MEASURING GROUP MODEL BUILDING INTERVENTION IMPACT THROUGH PREFERENCE ELICITATION

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***Abstract**: This paper addresses a gap in the System Dynamics literature, concerning the role of participants' goals and preferences in Group Model Building interventions. More specifically the paper discusses the role of changes in individual preference structures and the possibility to detect such changes with the use of traditional judgment modelling techniques. A review of the literature suggests that the importance of individual preferences has already been discussed in SD, and that their relevance is even higher to the Group Model Building setting where consensus and shared understanding of a problem situation is a key deliverable. The main proposition is that eliciting and structuring individual preferences from participants in the beginning and the end of the intervention can: (1) inform us about possible interpersonal conflicts on a value level, and (2) help us capture the effect of the intervention on individual preference structures. Several alternative methodologies for structuring objectives and measuring preferences are discussed and a suggestion is made that SMARTER and MACBETH seem to be most applicable in a Group Model Building intervention. This author emphasizes on the fact that this is a purely theoretical inquiry into the subject and suggests that a follow-up case study should be made.*

***Word-count without abstract and appendices**: 4,761*

Introduction

This paper addresses a theoretical gap in the System Dynamics (henceforth SD) literature regarding the relationship between preference structures and mental models or mental model reformulation in a Group Model Building[1] (henceforth GMB) context. More specifically, it focuses on determining the role of participant preferences in the consensus-building process and suggests ways in which this role can be addressed more formally. Emphasis is put on the suggestion that, on an individual level, both mental models and preference structures undergo a transformation in the course of a GMB intervention. Furthermore, this transformation is interdependent and could strongly affect the outcome of the intervention. Corollary to that, I suggest that it is important to explicitly consider participant goals and preferences alongside their mental models when guiding a GMB intervention. In addition, I hypothesize that changes in the preference structures can also be employed as an impact measure of a GMB intervention if they are made explicit through formal elicitation. Lastly, I discuss the suitability of alternative methods for preference elicitation and measurement to the context of GMB. The main contribution of this paper is that it provides theoretical grounding for a new, potentially useful, method of measuring the impact of GMB interventions. With this, it aims to support a future empirical inquiry into the subject.

Ideas in this paper are inspired by past research on the possibilities of augmenting the decision support potential of SD modelling by incorporating aspects of judgement modelling, such as multi-attribute value theory. This is particularly interesting in a GMB context where

[1] Group Model Building in this paper is understood as "a system dynamics model-building process in which a client group is deeply involved" (Vennix, 1999 p379)

commitment and consensus are influenced by conflicting individual goals and preferences (or value structures). Examining the means/ends model (Richardson et al, 1994; Andersen & Rohrbaugh, 1992), I suggest that systematically eliciting individual value structures of GMB participants can help facilitators to foresee potential conflict in the group and improve their understanding of the individual mental model reformulation processes that take place during the intervention. Furthermore, detecting a change in value structures before and after an intervention could yield a measure of impact of the intervention on the client group.

The rest of this paper is structured as follows. First, relevant literature concerning mental models, preferences, and mental model reformulation in a GMB setting is summarized and interrelationships are identified. This review is used as a basis for discussing the observed gap in mental model research and relating it to the GMB context with regards to the role of participant goals and preferences in an intervention. In this discussion, I suggest reasons why tracking participant preferences should be a formal part of the GMB process as well as ways in which this can be achieved without overburdening the facilitator. In addition, I present a brief overview of preference elicitation and measurement methods. The conclusions are summarized together with comments about the limitations of the suggestions made in this paper and possibilities for further research are outlined.

Mental models and their role in SD

Mental models are frequently regarded in SD as one of the key sources of information about system structure and action-guiding policies (Forrester, 1991; Forrester, 1962). In addition, they are assumed to represent "the cognitive model of the ways the system is [believed to be] structured and functions" (Richardson et al, 1994 p182)[2]. Thus, they drive our decision-making by creating an expectation of consequences from alternative actions. Aligning this expectation within the client group through "learning" or *mental model improvement* about the relationship between structure and behaviour of the studied system is amongst the fundamental goals of GMB interventions (Rouwette & Vennix, 2006; Rouwette et al., 2002; Andersen et al., 1997). The aforementioned implicitly assumes that such improvements will positively affect the performance of the studied system.

