Agent-based and Integrated Assessment Modelling for Incorporating Social Dynamics in the Management of the Meuse in the Dutch Province of Limburg

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Abstract: The European project FIRMA (Freshwater Integrated Resource Management with Agents) aims to improve water resource planning by combining agent-based modelling and integrated assessment to describe physical, hydrological, social and economic aspects of water resource management in an integrated way. This paper describes an approach that couples an agent-based model with an integrated assessment model as a conceptual framework. The aspired outcome of the model is to highlight the consequences of agent activities on each other as well as on the environment. The aim is to provide a DSS for decision makers in a water management situation. The case study presented here examines the river Meuse in the Dutch province of Limburg. An integrated assessment model was developed as a local example of a water planning initiative - the Maaswerken project - in order to assess the impacts of river engineering measures on selected river functions (safety, nature development and gravel extraction). An agent-based model represents the negotiations, decisions, and responses of stakeholders that may influence the selection of river engineering measures. The agent architecture is based upon the principles of cognitive agents. Information required to design the symbolic representation of an agent is gathered with the help of stakeholder participation. An innovative approach of the FIRMA project is to incorporate stakeholder participation for model development on the one hand, and, on the other, to raise the interest of stakeholders and to increase their confidence in the model results. In a second phase of the participatory process, stakeholders will be actively involved in the validation of the agent-based model.

Keywords: water management; stakeholder participation; negotiation; agent-based modelling; model coupling

1. INTRODUCTION

In this paper we describe the Maaswerken project as one specific case study of the FIRMA project. Maaswerken is one of the largest water-related infrastructure projects in the Netherlands. The planning of the two sub-projects 'Grensmaas' and 'Zandmaas/Maasroute' is a long-term and complex procedure involving three main actvities: flood control, improvement of the navigation route and nature development. This will be achieved by a combination of deepening and widening of the summer bed, lowering of the floodplains and side gullies, altering embankments, and upgrading of the navigation infrastructure.

On one hand, it appears to be logical to strive for an integrated approach, since the problems are spatially adjacent, and generally interrelated. However, the problems are not identical for specific locations, and relevant processes and impacts occur at various scales. In addition to multiple problems and scales, the complexity of the case study is characterised by the involvement of multiple actors. The project is planned by designated decision makers, but the involvement of stakeholders entails the consideration of diverse interests and perspectives on the process as a whole. Viewing the water resources within a river basin as common goods, the diversity of interests connected with these resources may be considered a social dilemma [Heckathorn, 1995]. The

development of the planning procedure including technological improvements on one hand, and the increasing involvement of stakeholders, on the other, indicates a shift from mono-centric decision making to a polycentric understanding of policy making in water management [Geldof, 2000]. Therefore, the analysis of policy making processes as well as the implementation of measures requires a sophisticated management style. The European Water Framework Directive [WFD, 2001] provides a valuable guideline for this purpose.
The model should be a tool for developing a long-term vision of the management of the river Meuse in Limburg.

2. METHODOLOGY

A successful result in designing a complex model, which is a candidate for utilisation as a DSS, can only be achieved by maintaining a clear model structure. The interaction between the social world and the physical environment must be made explicit.
In a previous investigation, Ernst and Spada [1993] describe the interaction of human beings in a situation of ecological-social conflict. A psychological model (kis) has been introduced based upon cognitive representations such as knowledge (belief) and intentions (here a similar use to the concept of goals). This case study demonstrates the usefulness of cognitive agents to represent processes of human interaction such as social learning and decision making in a changing environment.
Simulation models have been increasingly used as decision support tools during the last decade. Improved methods in agent-based social simulation provided a theoretical context for this purpose. Barreteau et al [2001], for example, describe a case study of water resource management in the Senegal River. Here a multi-agent system is designed in conjunction with a role-playing game to analyse a negotiation situation. In addition to creating decision scenarios the model has been used as learning and mediating tool within a negotiation process for the water resource conflict. This approach also shows the conjunction of stakeholder participation with model development in a validation process.
In a previous investigation Hoekstra [1998] has chosen a pluralistic approach to couple processes of water management on a global scale with various cultural perspectives. The perspectives were represented by cultural stereotypes [Thompson, 1990], which distinguish various world views and management styles. Our case differs from that investigation because of the regional scale and the specific set of actors. Instead of using cultural stereotypes, we endeavour to couple the virtues of an integrated assessment model to cope with a complex physical environment with the flexibility of a multi-agent system. The latter is capable of reflecting dynamic processes of social conflicts such as negotiation, learning processes and decision making.
Participatory methods are applied to obtain specific information about the individual perspective of each actor. Both approaches bring a social dimension to water management, and, moreover, make uncertainties arising in the modelling procedure more explicit [Rotmans & van Asselt, 2001].
In the following four sections we describe the four main components of the modelling approach: The (physical) integrated assessment model (IAM), the agent-based model (ABM), the involvement of stakeholders in the modelling process and the conceptual framework to couple the two models.

