario set. Numbers rounded to 3 d.p.

Minmax

q=5	A	B	C	D
Abs Robust	0.137	0.004	0.013	0
Abs Regret	0.152	0.006	0.018	0.011
Hurwicz Pess	0.134	0.003	0.01	0.001

q=5	E30%	E50%	E70%
Abs Robust	0.007	0.005	0.004
Abs Regret	0.009	0.006	0.004
Hurwicz Pess	0.007	0.004	0.003

q=7	A	B	C	D
Abs Robust	0.154	0.005	0.003	0
Abs Regret	0.176	0.006	0.037	0.022
Hurwicz Pess	0.15	0.004	0.024	0.002

q=7	E30%	E50%	E70%
Abs Robust	0.008	0.005	0.004
Abs Regret	0.01	0.007	0.005
Hurwicz Pess	0.006	0.004	0.003

Focus on Extremes

Focus on Coverage

q=5	A	B	C	D
Maximax	0.135	0.005	0.02	0.02
Laplace	0.12	0	0.0002	0.02
Hurwicz Opt	0.13	0.004	0.013	0.015

q=5	E30%	E50%	E70%
Maximax	0.009	0.006	0.005
Laplace	0	0	0
Hurwicz Opt	0.006	0.004	0.003

q=7	A	B	C	D
Maximax	0.16	0.006	0.03	0.005
Laplace	0.15	0	0.0002	0.03
Hurwicz Opt	0.15	0.005	0.03	0.03

q=7	E30%	E50%	E70%
Maximax	0.01	0.007	0.006
Laplace	0	0	0
Hurwicz Opt	0.008	0.005	0.004

Maximax

Figure 6: Average utility loss of different robustness measures and scenario sets for different numbers of uncertainties. The shaded cells indicate the lowest utility loss for a given scenario set. Numbers rounded to 3 d.p.

2.4 Discussion

The purpose of this simulation was to investigate how the utility loss of an option was influenced by the choice of scenarios as well as the mechanism for choice (i.e. minmax and maximax robustness measures). Findings are of course limited by the simulated cases considered. The focus on static robustness meant that no investigation of accuracy over time due to the ability to adapt or re-organise has been considered. However, a range of possible problem configurations has been considered in the analysis.

The first key finding is that from a practical perspective, robustness measures incur similar degrees of utility loss, which are relatively small for scenario sets that capture at least 7% of the space of knowable uncertainties. This is aligned with another study comparing three robustness measures (a weighted average of the best and worst expected regret; option regret of over a wide range of plausible values for the critical threshold of performance; and the number of options kept open), which revealed that similar options were chosen as the most robust regardless of the measure used (Lempert and Collins, 2007). The main implication of this finding is that an analyst can focus the choice of robustness measure on the learning benefits derived. The analysis here revealed that considering scenarios which represent high vulnerability can support such learning.

The second key finding is that the main difference among the measures is the extent to which they reflect a particular risk attitude, and their relationship to scenario selection. Based on the results, a matrix of the circumstances under which different robustness measures may be considered relevant (Figure 7). Minmax measures are better suited for more concave functions, and maximax measures for convex functions. While utility loss is lower for larger scenario sets across all robustness measures (in line with findings by Durbach and Stewart, 2012), the utility loss for Hurwicz Pessimistic and Laplace are considerably lower even for smaller scenario sets, hence their placement in the matrix as suitable across the spectrum of scenario sets. The Hurwicz Pessimistic operator is aligned with the finding that increasing the relative importance of poor performance is a promising conceptual and computational technique for identifying strategies that may prove more robust (McInerney et al., 2012). Absolute robustness guarantees a lower bound and so does not necessarily benefit from a large scenario set. Regret and maximax are robust to risk-averse and risk prone attitudes respectively and generally incur lower utility loss for higher coverage. The placement of robustness measures suggests that hybrid measures may further minimise utility losses for small scenario sets, such as (b,w)-absolute robustness and (b,w)-absolute deviation (Roy, 2010). From a practical perspective, variability in consequences does not favour any particular robustness measure.

Nonetheless, a range of scenarios that address potential vulnerabilities should be considered. Scenario selection does have an impact on utility loss, and particular selections perform better for certain robustness measures (e.g. set D with regret; set B with absolute regret, maximax and Hurwicz Optimistic operators). However, set C performs consistently worse than a random selection on all operators, indicating scope for further development of this selection technique. It appears that focussing on clusters of extremes (sets B or D) is superior to single representations of scenarios (sets A or C).

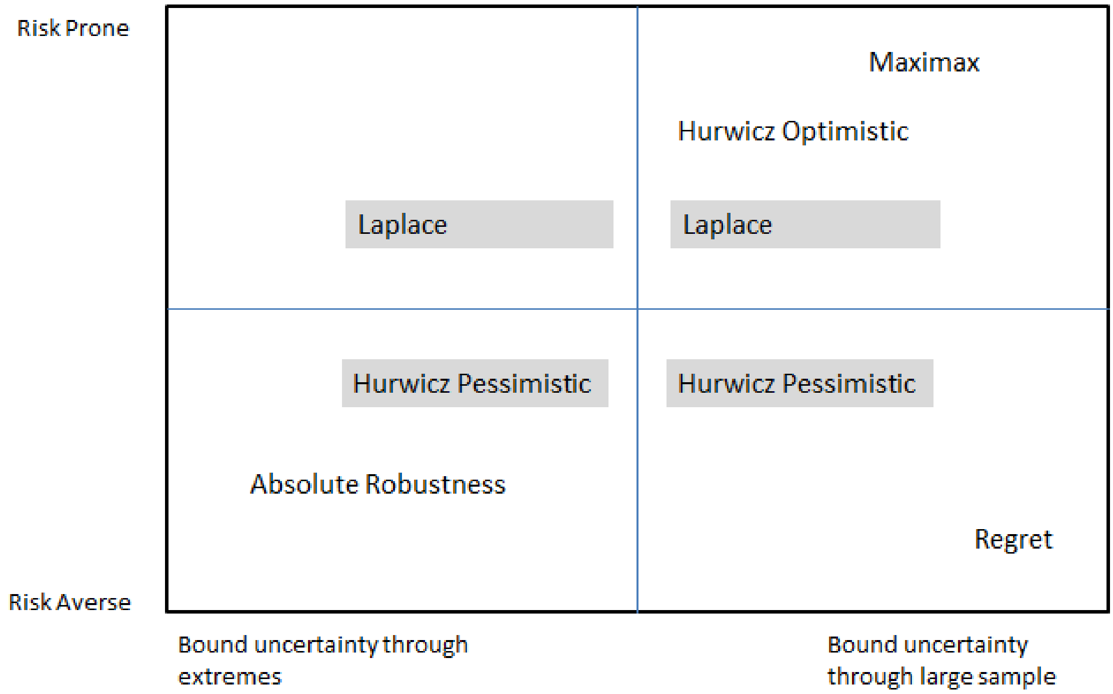


Figure 7: Representation of the suitability of robustness measures given risk attitude and scenario selection. The shaded text indicates duplication of measures in the matrix.

