Simulating stakeholder support for river management

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Abstract: River management is a typical example of a complex problem involving a variety of stakeholder interests and fundamental environmental uncertainties. The Dutch government aims to take the different interests and views explicitly into account by allowing stakeholders to participate in the planning process. The aim of our research is to analyse this participatory process to investigate stakeholder support, their influence on the decision-making process, and the role of norms and co-operation. To this end, we developed an agent based model representing a negotiation among stakeholders. Stakeholder support for a river management strategy is modelled on the basis of the Theory of Reasoned Action and a theory of Social and Cognitive Action. For evaluating the different river engineering alternatives the Agent Based Model is coupled to an Integrated River Model that describes possible long-term impacts (e.g. flood risk, nature development) of river engineering options. We show how the coupled model framework can aid to analyse the participatory planning process of the ongoing Grensmaas project. Also, we assess how the policy outcome might change when the agents would take climate change into account.

Keywords: Participatory Agent Based Modelling, River modelling, Stakeholders, River management

1 INTRODUCTION

Agent Based Modelling (ABM) has been identified as a promising technique for the explicit representation of stakeholder perspectives in policy relevant research. Agent based models may be incorporated into Integrated Assessment modelling frameworks for a better representation of stakeholder behaviour in Integrated Assessment models allowing us to investigate stakeholder-environment interaction (Rotmans, 2002). Furthermore, agent based models can be used to structure participatory processes, stimulating social learning by sharing viewpoints among stakeholders (Pahl-Wostl, 2002).

In this paper we apply the approach of ABM to a case study of river management. We will focus on the river engineering project ‘Grensmaas’ which is currently ongoing in the Dutch province of Limburg. The Grensmaas project was initiated in 1997 to achieve three main goals (Maaswerken, 1998): 1) reduction of flood recurrence to 1:250 years, 2) the development of a minimum of 1000 ha of riparian nature, and 3) the extraction of a minimum of 35 million tons of gravel for national use. To this end, measures are planned to widen the Meuse to the north of the city of Maastricht over a length of some 40 km.

The Grensmaas project affects many stakeholders with a variety of interests. The main stakeholder groups of the Grensmaas project are the inhabitants of the region, farmers, nature organizations, and the gravel extracting companies. It is an explicit aim of the project organization to involve these stakeholders as much as possible in the decision-making process in order to develop an integrated strategy and a broad societal interest and support.

In this paper we analyse the participatory planning process of the Grensmaas project. We thereby use an agent based model to assess stakeholder support for a river management strategy on the basis of their goals and beliefs. In the first model prototype discussed here we assume the cognitive representation of goals and beliefs to be static. In future research we will further investigate and implement mechanisms of adaptive cognition.

With the current prototype we assess optimal strategies from the perspectives of individual stakeholders ('ideal' strategies), as well as plausible negotiation outcomes ('compromises'). Finally, we show how the negotiation process could change when all stakeholders would take climate change into account.

2 A MODEL OF STAKEHOLDER SUPPORT

2.1 Determinants of support

The conceptual model of stakeholder support is depicted in **figure 2.1.** It is based upon the well-known Theory of Reasoned Action (TRA) (Ajzen and Fishbein, 1980) and a theory of Social and Cognitive action (Conte and Castelfranchi, 1995). Stakeholder support is determined by three factors:

Attitude: In the TRA attitude towards a behaviour is described as 'the individuals positive or negative evaluation of performing that behaviour' (Ajzen and Fishbein, 1980). We interpret this notion as an evaluation of self-interest goals that arise from a so-called pre-cognitive objective relation of interest (Conte and Castelfranchi, 1995). In the case study of the Grensmaas typical self-interest goals are flood reduction for the inhabitants, profit for the gravel extracting companies and so on.

Norm compliance: In correspondence to the 'subjective norm' in the TRA we adopt the notion, norm compliance as a formal evaluation of normative goals. A normative goal is related to the agent's belief that he has a social obligation to perform (a) specific action(s). According to (Conte and Castelfranchi, 1995) normative goals can be issued by a so-called 'sovereign' agent. For our case study typical normative goals are the primary objectives of the Grensmaas project of flood recurrence, nature development, and gravel extraction issued by the 'sovereign' policymaker.

Social compliance: Goal adoption can be considered one of the main mechanisms of stakeholder interaction (Conte and Castelfranchi, 1995). Therefore we include the notion 'Social compliance' as an evaluation of the agents' adopted goals.

