2. Problem Formulation and Classification in Integrated Assessment Modelling

Modelling group report

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Introduction

In this paper we address the steps that precede the creation of a mathematical representation of real world phenomena. More specifically, we investigate first the formulation of the 'problem statement' in an integrated assessment modelling study, seeking here to offer a more precise definition of problem formulation and examining its influence on later stages of modelling. We identify, through both numerous group discussions at the summer school and a survey of the Integrated Assessment literature, that although there is much discourse around the 'problem' formulation, it has not been well defined. Subsequently, a more precise definition may aid in helping us to understand the steps researchers might take in formulating and solving a problem. Furthermore, problem formulation will be improved through additional classification and detailed analysis particularly with respect to stakeholder involvement and participatory approaches. These steps may be of value to not only emerging researchers and professionals such as has attended this current and future Summer Schools, but also giving credence to the observed lack of attention to problem formulation in the literature.

In the initial stages of this Summer School project, the modelling group considered several possible areas of study for the subsequent paper. These included reviewing and evaluating all of the steps involved in exploring and modelling a study topic of interest, attempting a preliminary modelling exercise for one of several possible case studies, or coordinating with the sustainability group in order to model the problem formulated by that group. After discussion, the group decided to explore steps leading up to mathematical modelling of a particular problem. A significant factor that drove our desire to explore this topic was Pim Marten's presentation at the Summer School, which included material on this topic.

The decision was also motivated by the fact that the steps in model formulation that precede the mathematical and computational aspects are hard to deal with and thus receive little attention, as discussed above, yet are crucial for the modelling process in its entirety. These are hard to deal with because they connect the real, un-formal world of the problem to the mathematical, formal world. Mishandling these initial steps may thus lead to the creation of an inappropriate model. A careful consideration of the steps from the formal to the un-formal world is needed to legitimise the modelling activity and to determine the meaning of the model and the results of the model application.

The remainder of the paper is organized as follows. In the next section we describe a typical characterization of a 'problem' used in integrated assessment. This leads to a number of questions concerning the stages of problem formulation and analysis, and how problems may be characterized. We describe the stages of problem formulation, offering a set of characteristics by which problems may be classified, and consider during which phases of problem formulation each of the characteristics are relevant. Finally, we describe and present a classification of modelling methods and/or model types within the context of the stages of problem formulation.

Context and Research Questions

Problems that are of greatest interest to integrated assessment analysis are typically considered to be problems that are 'unstructured', a concept associated with problems that have both a high degree of uncertainty and a high degree of value conflict (see Figure 1).

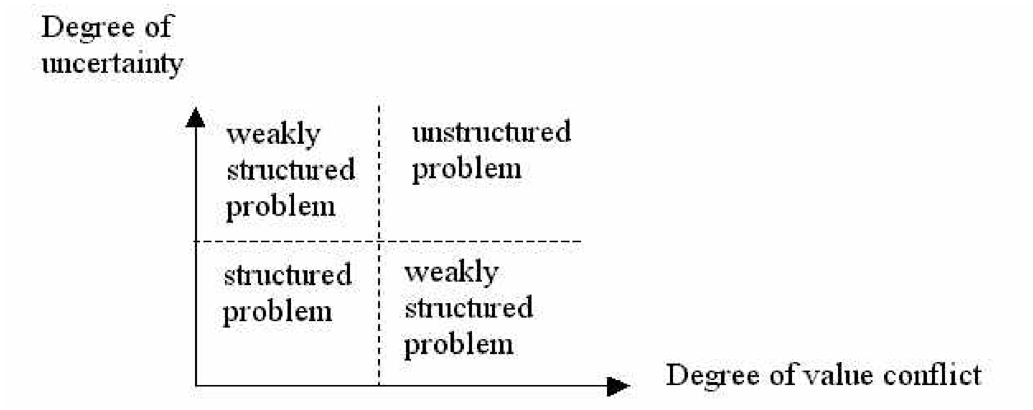

Figure 1: Characterizing Problems from an Integrated Assessment Perspective

This two-dimensional characterization raises a number of questions, as the respective axes are relevant at different stages in problem formulation and solving. In addition, other characterizations of what makes a problem specifically interesting as an integrated assessment problem will add insight to our understanding. The questions that are raised are:

1) What is meant by a 'problem', and what stages are involved in its formulation and analysis?
2) How might research problems be classified?
3) How might these axes be alternatively characterized or expanded?
4) At what stages of problem formulation are these axes relevant?
5) How are social science issues addressed in this characterization, and what sources of information may be used to aid the stages of formulating a problem?