These findings are of course subject to the limitations of the research design. The assumption of a complete scenario set is a contentious one, especially as scenarios are intended to help decision-makers consider the possibility that something currently non-existent can exist in the future. As a result, the focus of this investigation on retrospective accuracy of a scenario set may be seen as less meaningful than one focussed on establishing an enabling condition for robust decisions to be made (Hulme and Dessai, 2008). Triangulation (through controlled experiment) sought to address this, but even experimental approaches are limited to specific aspects (Chermack and Nimon, 2008). The second and related limitation of the design is that the learning benefit derived from outcomes that fall outside the evaluation distributions has not explicitly been explored. Investments in learning through creating additional degrees of decision freedom/strategy levers have proven necessary in creating robust strategies (Lempert and Collins, 2007). Third, comparison to a normative ideal means that measures such as regret might be expected to perform poorly because it is reflective of a behavioural aspect that is not considered in traditional utility theory (Gilbert et al., 2004; van Dijk and Zeelenberg, 2003; Bell, 1989). Indeed, it may be less than ideal to judge minmax and maximax measures when the assumed underlying preference model (MAUT) is itself expressed as a weight average. Nonetheless, within the confines of deep uncertainty, comparison to a normative ideal provided a consistent means for examining the degree of error incurred by various assertions of what defines an acceptable range of futures. Fourth, results are restricted to considerations of static robustness. Assessing the performance of options over the evolution of various states is perhaps better assessed through system dynamics and MCDA (Santos et al., 2002) or adaptive policy approaches (Walker et al., 2013).

3. Controlled Experiment: Assessing the impact of scenario presentation on the MCDA process

This section describes the data collection procedure and findings of an experiment to systematically assess the role of scenario presentation in option evaluation under MCDA. The design assumes that the proper problem is being analysed in order to focus analysis on specific aspects of the evaluation process, namely perceptions regarding the extent to which the most relevant information is provided; support for adequate search for better options; and satisfaction with insights gained in the process. To this end, the following hypotheses are tested:

H1: Scenario snapshots provide sufficient information to evaluate consequences in a MCDA framework.

A study on preferences for presentations of uncertainty has found weak support for scenario narratives being easy to understand and explain to decision makers, but that they did not convey information for planning in general or to specifically evaluate plans (Groves et al., 2008). Moreover, additional levels of detail in an already complex decision problem may simply add to the complexity of the elicitation task (Goodwin and Wright, 2009). It has been shown that linking the scenario construction process to objectives may be sufficient to support appropriate articulation of belief and preference judgments (Ram and Montibeller, 2013). Based on these findings, capturing the essence of a hypothetical future through a scenario snapshot may be sufficient for assessing consequences.

H2: Scenarios help a decision maker to think about a broad range of possibilities.

Through a causal structure a decision maker can consider a broader set of relevant pieces of information from the external environment (Kahane, 2012; Bowman et al., 2013; Beach, 2009; Volkery and Ribeiro, 2009). Yet there is evidence that scenarios that are brief and not causally linked do not negatively impact a decision maker's ability to accept that a wider range of outcomes is plausible (Kuhn and Sniezek, 1996). This leads to the hypothesis that regardless of whether scenarios are expressed as narratives or snapshots, they support thinking about a broad range of possibilities within a MCDA framework.

H3: Scenarios help a decision maker generate insights on how options might be improved within the MCDA framework.

Scenarios make individuals' implicit assumptions about the future explicit, thereby stimulating strategic thinking and communication, which can improve flexibility of response to environmental uncertainty and support the creative generation of options (Ramirez, 2008; Lindgren and Bandhold, 2003; Godet and Roubelat, 1996; Schwartz, 1996; Wack, 1985). MCDA has been proven to support this process (Belton and Stewart, 2002; Keeney, 1992; Keller and Ho, 1988). This benefit should therefore be retained regardless of scenario inclusion. Indeed, scenarios should enhance option improvement in a hybrid approach (Ram and Montibeller, 2013; Montibeller et al., 2006).

H4: Scenarios affect one's satisfaction about the process used to evaluate options given uncertainty.

Several studies on scenario development point to their positive role in overcoming overconfidence biases (Schoemaker, 1993) and learning (Glick et al., 2012; van Vliet et al., 2012), but little insight on their role in option evaluation. Satisfaction involves a comparison of actual and expected process effects. To assess this, selecting participants familiar with expectations of an MCDA process facilitates isolation of the change in satisfaction specifically due to scenarios.

H5: Scenarios affect the time taken to evaluate consequences in a MCDA framework.

A key argument for the integration of scenarios in the MCDA process is the support it provides for considering deep uncertainty. Decision problems of increasing complexity (i.e. more options and/or more criteria) tend to take longer and are viewed as more effortful (Payne et al., 1993). It has been found that the difficulty of a decision task is often related to the amount of information processing required to arrive at a choice, which in turn is associated with the amount of information provided to the decision maker (Durbach and Stewart, 2011). This suggests that scenarios, particularly when expressed as narratives, should lead to more time being taken to complete a MCDA exercise. Conversely, heuristics/selection of a few key cues are often used to reduce the effort involved in managing the additional complexity (Shah and Oppenheimer, 2008), and may result in less time taken. These findings lead to the hypothesis that scenarios have an impact on the time taken to evaluate consequences.

3.1 Design

Due to the paucity of information regarding the size of effect one can expect from using different scenario formats in the MCDA process, this experiment was treated as a pilot from which to derive initial insights on this issue. Participants were 78 summer school students from the London School of Economics who were taking the Judgment and Decision Making course and were familiar with MCDA. A between-subject design was used whereby each participant was randomly assigned to one of the following groups with equal probability:

- Group 1: No scenarios
- Group 2: A scenario set comprised of four snapshots, which describes the hypothetical state of the world based on all combinations of extremes on 2 key uncertainties for a time horizon of 10 years.
- Group 3: A scenario set comprised of four narratives, based on all combinations of extremes on 2 key uncertainties with causal statements to create a salient link between today and a time horizon of 10 years.

Each participant was presented with a defined career choice problem, with similar elements as in Bana e Costa and Chagas, 2004, and asked to complete a MCDA exercise based on the group they were assigned to (see Appendix 3 for details of the problem framing and scenarios used). This problem was designed to satisfy the main criteria for the use of scenarios and MCDA: (i) it addressed a relevant strategic concern for individual decision making; (ii) there was uncertainty on how to value the desirability of alternative outcomes and a long-term horizon; and (iii) the decision maker faced conflicting objectives. The scenarios were not developed by participants, but by another group of undergraduate students from the same university with a similar demographic profile during a pilot study. Scenario development was based on a 2x2 matrix (Schoemaker, 2002; Wack, 1985), and validated using an approach similar to that outlined in Rungtusanatham et al., (2011). Each participant was asked to answer the same questionnaire following completion of the exercise (See Table 10). The questions designed to test each hypothesis were aligned with tools developed in Green and Taber (1980) and Gouran et al. (1978). The statements further reflect the ability of individuals to generate fairly adequate notions about their effort levels through process feedback (Creyer et al., 1990).

Hypothesis	Data Gathered
H1: Scenario snapshots provide sufficient information to evaluate consequences in a MCDA framework.	Respondents asked to provide ratings on a 5-point disagree-agree scale[5] for the following questions: a)The process was presented in a way that made it easy to answer the questions posed. b)The process did not provide me with sufficient information to evaluate consequences in the career choice decision c)The process provided me with information that I could use in making a similar decision in future.
H2: Scenarios help a decision maker to think about a broad range of possibilities within the MCDA framework.	Respondents asked to provide ratings on a 5-point disagree-agree scale for the following questions: a)The process helped me explore a broader range of possibilities that could substantially impact the decision. b)The process helped me to consider the range of outcomes that could affect my final choice c)The process helped me to consider the range of factors that could be important in a career choice decision.
H3: Scenarios help a decision maker generate insights on how options might be improved within the MCDA framework.	Respondents will be asked to provide ratings on a 5-point disagree-agree scale for the following questions: a)The process gave me new insights on the performance of options b)The process did not tell me anything I did not know before c)The process helped me to examine options in a more constructive manner.
H4: Scenarios affect one's satisfaction about the process used to evaluate options given uncertainty	Respondents will be asked to provide ratings on a 5-point disagree-agree scale for the following questions: a)The process helped me to be more confident in my choice b)The process has increased my commitment to a solution c)I am satisfied with the quality of the solution. d)I feel that the solution reflects my inputs.
H5: Scenarios affect the time taken to evaluate consequences in a MCDA framework.	Calculate the time to complete a MCDA elicitation for a scenario for question q as follows: $T = T_{last} - T_{first} - T_{read}$ Where: T_{last} = Time at last elicitation question T_{first} = Time at first elicitation question T_{read} = Average time taken to read the scenario snapshots/narratives once (derived from pilot)

Table 10: Mapping of questions to hypotheses for controlled experiment

[5] 1-Not at all agree 2- Agree to a little extent 3-Agree to some extent 4-Agree to a great extent 5-Agree to a very great extent

3.2 Results

For each of the hypotheses H1-H5, two levels of analysis were considered. First, no scenario information (i.e. Group 1) was compared to some degree of scenario information (i.e. Groups 2 and 3 combined). If there was a significant difference here, then a second analysis was carried out to establish whether the degree of scenario information had any statistically significant impact. For H1-H4, there was no reason to assume normality, if only because the data are discrete, so a Wilcoxon signed-ranks test was deemed appropriate. Results for independent samples t-tests for all pairwise comparisons are also provided.