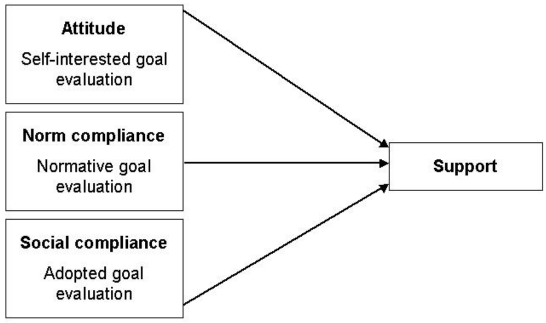

Figure 2.1: Determinants of stakeholder support

2.2 Calculating Support

The agents determine their support for a river management strategy by evaluating the expected impacts of the river management strategy in relation to their self-interest, normative, and adopted goals. For this evaluation we assume that the agents exhibit so-called lexicographic preferences. Lexicographic preferences imply that decision evaluations are made on the basis of a (ordered) set of minimal needs. When these needs are fulfilled, optimisation may occur on the basis of other criteria. The methodology has recently been discussed in the field of environmental economics (Stern, 1997) and applied, for example, for a stakeholder evaluation of wetland recreation (Spash, 2000).

The implementation of the lexicographic preference structure is shown in **figure 2.2**. Agents may express their goal satisfaction on a scale from –1 ('unacceptable') to 0 ('neutral') to 1 ('strongly supported'). Goal satisfaction is determined on the basis of two types of quantitative goal standards. Firstly, an agent can attach a minimal (maximal) requirement, referred to as a 'conditional standard' (*CS*). When its expected value for this goal is respectively below (above) this standard the agent will consider this goal value to be 'unacceptable', corresponding to lexicographic, non-compensatory behaviour. Additionally, agents may specify whether the goal should be optimised. They do so by expressing two optimisation standards: an optimisation zero point value OS_0 (the goal value for which their support is 'neutral') and a optimisation high value OS_H (the goal value for which their support is 'high').

The total support an agent attaches to a river management strategy is now simply calculated as the unweighted average of its goal evaluations. However, when one of its goals is evaluated as 'unacceptable' the river management strategy is considered 'unacceptable' (support is set to –1).

2.3 The negotiation outcome

The outcome of the negotiation process is calculated by maximizing support among

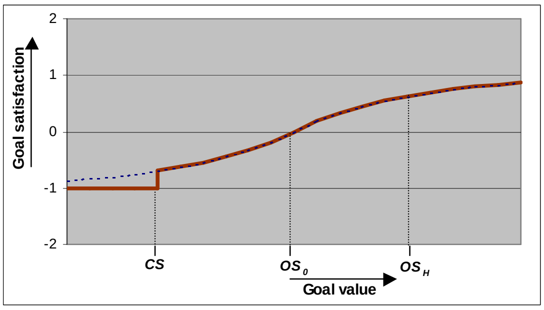

Figure 2.2: A typical lexicographic goal evaluation curve that specifies goal satisfaction as a function of the expected goal value. A goal evaluation curve is defined on the basis of a conditional standard *CS*, and/or optimisation standards OS_0 and OS_H.

stakeholders involved. This simple method allows us to assess 1) what would be 'ideal' river management strategies designed on the basis of one individual stakeholder perspective, and 2) a 'compromising' strategy designed on the basis of multiple perspectives. For compromising stakeholders are valued equally with the exception of the policy-maker and gravel extractor. These powerful parties must support the river management strategy (support > 0) for its overall approval.

3 THE INTEGRATED RIVER MODEL

For evaluating the different river engineering alternatives the agents use an Integrated River Model (IRM). The concept of the IRM is displayed in **figure 3.1**. The main input model variables are different river engineering measures - that together constitute a river management strategy. The main output variables are the long-term impacts with respect to flooding, nature, and agriculture as well as short-term costs and benefits (e.g. monetary costs, gravel extraction, and hindrance) associated with river engineering.

The model was implemented for a river cross-section representing the river Meuse at the location 'Borgharen'. The modules are based on basic principles of hydrology, hydraulics, groundwater dynamics, and nature development and are partially based upon existing expert modules (for example to assess flood and agricultural damage). The model was conceptually validated with experts from the Grensmaas project organisation, and partially numerically calibrated and validated with respect to their model results. For a detailed model description, see (Valkering *et al.*, 2004).