2.1 Participatory Integrated Assessment and Stakeholder analysis

The **Participatory Integrated Assessment** comprises four main tasks within the FIRMA approach:
1. eliciting mental models of organisations and institutions, collecting additional information as input for the agent-based model, and problem analysis (interviews and dialog methods),
2. communicating and developing the model with the stakeholders (interviews and dialog methods),
3. validating the model structure and simulation results with the stakeholders (focus groups),
4. identifying system problems and developing new strategies for system management (focus groups and interviews).

The aim of the participatory process is to establish an interactive model-developing process as well as a mutual learning process among stakeholders and modellers. To date, a series of interviews have been conducted bringing the project to the second task on the above list. Additionally, the results of the participatory process that has been conducted and documented by Maaswerken [1998] have been studied. This documentation provides an overview of the most relevant stakeholders, their knowledge (belief) of the project, and their goals including their preferences among goals.
The next series of interviews will quantify goals and validate the appropriateness of our model. Previous studies such as the MacKenzie Basin Impact Study [Cohen, 1997] or the Senegal River Basin Study [Barreteau et al, 2001] show the importance of the participatory component within an integrated assessment framework. First, stakeholders are a valuable source of information,

and can even discover yet unidentified but significant processes and problems within the targeted system. Second, the collaboration between scientists, planners and stakeholders requires a high degree of trust. Stakeholders want to be involved in the planning or modelling process, and are often suspicious of models developed without stakeholder participation.

Finally, the intent is to create planning scenarios (referred to later as "strategies"). This is important since the implementation of planning scenarios is based on the reasoning of the stakeholders as well as their specific perspective on the project.

At this point it has to be emphasised that scientists and modellers associated with FIRMA are merely observers within the Maaswerken project. The planning situation was entirely designed, and stakeholder participation conducted, by the Maaswerken organisation. Role game approaches, for example, applied by Barreteau et al [2001] appear to be unsuitable.

An analysis of the most relevant stakeholders and their interaction within the target system is required to create an interface between the participative process and the agent-based model. In the case of the Maaswerken project the ensemble of actors consists primarily of a number of governmental and non-governmental institutions respectively organisations at various scaling levels:

The national **Decision Maker** (planner) comprises national, governmental and professionally acting organisations within a well established structure. Specifically, the Department for Traffic and Public Affairs takes responsibility for the safety and the infrastructure of the area, especially in the sub project “Zandmaas”. In addition to policy makers, experts form a part of the Ministry.

The provincial **Decision Maker** consists of policy makers and experts associated with the Province of Limburg, who have primary responsibility for the “Grensmaas” project. The impact of this actor is restricted to the provincial scale. Both the national and the provincial decision makers are associated with the project ,organisation. “Maaswerken”.

Four **nature organisations** are involved in the Maaswerken project, and have special interest in the development of natural areas alongside the river.

The **farmers** association is mainly concerned with land use changes, and the impact of fluctuating groundwater levels on arable land.