H1: Scenario snapshots provide sufficient information to evaluate consequences in a MCDA framework.

	Sample size	**Mean**	**Median**	**Standard Deviation**	**Wilcoxon p-value**	***t*** **(Equal variances not assumed)**	**df**	**Sig. (2-tailed)**
No scenarios	30	2.90	3	0.74				
Scenarios	48	2.81	3	0.57	0.31	-0.72	53	0.48
Snapshot	30	2.83	3	0.59	0.38	0.58	55	0.57
Narrative	18	2.78	3	0.55	0.32	0.83	44	0.41

Table 11: Statistical analysis for all groups considered in the analysis relating to sufficient information. Group 1 (No scenarios) acted as the control group.

Table 11 indicates that there is no significant change in perception regarding sufficiency of information to evaluate consequences under MCDA whether scenarios were provided or not. The lower average rating for scenarios, and narratives in particular, on this measure may reflect lack of direct involvement in development of the scenario narrative to engage the participant in counterfactual thinking (Schoemaker, 1993; Koriat et al., 1980). This is further supported by findings in the attitude change literature that reading or hearing scenarios generated by others may require less information processing, but might be less compelling and easier to disregard (Hertwig et al., 2004; Weber et al., 2004). Similar results about the benefits of close collaboration between scenario developers and users lend further credence to this claim (Parsons et al., 2007; Clark et al., 2006).

H2: Scenarios help a decision maker to think about a broad range of possibilities within the MCDA framework.

	Sample size	Mean	Median	Standard Deviation	Wilcoxon p-value	*t* (Equal variances not assumed)	df	Sig. (2-tailed)
No scenarios	30	3.10	3	0.99				
Scenarios	48	3.29	3	0.65	0.12	-0.94	45	0.35
Snapshot	30	3.33	3	0.66	0.11	-1.1	50	0.29
Narrative	18	3.22	3	0.65	0.26	-0.52	46	0.61

Table 12: Statistical analysis for all groups considered in the analysis relating to range of possibilities.

Initial analysis shows that there is consensus on the value of scenarios for thinking about a broad range of possibilities (higher mean and lower standard deviations for scenarios than no scenarios in Table 12). Scenario snapshots appear slightly more effective in terms of encouraging a broad range of possibilities in the evaluation process than narratives. One possible reason is that the additional structure imposed by the narrative inhibits creative thinking, echoing findings in van Vliet et al., 2012. Conversely, direct participation in scenario development can change individual mental model styles (Glick et al., 2012).

H3: Scenarios help a decision maker generate insights on how options might be improved within the MCDA framework.

	Sample size	Mean	Median	Standard Deviation	Wilcoxon p-value	*t* (Equal variances not assumed)	df	Sig. (2-tailed)
No scenarios	30	3.07	3	0.58				
Scenarios	48	2.92	3	0.71	0.21	1.02	70	0.31
Snapshot	30	3.03	3	0.72	0.50	0.20	56	0.84
Narrative	18	2.72	3	0.67	0.03	1.81	32	0.08

Table 13: Statistical analysis for all groups considered in the analysis relating to option improvement.

Table 13 shows a general decrease in mean ratings on option improvement but increase in standard deviation as scenario detail increases. There is no indication of a statistically significant change in perception of option improvement being provided with scenarios. While snapshots do not yield significant difference (median=3; p=0.50), lower means for scenario narratives indicate that they appear to be a hindrance to option improvement (median=3; p=0.03).

Nonetheless, the MCDA only process was seen to be marginally better than any process involving scenarios. This supports the general finding of the strength of MCDA to aid option improvement (Keeney, 1992). One reason for this may be that all human acts are based on 'memories of the future' in that one brings knowledge, beliefs and intuition about the development of an issue into the decision making process (Aligica, 2003; Ingvar, 1985). Therefore, even without scenarios, participants may have engaged in some form of reasoning about the future, alongside the request to explicitly deliberate improvements to options regarding each objective.

H4: Scenarios affect one's satisfaction about the process used to evaluate options given uncertainty.

	Sample size	**Mean**	**Median**	**Standard Deviation**	**Wilcoxon p-value**	***t*** **(Equal variances not assumed)**	**df**	**Sig. (2-tailed)**
No scenarios	30	3.07	3	0.91				
Scenarios	48	3.21	3	0.74	0.32	-0.72	53	0.48
Snapshot	30	3.23	3	0.68	0.39	-0.81	54	0.42
Narrative	18	2.72	3	0.67	0.32	1.81	32	0.08

Table 14: Statistical analysis for all groups considered in the analysis relating to satisfaction with evaluation process.

Ratings on this dimension were intended to capture decision maker confidence in the choice made. Table 14 shows that scenarios appear lead to an increase in ratings on satisfaction with the process, but this is not significant. Despite this, the lower average satisfaction rating and standard deviations for scenario narratives concurs with the finding that methods which increase decisional conflict may reduce decision confidence despite a positive influence on actual decision quality (Cats-Baril and Huber, 1987). Therefore, scenarios may have resulted in reduced decision confidence through the pressures of an unfamiliar or challenging task. However, anxiety can promote or discourage learning (Schein, 1993; Vince and Martin, 1993). These findings suggest that higher ratings for snapshots should be evaluated with caution.

H5: Scenarios affect the time taken to evaluate consequences in a MCDA framework.

	Sample size	Mean	Median	Standard Deviation	Wilcoxon p-value	*t* (Equal variances not assumed)	df	Sig. (2-tailed)
No scenarios	30	30.98	31.75	8.26				
Scenarios	48	22.70	20.35	6.90	0.000	4.58	54	0.000
Snapshot	30	22.54	20.69	5.56	0.000	4.64	51	0.000
Narrative	18	22.97	19.52	8.88	0.001	3.10	34	0.004

Table 15: Statistical analysis for all groups considered in the analysis relating to time (in minutes) taken to evaluate consequences.

Table 15 shows that scenarios have a role to play in increasing the efficiency of the evaluation process using MCDA, with scenario snapshots yielding a more significant result (p=0.000 for snapshots; p=0.001 for narratives). One possible reason for the lower relative elicitation time for scenarios is that they provided a richer context and meaningful reference point for assessing the relative importance of objectives and differentiating knowns from unknowns. The snapshot may have resulted in reduced time because it helped them to prioritise the most important factors in their decision (Chip and Heath, 2013). One possible reason for increased variance among narratives is the response to the unfamiliarity of the task as discussed above, with some participants deliberating more than others on implications for choice. Analysis of time taken to complete tasks for each scenario was on average the same. This suggests that participants did not reduce effort by pattern-matching similarities from one scenario to another (Kahneman, 2011), but considered each independently.