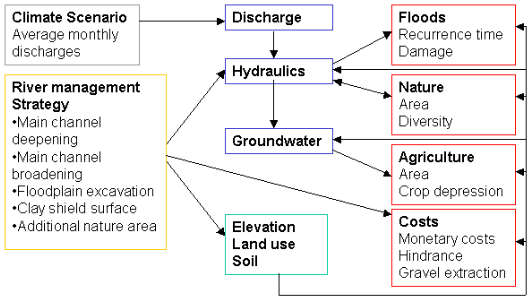

Figure 3.1: The Integrated River Model concept.

Estimating the impacts of river engineering involves numerous fundamental uncertainties in relation to climate change, nature development, and for estimating the monetary costs and benefits (Valkering *et al.*, 2004) According to (van Asselt, 2000) different legitimate interpretations of these uncertainties may exist. The agents may thus hold different perspectives on uncertainty as part of their subjective belief system. These perspectives are represented as value settings for uncertain IRM parameters related to climate change, hydraulic roughness, and costs and benefits. The agents feed these settings into the IRM, together with a set of river engineering measures, to calculate values for their goal criteria, see **figure 3.1**. These values form the basis of their outcome evaluation of the river management strategy described in the previous section.

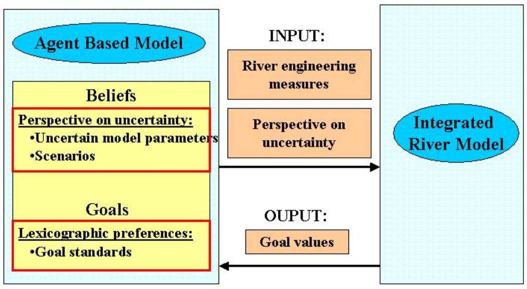

Figure 3.1: The interface between the Agent Based and Integrated River Model

4 STAKEHOLDER PERSPECTIVES

In the previous sections we have developed a framework for structuring stakeholder perspectives in terms of goals, quantitative goal standards, and perspectives on uncertainty. In this section we apply this framework for a preliminary assessment of stakeholder perspectives. The information was obtained from a series of stakeholder interviews, available governmental Environmental Assessment reports of proposed

Agent	Goal	Type	Direction	Conditional Standard	Optimization zero point value	Optimization high value
Policymaker	flood recurrence (yrs)	N	min	250	-	-
	nature area (ha)	N	min	1000	-	-
	ecosystem diversity (-)	N	min	0.7	0.7	1
	loss agricultural area (ha)	N	max	-	1000	2000
	Δ groundwater level (m)	N	min	-	0	-0.2
	hindrance (person*years)	N	max	-	20000	30000
	gravel extraction (*10^^{6} tons)	N	min	35	-	-
	profitability (%)	N	min	4	-	-
Citizen	flood recurrence (yrs)	SI	min	250	-	-
	hindrance (person*years)	SI	max	30000	20000	30000
	nature area (ha)	SI	min	1000	-	-
	ecosystem diversity (-)	SI	min	0.7	0.7	1
Nature org.	nature area (ha)	SI	min	1000	-	-
	ecosystem diversity (-)	SI	min	0.7	0.7	1
	Δ groundwater level (m)	SI	min	-0.2	0	-0.2
Farmer	flood recurrence (yrs)	SI	min	250	-	-
	loss agricultural area (ha)	SI	max	1000	0	1000
	Δ groundwater level (m)	SI	min	-0.2	0	-0.2
Gravel extractor	gravel extraction (*10^^{6} tons)	SI	min	-	35	70
	profitability (%)	SI	min	4	-	-

Table 4.1: Stakeholders' goals and conditional and optimisation goal standards. The goal standards determine the evaluation curve an agent uses to evaluate its goal, see **figure 2.2**. The goal 'type' indicates whether the goal is considered self interested (SI), normative (N) or adopted (A). The 'direction' indicates whether the standards refer to minimal or maximal requirements.

river management alternatives (Maaswerken, 1998), (Maaswerken, 2003), and on the official stakeholder commentaries to these reports. The description of the methodology for perspective elicitation is necessarily brief. A more elaborate description can be found in (Valkering *et al.*, 2004).