The **municipalities** have a strong interest in an efficient and reliable system of flood protection. Additionally, they support the concept of nature development to enhance recreational values of urban surroundings. About 20 municipalities co-operate in an association concerned with the planning procedure of the “Maaswerken” organisation.

Citizen groups have a manifold of locally related interests concerned, in particular, with inconveniences (noise, vibrations, dust) of planned measures. However, in the case of the “Grensmaas” project it was possible to unify these groups to improve their impact on the whole planning procedure.

Gravel extractors are basically concerned with the cost-benefit relationships of the gravel extraction process.

All actors or actor groups are described as organisations or institutions rather than individuals. Internal contradictory views as well as processes of emergence within these organisations must be neglected for the sake of clarity when modelling decision making processes in a framework such as this.

2.2 The Integrated Assessment model

The **Integrated Assessment model** describes the relevant processes related to the management of the Meuse in Limburg. It is structured according to the concept of pressure-state-impact–response (PSIR) [Rotmans et al, 1997]. The computer model will include simple hydrological modules to calculate the effects of various river engineering alternatives of the Maaswerken project on the state of water balance in Limburg. Impact modules will relate these results to consequences for river functions such as safety and nature. Input to the model will be derived from a set of integrated, perspective-based scenarios that sketch possible changes in climate and socio-economic boundary conditions in a consistent way. For a detailed description of the model, please refer to Valkering [2002].

2.3 The agent-based model

The **agent-based model** is based on a cognitive agent approach developed by social psychologists [Conte & Castelfranchi, 1995]. Agents represent stakeholders, with their particular perceptions, world views, and actions within the modelled target system. The internal structure of a cognitive agent consists, in principle, of the symbolic representations *goals* and *beliefs*. Goals are states of the world desired by a particular agent. Beliefs represent the particular knowledge, perspectives or world views of an agent. The main component of inter-agent communication consists of a negotiation process. This means a planning strategy proposal by one agent, and the response to the planning strategy by many agents indicating a level of agreement according to their symbolic representation.

As mentioned in section 2.1 agents (as representations of stakeholders) in this approach simply represent organisations. This means goals and beliefs of these organisations are assumed to be homogeneous. The heterogeneity of these organisations including sub goals and a variety of beliefs among the members are neglected for the sake of simplicity and transparency of the model. Furthermore, there is no attempt to model the emergence of a higher level of performance, which can be achieved by overcoming cognitive limitations of individual agents [Carley & Gasser, 2000].
The environment or world as it is perceived by each agent is incorporated within its individual belief system. The implementation of a strategy or measures can be seen as the 'response' part of the (PSIR) structure of the IA model.
In response to planning strategies each agent can evaluate environmental conditions by receiving information according to the output of the IAM. Similar to a real negotiation process in a planning situation, agents have the ability to broadcast their agreement or disagreement with the proposed measures. Instead of a simple 'yes' or 'no' each agent responds with a **level of 'satisfaction'** between the upper and lower limits of the relevant issue as shown in Figure 3, where '1' represents 'yes' and '0' represents 'no'.
The values $0 < y < 1$ represent a 'negotiation space'. The agent does not totally disagree, but signals the desire for an improvement of the value of a proposed measure. The approach is similar to semi-qualitative decision networks described in Donkers, et al [2001].

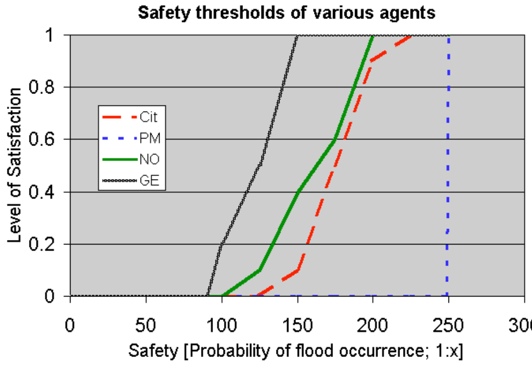

Figure 1. Levels of agreement for safety thresholds, (Cit = citizen, PM = policy maker, NO = nature organisation, GE = gravel extractor)

As a second evaluation option each agent has its own priorities or **ranking of issues** as shown in Table 1.