3.3 Discussion

The primary goal of this analysis was to systematically assess the influence of scenarios when evaluating options with MCDA on the dimensions of perceived sufficiency of information, consideration of a broad range of possibilities, option improvement and satisfaction with the evaluation process. No format performed exceptionally on any dimension, with responses concentrated around ‘agree to some extent’.

The results suggest that there is no detriment to using scenarios in the evaluation process. Their apparent benefit is the provision of a structure for clarifying preferences under deep uncertainty. This is supported by the finding that scenarios reduce between-subject variance on all measures, with increased averages for broad range of possibilities and satisfaction with evaluation process. This may be because they introduce a questioning attitude; or prompted them to articulate priorities through rehearsing extreme decision contexts. Nonetheless, while the elicitation process was more efficient with scenarios than without, it remains an open question whether the investment of time required to develop scenarios justifies this benefit. It has in fact been shown that this may be a deterrent to the use of scenarios (Grant, 2003).

Of course, the findings from this pilot study are subject to the limitations of the research design. It may be that there is a significant effect, but the sample size was simply too small to detect it. Another factor which may have affected outcomes was lack of direct involvement in each stage of the process, and the absence of facilitation, which are both fundamental to scenario planning (Ramirez, 2008; van der Heijden, 1996) and MCDA (Phillips, 1984; Ackermann, 1996; Geldermann et al., 2009). The use of a hypothetical, personal decision may not have been representative of real-world situations where multiple parties may be involved. Further, it is possible that the variety of individual backgrounds and lack of a common current issue or decision context affected ratings (Bradfield, 2008).

This study has been guided by the question, “To what extent do scenarios influence the evaluation process using MCDA?”. Further analysis of this question could involve at the most basic level, repetition of the design presented here for a larger sample size. A more advanced design could involve conducting independent experiments to assess each measure of process effectiveness in turn through a larger variety of formats for representing uncertainty and alternative techniques for option improvement.

Further research could also be guided by the broader question: “What is the relationship between scenario planning and option evaluation?”. This could take the form of work with multiple organisations in a phased manner, which follows the general framework proposed in Ram and Montibeller, 2013. This would facilitate broader representation of multiple industries, organisation sizes, and cultures; and engage participants at each stage of the process. Facilitators would be similarly trained, and hypotheses aligned to appropriate frameworks and instruments for measuring effective evaluation processes under deep uncertainty. Pre-workshop and post-workshop responses could then be compared. However, associational studies must bear in mind that evaluation processes under deep uncertainty, including formal MCDA, will not necessarily eliminate biases and judgment calls necessary for selecting remedial options, but can allow for transparent evaluation of individual scenarios consistent with decision maker values.

4.Conclusions

The growing interest in supporting decision making under deep uncertainty and multiple objectives has led to several proposals for integrating scenarios and MCDA (Durbach and Stewart, 2012; Montibeller and Franco, 2011; van der Pas et al., 2010; Wright and Goodwin, 2009; Montibeller et al., 2006; Stewart, 1997, 2005; Belton and Stewart, 2002; Goodwin and Wright, 2001; Phillips, 1986). Yet there is a paucity of systematic assessments regarding factors that influence the role of scenario presentation and option robustness in the MCDA with Scenario Planning approach. In order to explore these two aspects in this growing area of research, the unique role of scenario presentation in the option evaluation process was explored through a behavioural experiment; and the impact of different decision rules for robustness relative to a normative ideal was examined through simulation.

Three main findings were identified. First, as part of the problem structuring phase, it is important to understand the decision maker risk attitude and use this as a guide to applying a robustness criterion. A risk seeking decision maker should base choice on maximax, and a strongly risk-averse decision maker should base choice on regret, but only if a large scenario set is used. Second, as part of the scenario development phase, as few as four scenarios, even expressed as snapshots, may be useful in addressing cognitive barriers during the elicitation process under deep uncertainty. In order to enhance the ability of scenarios to facilitate consideration of a broad range of possibilities in the evaluation process, the extent to which the scenarios capture vulnerability of options may be beneficial. The third implication is therefore that ample time and mechanisms for option generation should be built in to enhance the existing option set. To this end, the choice of robustness measure may be best guided by the learning benefits to be derived. Collectively, these findings have three main implications for sequencing steps in a scenario-MCDA framework.

The analysis here is by no means a complete assessment. A full rendering should consider not only the quantitative results but also how users perceive the credibility, legitimacy, and saliency of the information and the processes that produce it (Hall et al., 2012). Consequently, the influence of direct involvement in scenario development on the quality of the evaluation process, particularly in a group setting, is a key area for further research. The influence of other representations of uncertainty on engaging the decision maker to proactively shape the future, in the context of stand-alone choices as well as part of a portfolio should also be considered. A deeper analysis of the types of scenarios whose omission leads to increased utility loss, regardless of the robustness measure used, is also needed. The role of an iterative MCDA process in enhancing effectiveness of process and outcome over time may also be considered.

Nonetheless, it is hoped that the techniques outlined in this paper stimulate a more systematic analysis of the relationship between scenario presentation and measurements of robustness in a multi-criteria scenario planning framework, and provide a template for such investigation in this emerging field.

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Appendix 1: Summary of studies relating to cognitive effects of uncertainty

Reference	Aim	Design	Analysis	Key Findings
Kreye et al., 2012	To investigate what type of display is required to assist the decision maker in considering uncertainty, and how much contextual information is required to represent uncertainty in the decision-making process.	44 experts were divided into three groups and each presented with one of three different displays for considering uncertainty: a three point trend forecast; a bar chart with minimum,medium,and maximum estimates; and a fan diagram. Participants were asked to give a cost estimate for 2014 and 2018 and reasons for their answer. They were also asked to provide a confidence level to estimate the extent they were willing to make ambiguous statements. Two questionnaires were used; one with general information and another with more detailed information on the forecast (what values meant, assumptions underlying forecast).	Chi-squared test to investigate the differences between groups in terms of confidence and forecasting values (low, medium low, medium, medium high, high). Reasons for estimates categorised and chi-squares test conducted.	Decision makers tend to simplify the level of uncertainty from a possible range of future outcomes to the limited form of a point estimate.However,contextual information makes one more aware of uncertainty.
Durbach and Stewart, 2011	To provide insights into how subjects make single- and multi-criteria choices in the presence of uncertainty (and some format for representing uncertainty) but in the absence of any real facilitation.	28 postgraduate students split into two groups, one providing commentary on decision making process, the other not. 12 decision tasks provided, involving a choice among 5 alternatives on 1,2 or 3 attributes across a possible six uncertainty formats. An incomplete block design used such that each participant sees two uncertainty formats and two attribute set sizes, and answers three questions within each of these combinations. Effects on decision making are tracked in terms of the quality of the final choice, the specific characteristics of the selected alternatives, and the difficulty experienced in making a decision.	Compare parameter estimates for each uncertainty format, with 90% confidence intervals represented by ellipses.	How uncertainty is represented influences decision making and the alternative that is eventually chosen. Probability distributions appeared to overload subjects with information, leading to poorer and more difficult choices than if some intermediate level of summary was used – in particular three-point approximati ns or quantiles
Hodgkinson et al., 1999	To investigate the extent to which judgmental biases arising from the framing of risky decision problems can be eliminated through cognitive mapping.	500-word case study provided and 88 final year students asked to assume the role of a board member and allocate a fixed sum of money to a 'safe' or a 'risky' option directly in proportion to their preference. They were asked to represent the ways in which they thought about the problem in the form of a cause map. Two-by-two between participants design used (positive versus negative problem frame and pre- versus post-choice mapping).	Means across problem frames compared using Mann-Whitney U test	Cognitive mapping reduces framing bias
Kuhn and Sniezek, 1996	To investigate the cognitive effects of scenario presentation.	186 students asked to individually complete questionnaires concerning future values of eight different forecast variables covering a broad range of topics (e.g. murder rate, world population, number of nuclear plants in operation worldwide). Current values were provided and predictions were asked for each of the next five decades. A mixture of uni-directional and hybrid scenario(s) were provided and participants asked to consider them before making predictions. For each of the five predictions, they gave a confidence rating on a 9-point scale (1= completely uncertain: a complete guess to 9 = very certain).	Confidence ratings analysed using MANOVA with forecast variable and decadeas within-subjects repeated measures	Reading any type or number of scenario information increased confidence in forecasts. Differences in number and in type of scenarios presented did, however, lead to acceptance of a wider range of outcomes.
Shanteau, 1992	To establish how experts versus non-experts differentiate between relevant cues	24 third-year nursing students and 7 faculty nurses were asked to rate the relevance of information in a nursing scenario in terms of essentiality to making a decision. The test was re-run after students took a course on decision-making and problem solving.	Compare percentage of items rated as essential before and after the test.	Experts differ from novices in what information is used, not how.