Each of these questions are addressed in turn in the sections below. The term 'problem' in the context that was used in the diagram above is represented with apostrophes throughout this article.

Problem formulation and classification

How can a problem be formulated and analysed?

The steps involved in formulating and analysing a problem, such as those presented by Dr. Martens during the Summer School, may be improved through further clarification and detail. Figure 2 shows a proposed restructuring that allows us to consider more explicitly the importance of issue identification and 'problem' definition, as these steps play a fundamental role in shaping and constraining the question that will be analysed. In this paper, we only explicitly address the stages above the line – those stages that precede establishing mathematical equations that will represent the relationships determined in the conceptual model(s).

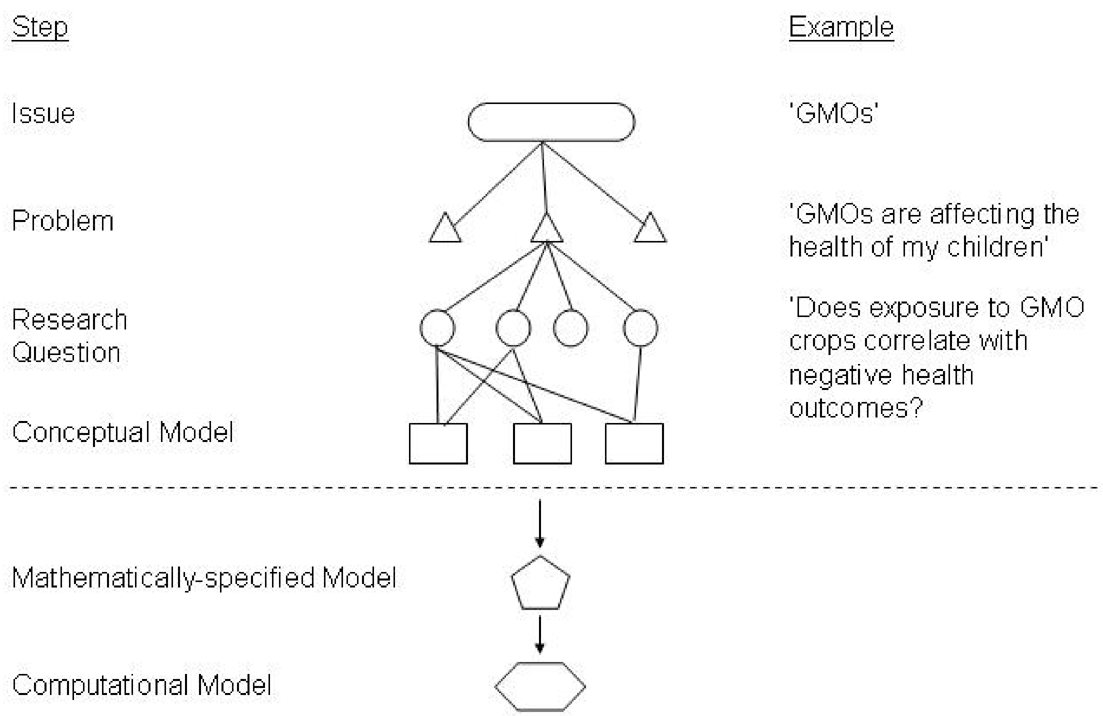

Figure 2: Steps in 'Problem' Formulation and Analysis

It is common for scientists to assert that problem-solving exercises begin after a research question has been determined, but we assert that, in many instances, the most relevant and controversial aspects of problem formulation occur in the first two stages. For example, suppose the issue at hand is water management in the polders of The Netherlands. One might easily elicit very different definitions of the problem from different groups of scientists. For example, one group might consider the problem to be 'How might we alleviate flooding of the polders?', but another group might consider the problem to instead be 'How can we reduce societal infrastructure damage in polder areas?'. How one views the problem, or even considers and prioritises issues, strongly influences the conceptual model that is consequently developed. Note that the term problem as applied here differs from the more general use of the term 'problem' as applied in Figure 1.