While there is no dispute about their importance, Doyle and Ford (1998) suggest there is lack of clarity and consensus in the SD community regarding the formal definition of mental models. Their interdisciplinary literature review has identified that the available definitions: (1) "lack coverage of critical issues", (2) "are brief and somewhat vague", and are (3) "used very generally to indicate any among a wide variety of quite different and distinct mental constructs" (Doyle & Ford, 1998). The authors suggest a conceptual definition to the SD community that describes a mental model of a system as "a relatively enduring and accessible, but limited internal, conceptual representation of an external system whose structure maintains the perceived structure of that system" (Doyle & Ford, 1998) or simply – *"The way*

[2] Text in square brackets is added by this author

we imagine things to work!"[3] While the authors do not suggest this definition to be complete, it builds on the major definitions coming from a variety of fields and authors.

Preferences and their relationship with mental models

What becomes apparent from the aforementioned definition is that the conception of how the system's structure produces its behaviour is decoupled from our attitude towards that behaviour and the value-outcomes associated with it. However, as part of the evaluation and choice process, rational analysis always requires two guesses "a guess about uncertain future consequences and a guess about uncertain future preferences" (March, 1978). While SD research has diligently focused on explaining and (without formally admitting to it) forecasting future consequences based on certain assumptions about causal structure of the studied system, little is said about the role of objectives, preferences, and attitudes. Nonetheless, in their paper discussing the *Foundations of Mental Model Research*, Richardson et al. (1994) point out the importance of addressing conflicting objectives and claim that a "failure to understand aspects of subjects' goals can invalidate conclusions about the role of mental models in dynamic decision making" (Richardson et al, 1994).

A critical aspect concerning (conflicting) goals are the trade-offs between them. This becomes even more apparent in situations where multiple perspectives are involved, such as a GMB intervention. In classical decision theory, trade-offs are addressed by defining a preference structure over an objectives hierarchy associated with the specific decision (as opposed to evaluating/rating the alternatives or policies directly) (Keeney& Raiffa, 1993; Keeney, 1992). The product of this exercise is sometimes called a value tree or a value structure. In fact, our preference structures and values, according to Keeney (1992), are the major reason why we become interested in a decision situation in the first place. We employ them "to evaluate the actual or potential consequences of action and inaction" (Keeney, 1992). Whenever a decision is being contemplated, it usually involves a number of trade-offs, which are traditionally made implicitly in the mind(s) of the decision-maker(s). Formalizing the notion of preferences in Decision Analysis is a way to make those trade-offs *explicit and debatable* (Keeney& Raiffa, 1993). Making the goals and preferences of GMB participants explicit can provide the consultant with a clearer picture about differences in the client group.

In SD literature the role of goals and preferences was first acknowledged in the works of Gardiner & Ford (1980) and later by Andersen & Rohrbaugh (1992 and1983). Gardiner & Ford propose a combined framework employing SD and Multi-Attribute Utility Measurement (henceforth MAUM) for evaluating policy alternatives in a study of boom cities. Describing their motives, the authors note that SD efforts usually stop after displaying the consequences of policy alternatives (Gardiner & Ford, 1980). The authors argue that, while this output is certainly of value to understanding what behaviour could result under different conditions, it tells nothing about how to choose among the policies that produce different behaviours. Thus, management problems tend to be insufficiently addressed by SD, since what's ultimately

[3] This is this author's personal interpretation of Doyle and Ford's definition

important in a decision situation is "arriving at a conclusion of which policy is best" (Gardiner & Ford, 1980).

Andersen & Rohrbaugh elaborate on the issues raised by Gardiner & Ford by examining the construction of a dynamic objective function (1983) and later exploring a variety of conceptual and technical problems with the integration of SD and MAUM (1992). As part of their study, Andersen & Rohrbaugh (1992) develop their basic means, ends, means/ends model for policy formulation which outlines the fundamental aspects of any policy-formulation exercise. The authors suggest that 'ends' relate to the desired outcomes (the goals), 'means' describe the alternative strategies and tactics to achieve those outcomes (decision/policy alternatives), while 'means-ends' represents the assumed causal relationships between means and ends (Andersen & Rohrbaugh, 1992). Furthering their argument, the authors suggest that there is another critically important aspect – the policy makers' preferences towards both the means and the ends. In conclusion, the authors state that traditional simulation models tend to focus on the means-ends (or causal structure), while judgement models "concentrate on precisely measuring the users' preferences about policy ends and policy means" (Andersen & Rohrbaugh, 1992).