Appendix 2: Comparison of Random Selection with Selection Techniques B, C, D

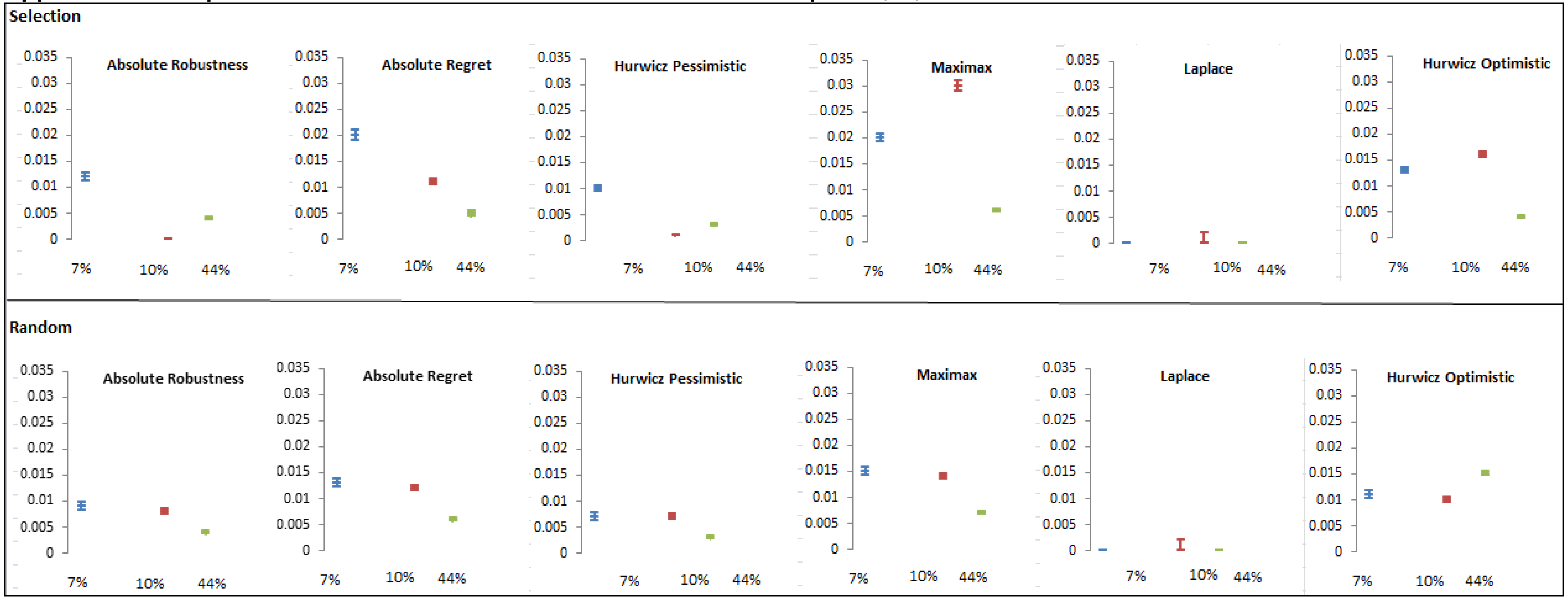
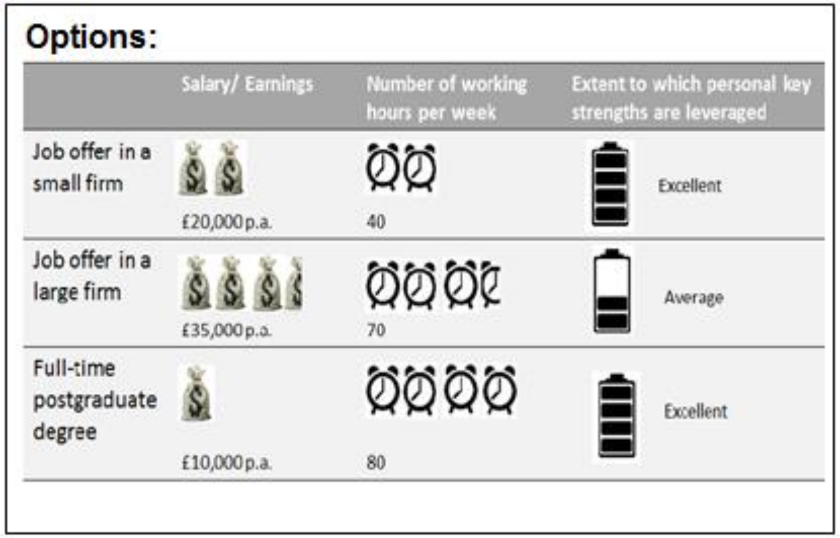


Figure 8: Mean utility loss ± 1.96*standard error for different robustness measures for random scenario selection versus deliberate selection techniques (assuming n=11, q=5 and 100 iterations).

Set B has coverage of 44%; Set C has coverage of 7%; and Set D has coverage of 10%

Appendix 3: Decision Problem and Scenarios used in Experiment

Context:
Imagine that you are in your final undergraduate year at university. You have been performing consistently well, and you have a couple of job offers in a sector that typically pays above average salaries. However, it has been a personal ambition of yours to pursue a post-graduate degree.


Options:

	Salary/ Earnings	Number of working hours per week	Extent to which personal key strengths are leveraged
Job offer in a small firm	£20,000 p.a.	40	Excellent
Job offer in a large firm	£35,000 p.a.	70	Average
Full-time postgraduate degree	£10,000 p.a.	80	Excellent

Objectives	WORST	BEST
Financial Security	Struggle to meet basic needs	Able to meet needs comfortably for the next year
Work/Life Balance	Little or no time for leisure due to work constraints	Flexibility in weekly schedule for leisure activities
Professional Fulfilment	Monotonous tasks with no clear career progression or support for growth in other areas	Very clear, meritocratic career path with sufficiently diverse and challenging tasks

Group 1: MCDA Only
After the MCDA exercise without scenarios, participants asked to consider uncertainty in an unstructured manner as follows:

- Given the performance of options, how might you try to improve the performance of options?
- What are the five (5) most important changes that one might experience over the next 10 years that could affect career choice? (Rank top 5 from list provided)
- Please explain briefly why you think that the ranking of options may/may not change given these uncertainties.
- Imagine now that in making the choice, your family and friends advise you against pursuing the postgraduate degree because it is too time consuming and will not add significantly to your earnings potential in the future (MCDA process repeated).