Any problem may have several consequent research questions. It is also useful to note a particular research question might be assessed using several possible conceptual models (and consequently several mathematical models), leading to the possibility of different conclusions. These different conclusions may be driven by different assumptions within conceptual models and/or by different sources and interpretation of data, in addition to differences associated with framing the problem differently at a conceptual level. On the other hand, it is also important to note that not all conceptual models are capable of assessing any particular research question.

How might research problems be classified?
The third stage of formulating and assessing a 'problem' involves determining a particular research problem. Research problems may be meaningfully classified from a modelling perspective as follows, which an example of each classification given.

1. ***"What"*** - What is the current state of the system? (e.g., How much biodiversity exists?)

2. ***"What if"*** – How does the state of the system change when one or several of the system drivers change? (e.g., How does biodiversity change under globalisation?)
3. ***"How"*** - What state of all (or some) of the drivers will achieve or maintain a certain state of the system? (e.g., How may we preserve the existing state of biodiversity?)

These classifications have relevance in the context of the characterizations (represented as axes) that may be used to define 'unstructured problems'. We now consider a possible expansion to these axes, then explore the relevance of these axes in the 'problem' stages and research problem classifications identified above.

How might characteristics of 'unstructured problems' be expanded?
The characteristics of 'unstructured problems' given by Pim Martens appear frequently in integrated assessment literature. However, these axes are not sufficient to capture the complexity of 'unstructured problems' in the context of the 'problem' formulation stages that were introduced earlier. An alternative suggested set of relevant characteristics given in Figure 3.

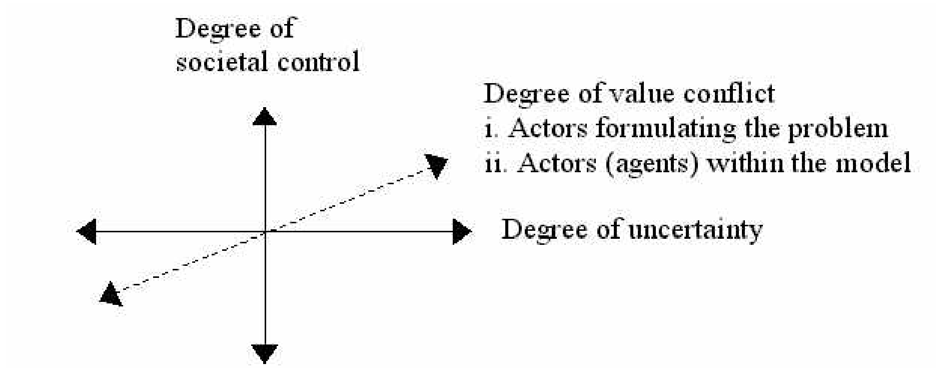

Figure 3: Relevant Characteristics for Assessing 'Problems' in Integrated Assessment

The degree of value of conflict continues to be an important characteristic of 'problem' definition. However, it is important to distinguish between value conflicts that occur among groups that are determining issues, problems, and research questions, and value conflicts that occur between conceptualised and modelled agents, such as are common in agent-based modelling techniques.

The degree of uncertainty also continues to be an important characteristic of 'problem' definition. It may be useful to explore the degree to which different types of uncertainty, such as those described by Dr. van Asselt, play differing roles in determining the unstructuredness of a 'problem'. In addition, different types of uncertainty apply during different stages of 'problem' formulation, and must be addressed by different actors and by different techniques.