Building upon Andersen & Rohrbaugh's (1992) work, Richardson et al. (1994) combine the means, ends, means/ends model with the *Brunswikean lens model* (Brunswik, 1952) to propose a cybernetic loop-structure of learning as a product of interaction with the external environment (see Appendix I). The suggested model describes a learning mechanism that compares desired and actual outcomes from exercised policies to adjust future strategies (Richardson et al. 1994). However, the role of preferences noted by Andersen & Rohrbaugh (1992) is no longer acknowledged in this improved description of mental models. Thus, this framework is not able to address 'if' and 'how' preferences between conflicting goals can affect the decision-making process or the mental model reformulation (learning). This gap is especially critical in a group setting where the mental-models and preference structures of individual participants interact and affect each-other. Acknowledging the importance of preferences in a GMB intervention can help us study how prior attitudes could impede learning about the causal structures.

Mental model reformulation in GMB

Flaws in mental models and cognitive capacity limitations are often blamed for the poor (undesired) performance in complex dynamic systems (Sterman, 1994). Formal modelling and simulation techniques enable the augmenting of human processing capacity, which is aimed at helping us to detect flaws (or blind spots) in our own mental models (Zock, 2004). Using similar arguments, SD literature commonly (and implicitly) assumes that "providing a better understanding of the structure and behaviour of complex systems by employing system dynamics simulations will solve most of these problems" (Vennix, 1999). However, even the best simulation model is not sufficient in addressing "messy" or "wicked" problem situations (Churchman, 1967). Such cases, not only involve limited access to quantifiable data, but are

also frequently characterized by a pluralistic "client system" (Tomlinson, 1984), holding conflicting objectives, and having uncertainty about their goals and values (Rosenhead & Mingers, 2004; Vennix, 1996).

Vennix (1999) suggests that GMB (see *footnote 1* for definition) is particularly effective in addressing messy problems through rigorously mapping and modelling the perspectives of important stakeholders from the client organization in a group setting. In this process, GMB participants expose, communicate, test, and reformulate their mental models "in such a way that a shared definition of the problem results" (Vennix, 1996, p 5). This shared problem definition is assumed to help the client group in achieving consensus, commitment to further actions, and ownership of the devised problem solutions (Vennix, 1996). According to Andersen et al (1997) further outcomes of a Group Model Building process include, amongst others, participant mental model refinement, organizational consensus and alignment, and "...change in *attitudes* towards a proposed policy" (Andersen et al., 1997, p 191). Here, mental model refinement relates solely to an improvement in the individual participant's understanding of underlying system structure and feedback effects and attitudes can be interpreted as the relative preference over alternative policies.

While Andersen et al. (1997) have listed a variety of effects that group model building has on different levels in a system (e.g. individual participants, the group, and the overall organization), Rouwette and Vennix (2006) note that on a more detailed level "it is still unclear how these levels interact". Amongst the important questions they raise is the need for better understanding on how the group affects individual learning processes and in turn, "…how (individual) learning contributes to consensus [building]". In addition, there is limited understanding in the SD field of "the impact of exchanged information and other cues on participants" (Rouwette & Vennix, 2006, p 462) in a GMB setting. Getting more insight on how interactions during GMB intervention affect the objectives, preferences, and mental models of participants could improve our understanding of the processes that take place during an intervention. In turn, this could help us design and perform more effective and consciously guided group decision interventions.

However, in order to be applicable, individual preference elicitation techniques need to fit the form and flow of GMB interventions. Thus, in the next section I review and evaluate the suitability of alternative preference elicitation techniques to the GMB process.

Discussion

Based on the previous sections, one can conclude that the current definition of mental models does not address the evaluation aspects of decision problems. More specifically this relates to critical aspects such as goal formulation, trade-offs between goals, selection of cues to assess the system state, and the choice between alternative strategies to achieve the formulated goals. One effect of this limitation is that the problem formulation and structuring phases carried out in a GMB intervention do not formally surface participants' prior assumptions. As a result, this poses limitations to the creation of a shared understanding about how system structure

produces its behaviour, since each participant might be attributing different meaning or have different attitude towards alternative states of each of the aforementioned aspects. In relation to this GMB researchers have recognized that "... [a] necessary prerequisite for behavioural alteration is a change of attitude" (Andersen et al., 1997, p 191). This gap in literature creates opportunities for further research and for "increasing the pertinence of simulated environments to actual policy-making processes" (Andersen & Rohrbaugh, 1992). Moreover, empirical inquiries could help us devise new methods for evaluating the impact of GMB interventions on the session participants that base on detecting changes in their preference structures. Consequently, I suggest that the formal measurement of preferences in GMB setting is a way for addressing this gap and providing a *behavioural*[4] bridge between facilitated simulation modelling and judgment models for policy analysis and evaluation.