The main stakeholders of the Grensmaas project are represented by the corresponding agents 'policymaker', 'citizen', 'farmer', 'nature organization', and 'gravel extractor'. The stakeholders' goals and goal standards are presented in **table 4.1**. The policymaker is considered to be a sovereign agent issuing the norms of flood reduction, nature development, and gravel extraction in correspondence with the main objectives of the Grensmaas project. The negative side effects (loss of agricultural area, groundwater level decrease, and hindrance) are to be minimized (Maaswerken, 1998). The policymaker also issues the norm of profitability, since it requires the monetary costs of river engineering to be fully covered by the benefits of extracted gravel. The non-governmental stakeholders hold various self-interest goals as presented in **table 4.1**.

The adopted stakeholders' uncertainty perspectives are displayed in **table 4.2**. We assume that, in order to avoid risk, stakeholders adopt an uncertainty perspective that minimizes their goal fulfilment. The citizen, for example, claims that a high estimate of climate change has to be taken into account in the estimation of the safety level.

Uncertainty / Stakeholder	Climate change	Hydraulic roughness	Costs and benefits
Policymaker	No	Central	Central
Citizen	High	High	Central
Nature organization	No	Central	Central
Farmer	No	Low	Central
Gravel extractor	No	Central	Negative

Table 4.2: Assumed stakeholder perspectives on uncertainty

5 SIMULATION RESULTS

In this section we present an overview of some simulation results. In particular, we will construct optimal river engineering strategies for different boundary conditions. To this end, a river management strategy is represented as a set of river engineering parameters: main channel deepening (MC deepening), main channel broadening (MC broadening), floodplain excavation (FP excavation), surface elevation of the clay shield (CS level), and additional nature area (Add. nature). For simulating a river management strategy the parameters are varied within predefined ranges in order to maximize total agent support.

In **table 5.1** the following simulated river management strategies are displayed: 'Ideal' strategies maximizing support for each individual agent, and a 'compromising' strategy maximizing total support (see **section 2.3**). These optimal strategies are constructed on the basis of the stakeholder perspectives presented in **section 4**. The compromising strategy corresponds well with currently preferred river engineering alternative of (Maaswerken, 2003), see (Valkering *et al.*, 2004).

	cit	ge	pm	no	farm	comp
MC deepening (m)	1	2	-2	-2	-2	0
MC broadening (m)	100	200	50	50	0	100
FP excavation (m)	125	500	250	375	250	125
CS surface (m)	0	4	0	0	4	4
Add. nature (m)	250	0	375	125	0	250

Table 5.1: Calculated 'ideal' river management strategies for the agents citizen (cit), gravel extractor (ge), policy-maker (pm), nature organisation (no) and farmer (farm), and the 'compromising' strategy (comp).

5.1 A short analysis the Grensmaas project

The 'compromising' river engineering alternative can be characterized as, indeed, a compromise between the different stakeholders, but within the normative boundary conditions of safety, nature area and profitability set by the government. This is illustrated in **figure 5.1**, which shows calculated stakeholder support for the 'compromising' alternative. The goal evaluations for safety, nature area, gravel extraction, and profitability are equal to 1, indicating that the main project objectives are fulfilled. However, other criteria are valued negatively. In particular the farmer strongly objects to the expected loss of agricultural area and change in groundwater level.

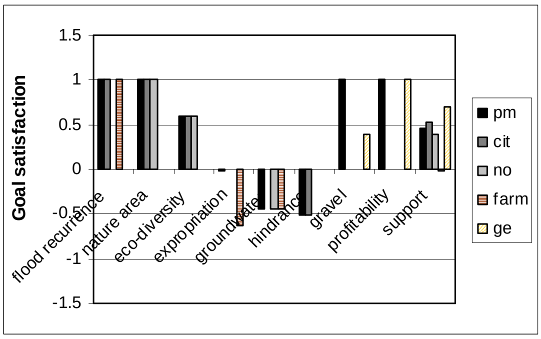

Figure 5.1: Calculated goal satisfactions and stakeholder support for the 'compromising' alternative.

The analysis of the 'ideal' strategies shows that the mutual agreement among the policy-maker, citizen and nature organization is large. Each one of their respective ideal strategies is valued relatively high among this group (see **figure 5.2 a)**) indicating common interests and win-win. The farmer and gravel extractor, on the other hand, generally disagree with the other parties, as illustrated in **figure 5.3 b)**. Their respective ideal strategies are valued high only by themselves and are considered unacceptable by the rest.

For the farmer the disagreement is related to conflicting goals. Its interest of agricultural land and proper groundwater conditions inherently conflict with the approach of river widening and nature development. For the gravel extractor, however, the disagreement results from a difference in uncertainty perspective with respect to the expected costs and benefits of the river engineering measures (see **table 4.2**).