The degree of societal control is also relevant for determining the 'unstructuredness' of a 'problem', as it relates to the stages and types of research problems described above. For example, 'problems' centred on physical systems have been traditionally (and to some degree continue to be) treated as problems over which society has a large degree of control. This is also true to a certain degree for 'problems' involving economic systems, although the *animal spirits* of Keynes illustrate the injection of unpredictability associated with human systems and behavioural uncertainties. The range of societal control across such systems varies considerably, and is therefore relevant to the discussion of what makes a 'problem' unstructured.

We turn now to the issue of how these characteristics interact with the stages of 'problem' formulation.

At what stages of 'problem' formulation are the 'problem' characteristics relevant?
The axes considered above affect 'problem' formulation at different stages, and must therefore be treated differently. Value conflicts among actors within the process of 'problem' formulation are distinct from actors, or agents, within conceptual models. Issues of societal control play an important role at several stages of 'problem' formulation.

Stage	Relevant Characteristics (axes)
Issue	
Problem	Value conflict (i); Uncertainty; Societal control
Research question	Value conflict (i); Uncertainty; Societal control
Conceptual model	Value conflict (i) and (ii); Uncertainty; Societal control
Mathematically specified model	Uncertainty; Societal control

Table 1: Stages at which 'Problem' Characteristics are Relevant

What role do they play in assessing different types of research questions?
"What" research problems are principally concerned with uncertainty. They do not concern the degree of shared values, or the degree to which we ('society') may control this system.

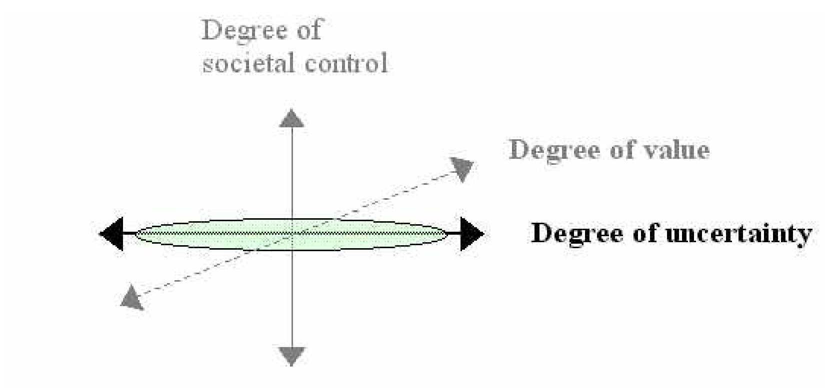

Figure 4: Relevant Characteristics for "What" Research Problems

"What If" problems are also principally concerned with uncertainty. They do not address the level of societal control (because they are interested in examining the impact on the system under an existing level of control). The degree of shared values do not play a role except to the extent that they affect society's perception of the degree of uncertainty.

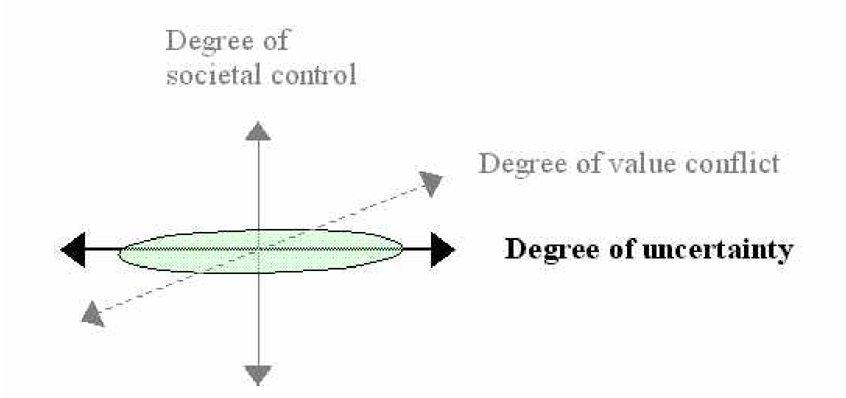

Figure 5: Relevant Characteristics for "What If" Research Problems

"How" problems concern societal control, in the sense that we wish to use control to achieve a certain state of the system. Therefore, it tends to concern problems that operate on the higher range of the degree of societal control, because "How" problems over which we have low or no societal control may be difficult or impossible to solve. There are also likely to involve a moderate to high degree of value conflict, because different actors within a system are likely to prefer certain methods of achieving the desired state of the system. "How" problems are also the most likely to involve value conflict in the formulation of the problem, because they ask questions concerning whether we should take action, and if so, how much.