Andersen and Rohrbaugh (1992) implicitly touch upon this, suggesting that, apart from means (how we achieve our goals), ends (what are our goals), and the relationship between them (means-ends), all policy formulation should regard the relative preferences towards alternative means and conflicting ends. In relation to this, there are at least two highly important implications of preferences in the context of GMB and mental model research in general. From a prescriptive standpoint, client preferences are necessary to produce an evaluation of policy alternatives in order to enable choice amongst them (Gardiner & Ford, 1980; Andersen & Rohrbaugh, 1992). From a descriptive view, as preferences are dynamically constructed, they could bias the problem formulation (Keeney, 1992; Slovic, 1995). In both cases, being aware of participants' goals and preferences in the course of a meeting would provide the facilitator with better understanding of the motivations behind certain behaviours, especially in situations where conflict and disagreement arise.

Through the course of a GMB session, the facilitator helps the group in formulating a shared description (Vennix, 1996) of the problem, and surfacing, challenging, and improving their assumptions about how the system works (their individual mental models). However, researchers in group negotiation support have pointed out that conflicts amongst parties arise even in situations where there is complete agreement on what the fundamental goals and the consequences from decision (or policy) alternatives are (Darling et al, 1999). Such conflicts arise due to the fact that decisions (or policies) involve the inevitable commitment of limited resources, and resource constraints lead to interdependency amongst the individual (personal) objectives and preferences of group participants (Darling et al, 1999). To prevent or resolve such conflict, an early clarity (transparency) about the differences in participants' preferences and objectives is critical as it provides an understanding of the motivations behind assumed positions. In traditional decision analysis, such clarity is achieved by making the assumptions about individual goals and preferences explicit. This could help GMB interventionist gain a better understanding and influence over the consensus-building process.

Keeping track of individual preferences is especially critical in situations involving a pluralist stakeholder group which holds conflicting objectives – situations in which GMB

[4] As opposed to technological

tends to be most suitable. In this context "[t]he observer of a system [the client group] and his relationship to the system including for example goals, interests, sympathy or antipathy [preferences and their direction] are not suitable objects of the epistemological theory underlying SD"[5] (Zock, 2004). Thus, while SD helps us to elicit and document the evolution of participants' mental models through continuously mapping their means-ends structure (using causal or stock and flow diagrams), it does not help us surface the objectives of participants and the relative importance/preference they allocate to those objectives. Hence, we could benefit from employing methodologies that make individual goals and preferences of group participants explicit and debatable. In alignment with this, Gardiner and Ford (1980, pp 244) note that involving judgment models in SD interventions shifts attention "from seat-of-the-pants 'gestalt' evaluations of policies to focus instead on the impacts of policies and the values these impacts serve" (Gardiner and Ford, 1980). Differentiating from past research, my suggestion is to combine SD with judgement models on a process level in a group decision support setting rather than on a technical (modelling) level.

At least two important questions need to be answered before proceeding: (1) which preferences and objectives exactly should we track? And (2) what methodologies should we use to elicit them? While Andersen and Rohrbaugh (1992) talk about preferences with regards to means (actions) and ends (objectives/desired states), MAUM and *Multi-Attribute Value Theory* (Keeney & Raiffa, 1993) suggest that objectives should be structured hierarchically in a value tree format (example in Appendix II) to ease the subsequent application of a *value model* (Keeney, 1992)[6]. Relative preference weights can be allocated to the sub-objectives to produce a co-measurement scale for their achievement. Thus, to account for changes in preferences we should track both the structure of objectives of each GMB participant, framed in the context of the specific problem definition, and the importance allocation to sub-parts of this structure. Translating this definitions into Andersen and Rohrbaugh's (1999) *means-ends* model, *means* correspond to the policy alternatives, the performance of which we need to evaluate against each of the *ends* (or objectives) in the constructed hierarchy (Keeney, 1992; Keeney & Raiffa, 1993). Thus, trade-offs between *means* are addressed with the use of *ends*.

To address the second question, I will briefly review and compare four alternative methods for eliciting preferences in MAUM (*direct rating, swing-weighting, ranking, and MACBETH*). Subsequently, I will comment on their applicability in a GMB setting. In 1971 Edwards developed SMART (Simple Multi-Attribute Rating Technique), which was adopted by the decision-analytic community as a simple method to formulate and analyze decision problems. With SMART, after structuring objective hierarchy, preferences (importance weights) are elicited through directly assigning a number between 0 and 100 to each objective and then normalizing to 1 (**Direct Rating**). In 1977 SMART was fully replaced by SMARTS (SMART using Swings), which "remedied an intellectual error of SMART" (Edwards & Barron, 1994, p316) with regards to the conjoint measurement of range and relative