Group 2: Scenario Snapshots
Scenario A- A growing economy leads to high demand for jobs and an abundance of job openings. However, employers are very selective in recruiting due to a high supply of qualified people.
Scenario B- A growing economy leads to high demand for jobs and an abundance of job openings. Despite a high supply of qualified people, recruitment procedures are not very selective due to competition for similar skills in other sectors.
Scenario C- An extended recessionary period leads to few job openings. Employers are very selective in recruiting due to a high supply of qualified people.
Scenario D- An extended recessionary period leads to few job openings. Given a high supply of qualified people, competition for jobs is relatively low due to competition for similar skills in other sectors.

Group 3: Scenario Narratives
Scenario A- The economy continues to underperform. This results in strong political pressure to stimulate growth, which spurs on greater collaboration for innovation. This leads to continuous and rapid economic growth. During the recession, a shortage of jobs had motivated graduates to invest in further skills development, which position them well for this scenario. However, employers pay a premium for skills in this sector relative to others. As a result, they are very selective in their recruitment procedures.
Scenario B- The economy continues to underperform. This results in strong political pressure to stimulate growth, which spurs on greater collaboration for innovation. This leads to continuous and rapid economic growth. During the recession, a shortage of jobs had motivated graduates to invest in further skills development, which position them well for this scenario. However, salaries in this sector are not as competitive as others which are experiencing more rapid growth and pay a higher premium for skills.
Scenario C- Prolonged, sluggish global economic recovery leads to overall low demand and consequently a less urgent need for skills. This situation is exacerbated by employers who are very selective in their recruitment procedures, especially as they pay a premium for skills in this sector relative to others even in the downturn. This leads to a general trend to increased personal investments in further skills development.
Scenario D- Prolonged, sluggish global economic recovery leads to overall low demand and consequently a less urgent need for skills. However, a spate of high profile incidents relating to corrupt practices has resulted in a poor image for the sector. As a result, graduates are more attracted to other sectors despite premiums offered.

1.Concluding Remarks

The aim of this thesis was to propose a method for assessing options with multiple scenarios and Multi-Criteria Decision Analysis (MCDA) and examine their impacts. Such method was devised to support decision making under deep uncertainty, which poses three challenges to the application of probabilistic decision analysis (Cox, 2012). First, the scenario framework sought to capture the essence of the strategic challenge by establishing plausible bounds on knowable uncertainties (Schoemaker, 2004), which the MCDA framework lacks. Second, scenarios were uniquely placed to help a decision maker consider simultaneous variations in external uncertainties to better address uncertainty about the important consequences that could affect choice (Schoemaker, 2002). Third, the individual strength of MCDA and scenario planning to support thinking about option improvements (Belton and Stewart, 2002; Wack, 1985) could cope with the premature focus on salient options that is typical under deep uncertainty.

The proposed extensions were developed with a sensitivity to the tension between the attributes that make scenarios useful for decision structuring under deep uncertainty (i.e. a small set of scenarios as capturing extreme but plausible developments in the external environment through the development of narratives) and the attributes useful for choosing among options (i.e. scenarios as a useful approximation to a predictive ideal). To this end, a series of intermediate strategies were considered.

A larger set of scenarios based on multiple uncertainties and expressed as snapshots was suggested instead of the traditional scenario narrative based on two uncertainties. This choice was intended to achieve a compromise between coverage (i.e. a set of scenarios representative of the knowable uncertainty space) as advocated in the risk management literature (Cox, 2012) and diversity (i.e. a scenario set to challenge existing mental models) as advocated in the scenario planning literature (Schwartz, 1991; Wack 1985).

A metric was also developed to compare performances across scenarios when separate MCDA models exist. This became relevant in light of separate MCDA models per scenario being cognitively easier (Montibeller et al., 2006), and practically meaningful when consequences are very different depending on whether a particular event occurs or not (French et al., 1997). Cost-equivalent regret for an option was defined as the degree of difference of an option's value, measured in terms of its cost-equivalent, from the maximum achievable performance across all options in a given scenario. The main advantage of the cost-equivalence concept was that it captured value for a given option under a single criterion, facilitating more efficient comparison across as well as within options. While the use of regret may violate the principle of independence of irrelevant alternatives, it was seen as complementary to the scenario concept in providing ‘hypothetical references’ to help sort out preferences under deep uncertainty and prompt thinking on viable responses to a future that is yet to be determined (Groves et al., 2008; Hodgkinson and Wright, 2002). This choice was intended to achieve a compromise between the traditional MCDA view of options as fixed and complete, and the scenario planning view of options, and more broadly, its success formula, as subject to re-design. Given that the set of options initially considered may not necessarily the best that could be devised (Cox, 2012), the focus of regret on vulnerability was therefore seen as a mechanism to stimulate option improvement. This was based on the finding that only negative outcomes stimulate the search for causes and criticism of choices (Peeters and Czapinski, 1990; Taylor, 1991), while good outcomes tend to elicit little cognitive activity. Regret also reflected the behaviour of decision makers who could be expected to have decisions scrutinised with hindsight, such as physicians, CEOs and politicians who work within performance cultures (Kahneman, 2011).

Three papers were developed to explain and explore the proposed extensions. The first paper detailed the rationale for the extensions and provided a brief illustrative application. The second paper tested the usefulness of the method in a more formal manner through action research in three case studies in the public sector of a developing country. The third paper compared the choice of scenarios and robustness metric to alternative strategies in a more controlled setting, using a behavioural experiment and computer simulation. The intended contribution was to develop a rigorous basis for improvements in this growing area of research, through practical and theoretical assessment of the proposed elements.

The subsequent sections of these conclusions are organised as follows. First, a summary of findings from each paper will be provided. This will be followed by a critical discussion, which seeks to incorporate these findings into a more cohesive whole than would be possible if they had remained entirely separate. The discussion is placed in the context of overall aim of the thesis, and relevance to wider academic literature and professional debates on decision making under deep uncertainty. The limitations of the present study will then be discussed, followed by directions for further research.

2. Key Findings

The overarching research question was whether the proposed extensions provided a coherent method for assessing option robustness under deep uncertainty. This question was explored through three papers. The first paper outlined the rationale for each extension and presented findings from one practical application. The second paper explored a more rigorous analysis of the coherence of the extensions in the context of three different real-life decision contexts. The final paper sought to provide a more in-depth investigation of the theoretical soundness of the proposed extensions in a more controlled setting. To this end, a behavioural experiment and a simulation were used. The aim of the triangulated approach was to counteract the biases arising from individual research methods, and so provide a more complete representation of the benefits and drawbacks of the extensions as a whole and relative to their competitors in the literature. Investigating the effectiveness of a decision method through real-life decision making, experiment and simulation was in itself a novel contribution to this developing area of research.

In Paper 1, the proposed extensions acknowledged the three key intersection points for scenarios and MCDA in the decision process:

i. defining and structuring the problem (i.e. objectives, criteria, options and combinations of uncertainties that affect can affect outcomes)

ii. estimating the consequences of each option and the trade-offs incurred in terms of their ability to meet the objectives under each scenario

iii. option selection based on performance within and across scenarios.

The paper also outlined key assumptions underlying the extensions. First, complementary use of scenarios and MCDA would mitigate inherent weaknesses in each to better address the complexity and multi-dimensionality of a deeply uncertain future (Goodwin and Wright, 2001). The ability of scenarios to consider combinations of uncertainties provides a new perspective over traditional techniques such as sensitivity analysis and the incorporation of risk measures in the value model which consider shifts in one uncertainty at a time. However, on their own, scenarios can be insufficient for systematically assessing how a set of strategic options might perform in those futures given multiple objectives, which MCDA can cope with. Second, a concern for robustness should guide choice under deep uncertainty (Bodwell and Chermack, 2010; de Vries and Petersen, 2009; Roubelat, 2006; O'Brien, 2004; Harries, 2003; Wilson, 2000), accepting that perfect robustness is unattainable. The robustness criterion should not merely achieve a reasonable level of performance relative to other options across the set of scenarios, but it should help a decision maker better understand the enablers and barriers to success under different circumstances (Hulme and Dessai, 2008). To this end, a focus on plausible outcomes on the boundary of knowable uncertainties was meaningful. The third, related assumption was that the method was to be used in a prescriptive not normative sense.