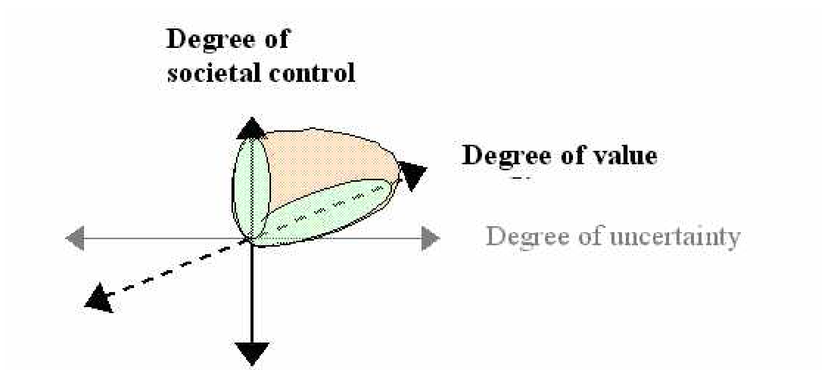

Figure 6: Relevant Characteristics for "How" Research Problems

Who is typically involved in assessing each stage of formulating a 'problem'? What additional sources of information are sometimes used?
A limited amount of discussion occurred on these topics, yielding the information in Table 2, which should be treated with this in mind. Note that 'Expert' assessment may be considered relevant and important in stages as early as Problem' determination, or perhaps even Issue identification. This contrasts with the traditional approach to formulating and solving 'problems', in which science plays the role of a objective provider of knowledge and truth.

Stage	Actors Involved	Information Sources
Issue	Decision maker, 'Expert'?	'Design' approach (sometimes advocated for social science) and/or Participatory methods

Problem	Decision maker, 'Expert'?	'Design' approach; Participatory methods
Research question	Decision maker; 'Expert' (academic; govt; private firms)	'Design' approach; Participatory methods
Conceptual model	'Expert'	Scientific literature; Existing conceptual and mathematical models; Participatory methods
Mathematically specified model	'Expert'	Scientific literature; Existing mathematical models

Table 2: Actors and Information at Different Stages

Other Explorations – Model Clustering

The group was also interested in considering how modelling methods might be classified to analyse the characteristics explored earlier, as well as exploring how model types might be clustered according to the classifications of research problems discussed in previous sections.

The group began by attempting to identify modelling methods through a brainstorming session. Next, an attempt was made to classify the methods and to consider which methods might be more appropriate within the context of the axes explored earlier. For example, might certain methods be more appropriate for addressing situations that including high levels of uncertainty? Similarly, certain modelling methods may be appropriate for formulating and solving one research question but not for others.

Although the brainstorming session was somewhat fruitful, few clear patterns emerged that allowed classification. Issues were raised concerning the difference between modelling methods and model types. What is meant by methods? Does it involve the way that information is collected or aggregated? Can a method be separated from a model type, or in general is there a well-defined relationship between the two? Neither 'model type' nor modelling method' were defined to the satisfaction of the group. Lack of time prevented the extension of this discussion, but it is worth noting that the topic may be of future interest, as it was well received and the topic of some debate by other Summer School participants during the concluding presentation.

Conclusions

Unstructured problems are of particular interest to researchers in the field of integrated assessment. The characteristics of such problems, however, require greater clarification and definition, which in turn may lead to insights concerning how such 'problems' might be formulated and addressed, both in terms of developing useful typologies and in terms of the stages through which 'problems' are formulated and analysed. This paper is an initial effort in this direction. It may prove as a useful guide for further, deeper, and more careful exploration of these topics within the context of integrated assessment.

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