[5] Text in square brackets is added by this author

[6] See Appendix IV for a description of Multi-Attribute Value Theory and the value model and Chapter 3 from Keeney (1992) for more details on structuring the hierarchy of objectives

importance of variables[7]. Swings or **Swing-Weighting** in SMARTS referred to "changing the score of some object of evaluation on some dimension from one number to a different one (typically from 0 to 100)" (Edwards & Barron, 1994, p316). The procedure happens in two steps – first, the decision maker is asked to rank-order assessment dimensions, associating with the decision-makers' objectives according to their relative importance; then the decision maker is asked to trade-off 0-100 swings in one dimension for swings in another one (Edwards & Barron, 1994). This provides an estimate of the relative importance of objectives. While this method of measuring strength of preference is perceived to have high validity and is widely employed in judgment models, it is tedious and complicated (Fasolo & Bana e Costa, 2009; Bana e Costa et al, 2005). It requires multiple "swings" and works best with decision makers who are comfortable with working with quantitative estimates (Fasolo & Bana e Costa, 2009).

Two simplified versions of SMARTS were proposed, which yield similar results but do not require sophisticated quantitative skills or tedious swing-procedures. First, SMARTER (SMART Exploiting **Ranks**) assumes that "if nothing else were known about weights except their sum, set at 1 by convention, then the set of possible non-negative weight vectors would be any that have that sum" (Edwards & Barron, 1994). Knowing the importance-ordering of evaluation objectives the analyst can then use the smallest simplex, consistent with the ranking to estimate preference weights (Barron & Barrett, 1996). A simulation check by Barron and Barrett (1996), who developed SMARTER, suggests that this method is 75-87% likely to reproduce weights allocated through the SMARTS technique (corresponding to an estimated average utility loss of 2%), with only a fraction of the effort. Thus, Edwards and Barron (1994) who reviewed the approach before the original paper was published, suggest that it deserves credit and is definitely better than any techniques that assign equal weights.

Lastly, **MACBETH** (Measuring Attractiveness by a Categorical Based Evaluation Technique), was developed by Bana e Costa et al (2005) as a method for eliciting qualitative judgments of preference and transforming them into quantitative weights. The method relies on rank-ordering the evaluation criteria from most important to least important and then providing a series of pair-wise qualitative comparisons about the "difference of attractiveness between the most attractive of the two elements and the other" (Bana e Costa et al, 2005, p411). The qualitative judgments of importance difference are reported to a software interface (see appendix IIIa) and a linear optimization model is then used to convert them into quantitative measurements. The decision-maker can then adjust weights on a 'thermometer' displaying the assigned numbers on a 0-100 scale (see appendix IIIb). While it is more rigorous than SMARTER, this method for eliciting relative preference weights is also more precise and allows for a subsequent correction of judgments. Furthermore, as Fasolo & Bana e Costa (2009) suggest, its qualitative nature enables its application in a broader audience.

[7] Namely that "weights must be proportional to a measure of spread times a measure of importance"(Edwards & Barron, 1994 p316)

Analyzing the applicability of the aforementioned methods for eliciting preferences, we need to account for the time and focus requirements on both the consultant and the client. Furthermore, a broadly applicable technique would need to be easy to explain and deploy in a group setting and should not rely on high numerical literacy on behalf of the client group. I foresee three possible approaches to the elicitation: (1) In individual interviews prior to the intervention and then at the end of the intervention; (2) Individual work during the course of the group intervention; (3) Group work during the course of the group intervention. Of course, a combination of the above might be employed if it seems appropriate. Elicitation in individual interviews provides the benefit of direct individual feedback, which ensures clearer communication between the consultant and the client. However, elicitation from a larger number of stakeholders will be time consuming and costly. Individual elicitation in a group session could save time but result in low-quality data as misunderstandings would be more difficult to detect and address. Group elicitation might take too much time from the group's attention and could also result in group-think or premature convergence of opinions. Empirical comparison between the costs and benefits of the three approaches based on experimentation or case-study work would result in better understanding.

A combination of the three approaches might be most fruitful as the consultant needs at least two measures to detect a change in the individual (and group) goal and preference structure. An individual elicitation in an interview setting might prepare the participants by introducing them to the methodology and thus – save time in the group setting. Furthermore, individual elicitation in a group or interview setting would isolate the effects of group-think and premature consensus and thus, allow the consultant team to explore possible areas of conflict more deeply.

Based on the elicitation methods presented above, I suggest that techniques such as SMARTER and MACBETH are most appropriate for preference elicitation in a GMB setting, regardless of the approach (individual interview, individual work during the group intervention, or group-work during the intervention). This is due to their (task) simplicity and ease of access (they are easy to communicate). Moreover, since at least two measurements per participant are necessary to detect changes in the objective structure and preferences, SMARTER might be most appropriate due to its minimal time and technology requirements. However, in order to provide a better argumentation, further empirical research is necessary.