One practical application showed that the decision-maker felt the extensions provided a coherent framework for highlighting uncertainties, objectives and options as well as a purposeful display of measures to facilitate the comparison of options across scenarios. However, the elicitation of weights and values was time-consuming. These results led to an interest in more formal assessment of the method, which was explored in Paper 2.

In Paper 2, the extended method was formally tested through application in three in-depth case studies in the public sector in Trinidad and Tobago. This context was not only chosen as it reflected the conditions of deep uncertainty, but also to respond to the call for OR tools to be more widely applied in the area of development (Rosenhead, 2006). The timing for the cases coincided with a half-way review of a strategic development plan for the country. Cases were chosen following interviews with several potential participants on the basis of willingness to engage with a new process and perceived fit with key characteristics of organisational challenges. While others were engaged in providing alternative perspectives on key issues and dynamics of the decision context, a single decision maker was selected to ultimately frame the decision problem and evaluate options in order to provide an understanding of capability at its simplest level of involvement. Nonetheless, others involved in the decision-making process were engaged during the problem structuring phase to canvas alternative views. Application to three diverse decision contexts was seen as a way to achieve content validity, in the knowledge that the research design would limit external validity as defined within natural science. Within the action research framework, any claims to knowledge were supported by a traceable process to link conclusions, intervention and data as well as a clear statement that the findings were tentative and transferable to similar situations in a similar setting to the ones found in the interventions (Montibeller, 2007).

Assessment criteria included ease of understanding, capacity to capture relevant aspects of the strategic problem in a manner that provided a degree of challenge to current assumptions, support for the exploration of new/improved options. Paper 2 concluded that the extended method could be helpful in three ways. First, MCDA combined with the selection of external uncertainties for scenarios helped in structuring the problem and developing options that were targeted towards the achievement of objectives. Second, the level of detail in scenarios developed was deemed sufficient for value and weight elicitation, but unfamiliarity with the context affected one's ability to make judgments, and repetition of the process affected one's willingness to engage in the process. This suggested scope for development in terms of addressing the elicitation burden. Third, there was perceived value in being able to compare performance across scenarios to understand why performance differed. However, there was general agreement that regret was too restrictive given the decision context. As such, regret did not prompt thinking about re-designing options as much as the MCDA framework itself.

Paper 3 sought to add further breadth and depth to assessing the contribution of each of the proposed extensions. Specifically, the use of snapshots for evaluating options under MCDA was compared against scenario narratives through a controlled behavioural experiment. The scenario selection technique was compared against a selection of competing techniques in the scenario planning and risk management literature through simulation. This evaluation was conducted for different measures of robustness. While the experiment and case studies confronted the process elements of the method, the simulation addressed the ability of the method to approximate the best solution in an idealised procedure. This mode of assessment challenged a key assumption that the set of possible future states is not known, but nonetheless has been cited as a criteria under which both scenarios and MCDA should be assessed (Hulme and Dessai, 2008; Durbach and Stewart, 2009).

The main finding from the experiment was that scenarios could achieve similar levels of perceived quality on option improvement and learning about a range of possibilities in the external environment as MCDA only, in statistically significantly lower time. The conclusion drawn was that scenarios appeared to increase the efficiency of the elicitation process due to its capacity to provide a structure for clarifying preferences under deep uncertainty. On the other hand, simulation results unsurprisingly favoured the selection of a large scenario set for all robustness measures, including regret. Low utility losses were incurred for scenario sets that covered as little as 7% of the space defined by knowable uncertainties, and the nature of the scenarios selected did have an impact on accuracy. For instance, scenario sets which captured coherent clusters of extremes achieved lower losses than a sets based on single scenario representations of extremes. The threshold levels above which the utility function was concave was identified as a key factor influencing the accuracy of the solution. For high threshold levels, maximax measures tended to be more accurate, and for low threshold levels, minmax measures appeared more suitable.

The findings from Paper 3 reflected marginal differences in the use of various robustness measures. This suggests that the choice of robustness measure can be justified by the benefits they accrue to learning about options. The results also highlighted the costs and benefits of different scenario sets. A small scenario set is appropriate for addressing cognitive barriers but not for minimising error relative to a normative ideal; and a relatively large scenario set focussed on scenarios where there is weak performance is relevant for achieving this, although the improvement in accuracy may be expected to be marginal above coverage of 10% of the scenario space defined by knowable uncertainties.

3. Implications for Scenario Planning and Decision Analysis

The findings outlined have implications for scenario planners who wish to use scenarios for evaluating options, and for MCDA practitioners who wish to apply the technique in the context of deep uncertainty. Their interests mirror the three inter-related key areas of intersection of these methods (problem structuring, value elicitation and option choice).

From the perspective of problem structuring under deep uncertainty, applying backward logic based on identifying and extending the range of plausible achievement on objectives as defined under MCDA (Wright and Goodwin, 2009) creates a more coherent link to objectives in the scenario construction process. As such, it triggers creation of the narrative around consequence much earlier in the process, which further stimulates option improvement (Paper 2). This approach is not only aligned to the principles of value-focussed thinking (Keeney, 1992), but to the finding that strategy is driven by a search mechanism guided by the representations and values of the management team (Gavetti and Rivkin, 2007).

From the perspective of elicitation under multiple scenarios, findings from investigations are mixed. Extreme scenarios with little or no reference point provided challenges to determining preferences (Paper 2). However, even a few scenarios, when expressed as snapshots appear to make the elicitation process more efficient, but the scenario narrative yielded a marginally better confidence score (Behavioural Experiment, Paper 3). This is in line with assertions in the scenario planning literature of the benefits of constructing a narrative (Schoemaker, 2004; Wack, 1985). Moreover, a relatively large scenario set is likely to increase accuracy (Simulation, Paper 3) at the expense of a higher degree of repetition (Paper 2). Collectively, these findings suggest that managing the elicitation process requires consideration of a scenario set that achieves a balance between diversity (scenarios that represent extreme outcomes relative to the status quo) and coverage of possibilities defined by knowable uncertainties.

This balance is ultimately dependent on the decision context (Paper 2). For a context with few uncertainties and stakeholders, a relatively small set may be appropriate (Parsons et al., 2007). If the onus on accuracy is high, then a more sophisticated modelling approach that evaluates options against a large scenario set is recommended. This is likely to require an automated process which may reduce the level of involvement and ultimately affect confidence in the process and even the ability to confront the possibility of surprise (van Notten et al., 2005). However, the opportunity to use scenarios as a tool for exploring an otherwise incomplete option set should not be underestimated (van der Heijden, 1996). To this end, one should consider clusters of scenarios that capture some extreme possibility (Paper 3). This aligns with the overall strategy in robust decision making (Lempert et al., 2003) and adaptive policy analysis (Walker et al., 2001)

With respect to the basis for choice, findings from the simulation indicate that no measure of robustness has a monopoly on choice. This is somewhat surprising since robustness is based on the notion of lowest expected error across a range of futures, which is conceptually similar to regret minimisation (Willis et al., 2005). Instead, the accuracy of a particular measure (relative to the normative ideal of expected utility) is dependent on the threshold level of risk, and the variability of evaluations (Paper 3). Given risk sensitivity and state-dependent outcomes, developing an understanding of how the long-term initiative translates into the short term is useful (Greeuw et al., 2000). This process of elaborating option development is well-suited to the combined use of scenarios and MCDA (Papers 2 and 3). From a practical perspective, the use of regret has been confirmed as restrictive in its accommodation of risk appetite, and has not proven as useful in supporting option development as initially conjectured (Paper 2). This appears to contradict findings that regret can support decision making (van Dijk and Zeelenberg, 2007; Lempert et al., 2006), but the simulation results indicate that the method here proposed lacked a sufficiently large scenario set. Choice strategies based on some average across scenarios (Hurwicz Pessimistic and Laplace) perform better across a range of risk atittudes. However, features such as across-scenario comparison of performance and exploring the value hierarchy better stimulated option development and should be retained in further development of the method (Paper 2).