Table 1. Goal ranking of Agents (example)

Rank\agent	PM	Cit	NO	GE
1.	Safety	Safety	Nature	Costs
2.	Costs	Nature	Safety	Safety
3.	Nature	Costs	Costs	Nature

The ranking of priorities may be used to combine preferences of agents by identifying a compromise. The advantage of this approach is that these graphs and priority ranking can be used as a communication tool for the stakeholders. Ongoing interviews aim to improve the satisfaction curves of the stakeholders themselves.
At this point the model is nothing more than a multi-criteria analysis. It is programmed in C++, and is capable of calculating changes to the environment as a result of a particular strategy. Furthermore, these changes can be compared to the goals of an agent, and indicate levels of satisfaction for particular goals as well as an overall agreement or disagreement with an employed planning strategy. This way a transparent model structure is provided and gives way for further modelling approaches dealing with social learning and negotiation.
With the help of a rule base each agent is capable of combining threshold values with preferences. The agent will observe the behaviour of other agents during several runs of strategy proposals, and will be able to adopt that behaviour by changing their own threshold values. An example of how the cognition of an actor is represented within a negotiation situation is given by endorsement mechanisms [Cohen, 1985]. Agents have rules with attached numerical interest coefficients. This is similar to our scheme of satisfaction levels and priorities. The design of an appropriate rule base for each agent is still in an experimental phase, and is implemented in Java.
Additionally, each agent will be able to observe the behaviour of other agents during several runs of strategy proposals, and to synthesise a history of outcomes of planning results. This way an agent can be enabled to adopt other agent's behaviour, for example, by changing their own threshold values.

2.4 Conceptual framework and model coupling

The **conceptual framework** of this approach generally consists of a coupled agent-based model and a (physical) integrated assessment model.
The entire framework consists of two main sub-processes:

1. Development of a planning strategy. A negotiation process will be simulated according to the beliefs of agents with respect to the adopted beliefs after observing the behaviour of other agents.
2. A chosen strategy will be simulated by incorporating integrated scenarios (including climate and land use change), surprising

events, and possible introduction of relevant technological enhancements.

The second item can be seen as a testing strategy for robustness, applicability and sustainability.

The changing (model) world as well as the changing behaviour of other agents is perceived by each agent, and may lead to belief updates and/or (re)actions according to the agent's endowment. In this way we are able to analyse two types of processes:

1. Agent-environment interaction (responding to changing river bed geometry, nature development, side effects of measures, floods, pollution, etc.)
2. Agent–agent interaction (communication about planned measures, negotiation, coalition forming, etc.)

The interface of the two main modules is characterised by parameters making up the riverbed geometry, probability of flood recurrence, costs and benefits of gravel extraction, costs of clay dumping, hours of hindrance per person, area of nature and depth of flood plains. These parameters are the main subject of the negotiation process related to the Maaswerken project. The choice and value of parameters are related to the beliefs of stakeholders.

The participatory process will be interlinked with the model during the model design phase as well as the model validation phase. In principle, stakeholders are confronted with the consequences of their actions on the environment as well as on other actors. In other words the communication between stakeholders and modellers is an essential part of the entire modelling process.

3. A LOCAL EXAMPLE OF MODEL COUPLING TO NEGOTIATE A PLANNING STRATEGY (PROTOTYPE MODEL)

In a local situation a simplified cross section (figure 2) of the river valley with a standard length of 500m was chosen to investigate the impact of measures.