Conclusions

Throughout the years, "SD has knowingly distanced itself from many of the ideas of OR/MS, this being seen as necessary for the establishment of the new discipline" (Lane, 1995 citing Forrester, 1962). However, as the discipline matures, it can afford to borrow concepts and techniques from related fields in order to increase its reach and usefulness. In this paper, I suggest that the traditional concept of preferences employed in judgment models should be considered in combination with the concept of mental models, especially in a GMB context. The benefits are that we can (1) provide a better understanding and support of the consensus-

building process in a GMB intervention, and (2) use measurements of the transformation of preferences throughout a GMB intervention as an indication of the intervention's impact.

One of the primary concerns of GMB is building a shared problem definition for the client participants. However, "problem definition is not a simple and straightforward matter. In a circular process, problems are defined to fit the methods available and the assumptions associated with a given methodology are more or less rigorously met as the problem is forced into the methodology's analytical framework" (Andersen, 1980). By incorporating preferences in the analytic framework incorporated by GMB, we will enrich the usefulness of our interventions by expanding our analytical framework. Taking goal and attitude differences between participants into account when guiding the process towards consensus building and a shared definition can lead to more targeted interventions. This will enable us to analyze the problem from the frame of a shared mental model and a shared objectives structure, as opposed to focusing solely on the dynamic hypothesis. Employing the concepts of goals and preferences in a GMB setting will help us ensure that in addition to helping clients converge around a shared definition of the problem, they also surface the motivations behind supporting different policies to deal with that very same problem.

This paper provides a brief overview on the importance of preferences in mental model research and some past efforts in filling that gap by combining SD with judgment models. In contrast to previous attempts to merge SD and judgment models on a simulation basis, I suggest that the combination seems to come more naturally on a process level. This is especially applicable in a GMB setting and will help to resolve some of the mathematical hurdles faced by previous attempts to address judgements in SD research (Gardiner & Ford, 1980; Andersen & Rohrbaugh, 1992). Four alternative methods for preference elicitation are summarized and SMARTER and MACBETH are suggested as most appropriate for a GMB intervention context. I suggest that those methods can be employed to provide practitioners and with a "radar" for guiding GMB interventions and tracking their impact on client participants.

The suggestions from this research present a integrative methodology that could help GMB facilitators guide their interventions and document impact on the client group. One should keep in mind, though, that at this moment the claims made in this paper are based on purely theoretical research and need to be supported by an empirical enquiry into the subject. Nevertheless, this paper provides an indication on which preference elicitation methods are less burdening for the facilitator and can serve as guidance for one such empirical inquiry.

