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PARTICIPATORY MULTI-AGENT SYSTEM MODELING FOR COLLECTIVE WATERSHED MANAGEMENT IN NORTHERN THAILAND : A COMPANION MODELING METHOD

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ABSTRACT

The companion modeling approach was used to facilitate collective learning process of key stakeholders of a highland watershed in northern Thailand, where a social-agroecosystem is located within the multiple political layers of resource uses and management. After analysis of the system, role-playing games (RPG) were conducted with stakeholders using simplified rules and a virtual environment. Performing the role allowed players to understand the consequences of their individual role on dynamic processes of the whole system. Information obtained from the games supplemented with interviews mutually improved knowledge of both researcher and stakeholders. The design and results from the games were applied to multi-agents system (MAS) model design using Unified Modeling Language (UML). Cormas platform was used to develop computer MAS model to replicate the dynamics and phenomena in the games. The aim is to apply the model in the field allowing stakeholders to verify, experiment with interesting scenario that could result in alternative sustainable resource management strategies desirable for all parties.

1 INTRODUCTION

Multi-agent system (MAS) approach and computational modeling techniques have been progressively developed to explore and understand individual behavior and interaction among agents and the environment that represent the complexity of the whole system (Gilbert and Troitzsch, 1999). They have been increasingly used to deal with ecological and socioeconomic issues arising from the management of scarce resources by multiple users. Integrating MAS with other biophysical or economic models and spatial database tools can enhance the adaptive learning capability of all stakeholders regarding their role and effects on ecological system dynamics. This has tremendous potential for assisting decision-makers in understanding and managing landscapes (Gimblett, 2002; Parker et al., 2003; Le Page et al., 2001).

The unified modeling language (UML) is commonly used in conjunction with object-based models because it has mechanisms to communicate the structure, processes, and rules that drive model outcomes. UML has now become the standard for object-oriented modeling and design, as it is in the MAS model (Fowler and Scott, 1999). Recent MAS applications have employed UML as a means of facilitating communication among multi-discipline researchers, model designers, and programmers. This seamlessly becomes a standard protocol among researchers belonging to different disciplines and having various experience in developing computerized MAS models (Parker et al., 2003; Trébuil and Bousquet, 2003; Le Page and Bommel, 2004).

It has been widely acknowledged that the key issues contributing to the failure and success are dialogue among multi stakeholders, multi-layered institutions, tools and methods that facilitate scenario experiment, knowledge improving, and co-management process (Borrini-Feyerabend et al., 2000; Dietz et al., 2003). A number of recent research and development projects have been moving towards decentralization and adoption of integrated participatory approaches. Broad range and different degree of involving and incorporating stakeholders have been explored (Caminiti, 2004; Lanini et al., 2004; Soncini-Sessa et al., 2003).

Role-playing game (RPG) is a well-known tool for understanding how interactions among individual behaviors and interaction contribute to the collective outcome (Ostrom et al., 1994). It helps enhancing in participatory rural appraisal, empowering stakeholders, and facilitating resource management (Forester, 1999). Recently, RPG has been integrated into participatory MAS modeling process, so called “companion modeling” (Bousquet et al., 1999a; Barreteau, 2003a). The RPG has been applied to improve understanding of complex phenomena and to develop, modify, and validate MAS models. This approach aims at empowering interested stakeholders through the acquisition of a clear understanding and a long-term vision of their system dynamics. RPG can facilitate collective learning, negotiation, and collective decision-making among stakeholders. Thus, this allows them to cooperate and manage their natural resources collectively (D'Aquino et al., 2002; Barreteau, 2003b; Etienne et al., 2003).

In northern Thailand, there were recent attempts to apply dynamic modeling and multi-agent system (MAS) approach for soil and water resource management in the watershed areas (Letcher et al., 2002; Becu et al., 2003). There were also experiences in the highlands of Vietnam (Boissau and Castella, 2003) and forest management in Indonesia (Purnomo and Vanclay, 2003). However, most of the model conceptualization, design, development, and validation phases were implemented by the researchers. Roles of local and government institutions were merely included in the model. The context where the conflict on forest, land, and water resource uses and management by multi-level stakeholders are bounded together has not come across.

Therefore, this study aims at applying participatory modeling approach by coupling role-playing games (RPG) with computer MAS models to tackle natural resource management problems in a watershed area. It intends to involve multiple political layers and stakeholders e.g., local resource users, forester and forest policy, land developer and soil conservation policy, and local forest resource management organization in the model and modeling process.