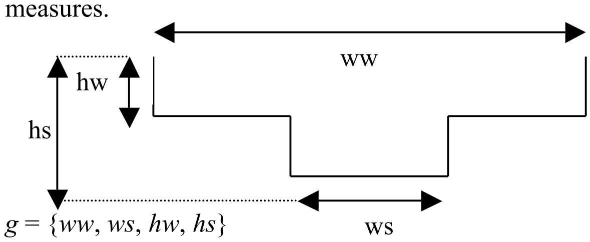

Figure 2: Simplified cross section of the river Maas

Four stakeholders, a policy maker (PM), a group of citizens living in the vicinity of the river (Cit), a nature organisation (NO) and the gravel extractors (GE) are chosen in a negotiation position. The most important goal (for all of the agents) is to reach a reasonable safety level for the Maas valley. The policy maker suggests a safety level of 1:250 (recurrence rate of floods on land use other than summer/winter bed of the river). For this reason the policy maker plans alterations to the riverbed geometry (figure 2) in order to enlarge the discharge capacity of the riverbed. This value in conjunction with runoff pattern determines the safety level. Additionally, the costs, as another goal (cost – benefit = 0), are coupled with the activities of riverbed alterations. The gravel extraction demands some investment. However, it can also generate some profit by selling the gravel to the building industry. An additional cost factor is determined by clay storage.

The third goal - nature development - is expressed in the area of the nature development, which is identical with the area of the winter bed.

Table 2 shows the parameters making up a strategy. This can be proposed by a stakeholder and implemented in the physical model. In this case it is a planning strategy proposed by the Maaswerken during the planning process [Maaswerken, 1997].

Table 2. Parameters making up a strategy

Strategy1:

Summer bed deepening (m)	-2
Summerbed broadening (m)	100
Winterbed deepening(m)	3.5
over a length of (m)	300
Dike building (m)	No
Clay storage	Yes
at location (m)	400 ->
Nature (m)	100 - 400

The IA model calculates a changed environment. However, in this example agents have various beliefs in the benefit that can be gained by selling gravel. The limiting factor is the density of gravel.

Table 3. Belief parameters generating costs

Belief parameters:	ge	pm	no
Costs wet extraction(EU/m^3)	3	3	3
Costs dry extraction (EU/m^3)	6	6	6
Costs clay storage (EU/m^3)	6	6	6
Gravel density (t/m^3)	1.8	2.2	2.2
Gravel benefits (EU/t)	4	4	4

Table 4. Reactions to policy measures

Issue	PM	Cit	NGO	GE
Safety	1	0	0.5	1
Nature	1	0.5	0	1
Costs	1	0.5	0.5	0

strategy	1	0	0	0

Table 4 shows the calculated levels of agreement concerning three single issues as well as an overall evaluation of the proposed strategy. In this case a rule was applied so that any '0' assessment among the issues reflects an overall disagreement with the strategy. However, this component is still under development.

4. OUTLOOK

The preliminary results of this research give way to further investigations of modelling techniques in an agent based modelling environment. As a first step, the incorporation of agents as indicators of the impact of policy measures, as carried out in this project, may help policy makers to comprehend the consequences of complex measures on a social environment. However, this must be enhanced by making negotiation processes explicit. The modular structure enables the modeller to expand the model in several dimensions. In particular, the shift from the local case study to modelling the entire region will lead to higher accuracy in both the spatial resolution for investigating locally related processes and their mutual impact, as well as the agency. Agents may be "down-scaled" in a hierarchical way, and entities, known as "instances of classes" of agents can achieve independency of each other. This is crucial for the modelling of heterogeneous group agents like "citizens". For the physical model the spatial analysis techniques will be incorporated.

5. CONCLUSION

The **aim** of the approach presented in this paper is not simply to describe but, additionally, to explain reasons for particular actions and their consequences on the environment as well as on other actors within a specific target system like a river basin. The combination of models as well as the simulation enable modellers and planners to address a complex set of interrelated issues and the consequences of human activities in an interactive, consistent and dynamic way. This approach is a step forward in the development of a decision support system (DSS) that enables planners not only to model the physical processes of a particular system, but also incorporate social dynamics from the early stages of planning activities. Moreover, it can improve the communication between planners, decision makers and stakeholders by making the relationship between physical and social processes explicit. The local case study provides a tangible example of how the model can incorporate stakeholders' concerns.

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