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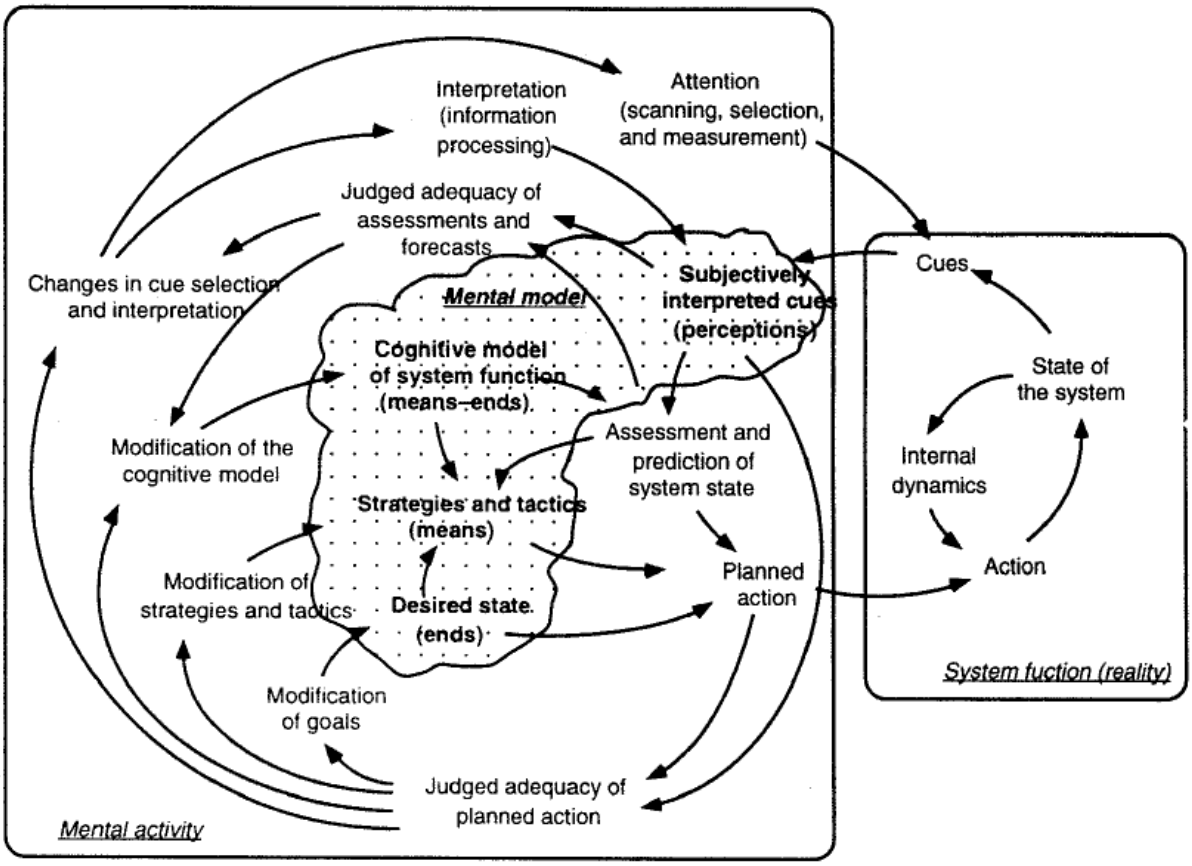
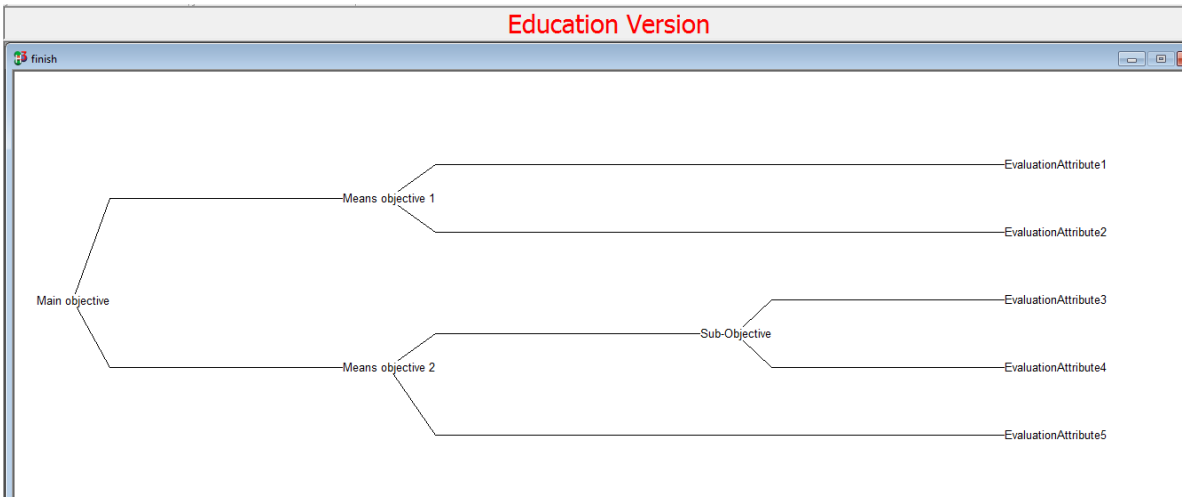
Appendix I



This diagram describes the suggestion of Richardson et al. (1994) on the interrelationship between the Brunswikean lens model and Andersen & Rohrbaugh's means/ends model. Effectively, the dotted part represents the mental model through the means/ends model, which interacts with the external environment (the box on the right). Surrounding the mental model we can also see the learning mechanism as described by Richardson et al. 1994