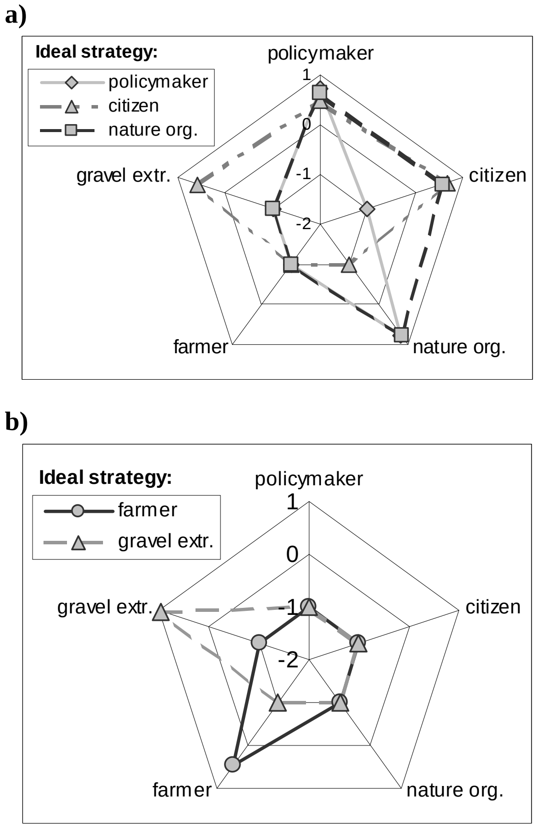

Figure 5.2: Calculated stakeholder support for the 'ideal' river management alternatives.

5.2 The case of climate change

The modelling framework allows us to assess how the negotiation process may change under changing boundary conditions. Consider, for example, the case of climate change. Climate change is currently considered an important issue for long-term water management in the Netherlands. It may lead to increasing peak discharges by some 20%.

The new 'compromising' strategy simulated for conditions of climate change contains large-scale riverbed broadening, in combination with raising the main channel riverbed. This would allow society to maintain current safety standards whilst mitigating decreases in the groundwater level, see **figure 5.3**. In this scenario the citizen would strongly object to the river engineering strategy, because of excessive hindrance levels, but he would be largely ignored.

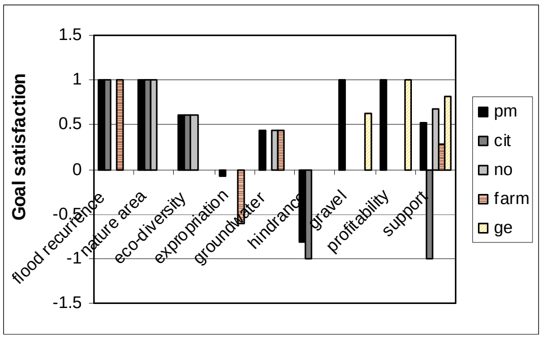

Figure 5.3: Calculated goal satisfactions and stakeholder support for the 'compromising' alternative under climate change conditions.

6 CONCLUSION

In this paper we have presented an Agent Based Model that describes stakeholder support and the outcome of a negotiation process among stakeholders of river management. The type of model that we developed must not be considered a 'truth machine' that predicts policymaking for river management. It rather provides a framework for a 'what-if' analysis. Given the goals and beliefs of stakeholders, the model calculates which river management strategy receives the maximal total support of the stakeholders.

We showed how the ABM can be used to analyse stakeholder perspectives and identify conflicting goals and mutual benefits among stakeholders. Also, the model can aid to reflect upon possible changes in the negotiation process (i.e. problems that are likely to emerge) as a result of uncertain future developments. The current model version is a 'stepping stone' for investigating

In future research we intend to implement mechanisms of goal adoption/rejection and belief change in the model framework, in correspondence with the notions of adaptive cognition and social learning, in order to study the interactions between the social system and river environment.

The current prototype is particularly suitable as a communication tool for application within participatory stakeholder processes. Using this model would encourage stakeholders to reflect upon their goals in a social context. When conflicting goals are revealed stakeholders may reconsider their goals and adopted standards. A participatory approach would thus be vital for a better understanding of the mechanism of cognition change. Eventually, we hope that the application of this model concept will induce social learning and the consideration of multiple perspectives in decision-making. This would be a small step further towards truly collaborative and sustainable river management.

7 ACKNOWLEDGEMENTS

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