4. Limitations

In designing the method, it was assumed that the decision maker could provide judgments on weights and values using a quantitative scale, an assumption which was challenged during the case studies. This is not a limitation of the method as much as an assumption underlying the use of MCDA (Belton and Stewart, 2002). It may have been alleviated by a group decision process, given that the context was characterised by multi-stakeholder concerns. However, practical application remained limited to one decision-maker. A further limitation in this respect was that MCDA models for each scenario were derived by direct elicitation, which meant that it was difficult to facilitate automatic updating of values and weights for new scenarios or options. In addition, swing weighting was the only method used to elicit weights, thereby assuming that trade-offs were inevitable. Acceptable alternative solutions that may not have required explicit trade-offs may have been disadvantaged under this approach (Rosenhead, 2001), but this is merely a limitation of MCDA rather than the method itself. While a range of preference models was explored in the simulation, findings from practical applications were restricted to a linear model. Given the difficulties in practically implementing them (Belton and Stewart, 2002), it may well be impossible to accommodate multi-linear or multiplicative models in multi-scenario settings. The application of MCDA was also underpinned by the assumption that there was ample time for the analysis, and the decision was inflexible and irreversible, and had significant impact (Salo and Hämäläinen, 2010). The application of scenario planning was further made on the assumption that the right organisation existed for the set of futures considered. Consequently, only business choices needed to be considered, not the business model (van der Heijden, 1996). There would be a bigger role for scenarios and MCDA in strategy if the business model proved to be inadequate.

Various limitations also exist in the choice of research methodologies. While triangulation was adopted to enhance validity of assessments on the method, it does not provide an objective answer to it (Flick, 1992). For instance, the action research methodology was limited by evidence from a small number of cases in different contexts. Despite attempts to make the process of analysis recoverable, findings from action research are at best applicable to settings that are similar to those encountered in the cases investigated (Montibeller, 2007). The experimental approach exerted some degree of control on the environment by providing a consistent, pre-defined setting within which to explore decision-making behaviour. However, given a hypothetical, imposed decision problem, one cannot guarantee that participant judgments accurately reflect what they would actually do. On the other hand, the findings from the simulation experiment did not consider the process impacts of different scenario selection strategies, and was solely limited to an investigation on accuracy. In practice, a quantitative simulation model to generate a database of results may restrict the range of phenomenon that can be considered. For instance, many social, cultural, political, and organisational factors may be important to a decision problem but difficult to meaningfully quantify in a simulation model (Bryant and Lempert, 2010).

Finally, any exercise involving scenarios is limited to consideration of known unknowns, which are circumstances/outcomes that are known to be possible, but whether or not they will be realised remains unknown (Brown, 2004). It does not cope at all with unknown unknowns. These are the uncertainties which could significantly affect outcomes, but that may not yet have entered the conscious mind of the decision-maker. Similarly, any evaluation framework that relies on elicitation of preference, such as MCDA, is limited by the fact that judgements made by the same people in the same situation could differ because they select different information and assess it differently at different points in time (Kay, 2010).

5. Directions for further research

The above discussion highlights various areas for further research. The first relates to a strategy for selecting scenarios that achieve a balance between diversity and coverage such that the decision maker remains connected to the concerns being addressed through scenarios. Related to this is further investigation of the impact of direct involvement in scenario development on the efficiency of the evaluation process.

In addition, the scope of the method would be greatly enhanced if guidelines were provided for how to conduct the assessment in a group decision-making context. Various strategies exist for achieving this. For instance, individual preferences may be aggregated through the use of weights (Herath, 2004). Alternatively, separate models could be developed and compared. One collective model based on debate and dialogue using a framework similar to that proposed by Belton and Pictet (1997) could also be considered. Either way, the exercise is likely to be time-consuming and relies on a group who is committed to and comfortable with a collaborative, facilitated mode (Franco and Montibeller, 2010) of making decisions. The generation of scenarios based on the technique proposed here is designed to cope with considering the diversity of stakeholder views by making each stakeholder’s best and worst outcomes the uncertainties to be considered. This should serve to capture the diversity of views that may be difficult under the traditional inductive approach (van‘t Klooster and van Asselt, 2006). The role of scenarios and MCDA in facilitating collaboration could be explored, building on the scope for collaborative efforts based on scenarios (Selsky et al., 2008).

The possibility of using the method to examine a portfolio problem, with decision areas that group similar options (Phillips and Bana e Costa, 2007) should also be investigated. These considerations may in turn create opportunities for the applicability of the method to a wider set of decision problems. This could also be linked to building a portfolio of actions that build the capabilities needed to succeed across multiple scenarios (Schoemaker, 2002), offering scope for closer integration of scenarios and MCDA.

The fourth suggested area for research is the role of the scenario narrative in inducing or reducing the use of heuristics in option evaluation. This could inform strategies for assessing weights and values given a range of plausible outcomes. Related to this is a broader consideration of the place of option evaluation in the wider strategy process. For instance, a resource-based view of strategy has led to scenarios being used to question whether an organisation possesses the right success formula (Schoemaker, 2002). Option development follows from ways to build a robust set of capabilities. Scenarios and MCDA processes could perhaps play a broader role in supporting organisational success by inculcating these ideas.

6. A final word

The key message of this thesis is that the effective application of scenarios and MCDA requires an explicit choice about the desired degree of accuracy, and about the degree of risk one is willing to take. If the motivation for accuracy is high, then a large scenario set ought to be considered. This makes the application of traditional scenario planning impractical. Conversely, if the motivation for engaging a decision maker on a deeper understanding of the issues shaping success under deep uncertainty is high, then a small scenario set with characteristics that prompt a decision maker to consider the vulnerabilities he/she is exposed to may be sufficient. This can be supported by the choice of scenarios as well as robustness measure, since the degree of loss from different operators is small in practical terms. The option development tools inherent in the MCDA framework are well-placed to support refinement of the option set.

With respect to the method proposed in this thesis, re-design should entail the following:

- Preservation of the existing strategy for defining uncertainties and corresponding boundaries
- Identification of a scenario cluster that better captures the opportunities and threats implied by extreme outcomes while maintaining involvement of the decision maker(s)

- A strategy for exploring the implications of changes in values and weights interactively
- Consider a hybrid measure of robustness that incorporates additional levers to drive improvements in option robustness (Lempert and Collins, 2007). A relevant candidate is (b,w)-absolute deviation (Roy, 2010), which bases choice on acceptance of a guaranteed value *w* but maximises the number of scenarios in which the absolute regret is at most equal to the boundary *b*
- Preservation of the cost-equivalent mechanism to enable comparison of MCDA performance across scenarios
- Evaluation of the amended approach in a group setting

The key message for practice is that any method for managing deep uncertainty must accommodate the fact that reality is constructed and re-constructed based on one's knowledge, experience and understanding of the decision context. The implication is that a static view of the option and criteria set as assumed under MCDA is challenged when one considers scenarios, which in turn affects the basis on which choice might be made. Practitioners are urged to embrace the benefits of scenarios in helping to structure a decision problem under deep uncertainty, but to be cautious about using them in small numbers for option evaluation and selection on the basis of robustness.

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