Source Richardson et al. 1994

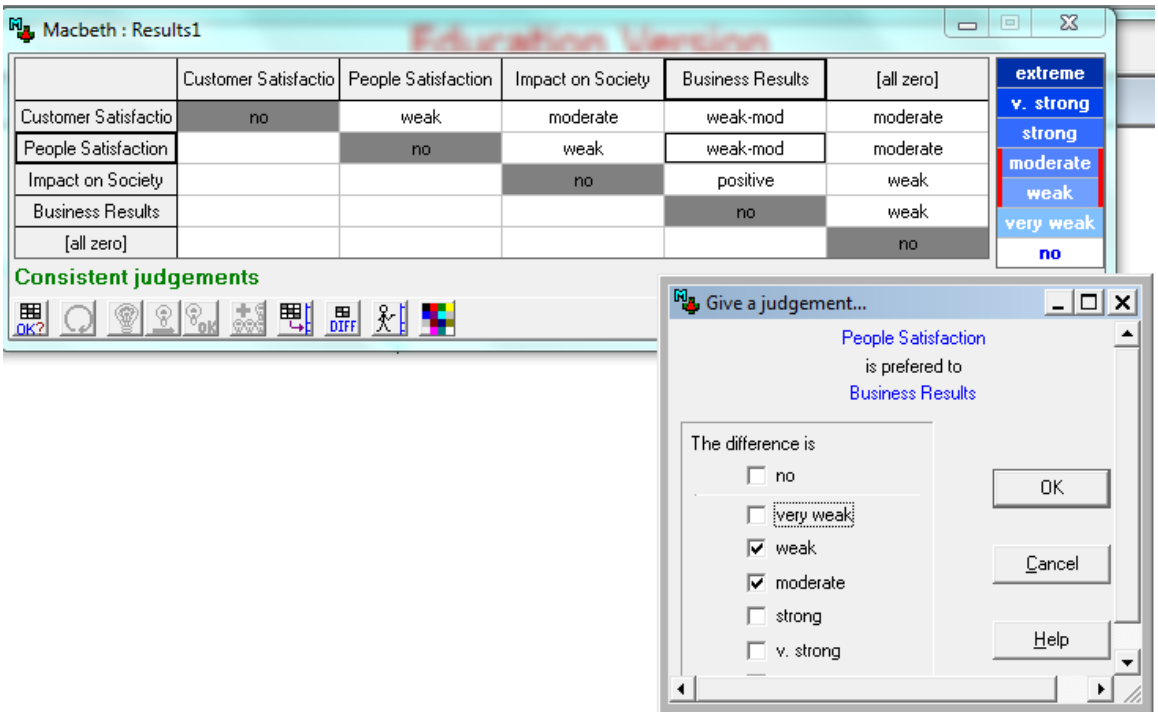
Appendix II



This figure provides an example of a simplified objectives hierarchy. On the left, we can see the fundamental objective, formulated in the frame of a specific decision problem. The means objectives below it are mid-level objectives which support the attainment of our main (fundamental) objective. At the end nodes of the objectives hierarchy we can find the attributes which help us operationalize (measure) how well different policy (decision) alternatives contribute to the attainment of our objectives.

Source: Hiview 3 – academic version

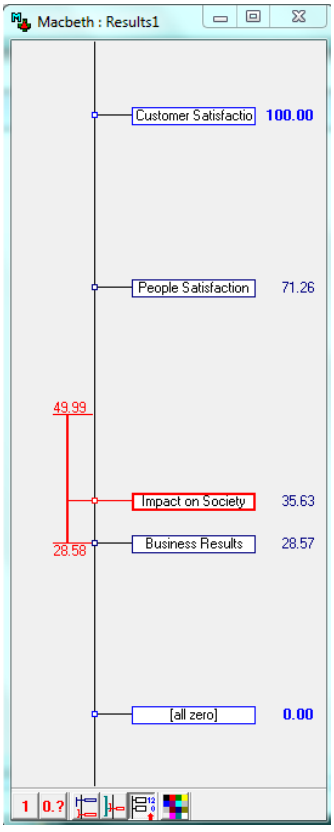
Appendix IIIa



This is how the qualitative importance differences are reported to MACBETH

Source: MACBETH for Hiview 3 – academic version

Appendix IIIb



This is the "thermometer", where the estimated relative importance from the linear programming model can be adjusted to fit the decision-maker's specific preferences.

Source: MACBETH for Hiview 3 – academic version

Appendix IV

Under the MAVT framework, the analyst structures a value tree, which represents a hierarchy of objectives and the associated trade-off weights between them. The analyst elicits a set value functions and a set of relative importance-weights associated with each value function from a decision maker to fully operationalize the tree. The purpose of this is to produce a combined measurement of benefits and costs (henceforth – total value score). The value tree provides a visual representation of how the objectives and the evaluation criteria relate to each-other. The value functions serve to transform the achievement (or performance) of each decision (policy) option on each evaluation criterion into the value score. Finally, the relative preference weights are applied to discount each achieved value score according to its relative importance while taking into consideration the scope of variables. Combining the value functions (v_i) and relative preference weights (w_i) with performance data for each evaluation criterion (c_i) on a decision (policy) option (O_p), enables the analyst to obtain the total value score for each alternative. This value aggregate, is produced employing a simple additive value model in the form of:

$$Total\ Value\ (O_p) = \sum_{i=1}^{n} w_i . v_i(c_i).$$