The paper describes the use of RPG followed by field interviews to verify the researcher's knowledge, to acquire knowledge on stakeholder behavior, and to enhance co-learning processes among stakeholders of a highland watershed system in northern Thailand. Then, the results and lesson learned from the games were applied to MAS model designing and developing processes accompanied by the use of various UML diagrams.

2 SYSTEM CONCEPTUALIZATION

The study site, Maehae is a watershed area in northern Thailand. It is located 80 km southwest of Chiang Mai, one of the major forest-covered areas in Thailand. This highland slope complex area is about 3,288 ha with 70% of pine mixed with evergreen and dry-dipterocarp forests. There are 14 villages and 550 households, scattered over three districts. The two major ethnic groups, the Karen and Hmong, are practicing agricultural activities in both traditional and high-value cash crops and fruit orchards, which have been actively introduced and supported by the Royal Project Foundation (RPF) development center.

The highland watershed areas in the north have been generally perceived as a fragile, vulnerable, susceptible national asset and subject to protection and management by government. Highland dwellers and agricultural activities in this area have contributed to highland land and water resources degradation. Meanwhile, the new Thai constitution in 1997 provided a range of new policies to empower stakeholders and local institutions to participate in managing their own local resources in a sustainable way. The Maehae watershed also falls into this category where common resources are located within the multiple political layers of resource management.

System analysis workshop of Maehae watershed was conducted with multi-discipline researchers. The patterns and contexts of interaction, and potential conflict between stakeholders were captured. Pre-system analysis resulted in a list of key stakeholders and their important roles in using and managing forest, land, and water resources in this watershed area. The farmers are likely facing insecure ownership of their lands because most of the cultivated lands are under the national forest reserved boundary. The RPF, Land Development Department officer (LDD), and Royal Forestry Department officer (RFD) are key government agencies working in the area. RPF development center is actively introducing and supporting cash crops and fruit cultivation to increase farmers' income. LDD and RFD are responsible for natural resource conservation. The LDD promotes soil conservation practices to reduce soil erosion. The RFD is responsible for forest law enforcement and promoting forest resource rehabilitation.

This pre-perception on environmental components, stakeholders, their actions and associations that influence the Maehae system dynamics was transformed and developed into a prototype MAS model using UML diagrams. The preliminary design of the "world" representing the Maehae watershed system consists of three major components, corresponding to the stakeholders, their ecological environment, and the local institutions. Stakeholders share and intervene in common resources with different objectives and perceptions. Local institutions are formal and informal groups or organizations representing stakeholders who share similar interests (Promburom et al., 2004).

After system analysis step, the main issue focused on how land and forest resources are being accessed and managed under different interests, and conflicting situations. The information obtained from personal interviews with some local key informant, local RFD and RPF officers could not provide a clear explanation on how this situation emerged and exists. To acquire better understanding on this unclear behavior of the local resource user and manager, the role-playing games were designed to play with local stakeholders. The conceptualization of the Maehae watershed system was simplified to represent the emphasized context (Figure 1), and then transformed to the game.

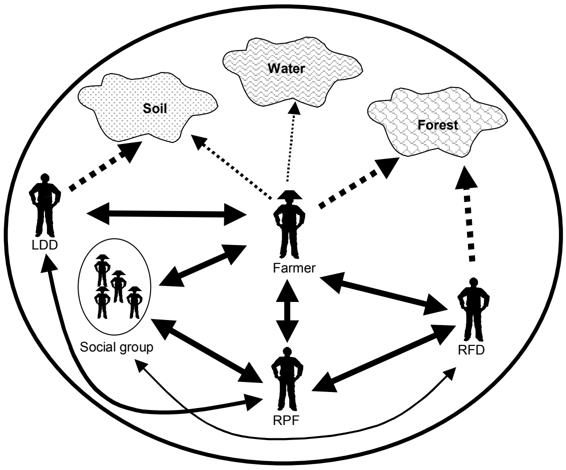

Figure 1: Simplified perception of the Maehae watershed system. The solid arrow line represents association between stakeholders, the dash line and its size shows the perception and understanding level toward the resources.

3 ROLE-PLAYING GAME

The two main objectives of conducting the games were: a). to verify and improve our understanding on the uses and managements of forest and land resources by stakeholders, and b). to initiate collective learning of the stakeholders on system components and dynamic processes. Furthermore, this will lead to the trust and friendship building between stakeholders and the researchers.

Two games were designed and played with local farmers and other stakeholders. In the first game, two participants were assigned to perform as government agencies and the rest acted as local farmers. In the second game, there was modification of some rules and a real local RFD officer was invited to play according to his real task.

The games were conducted with 10-12 participants from both Hmong and Karen communities, representing three different types of farmers corresponding to actual economic status in their real life. A 3-D block model was used to represent a simplified typical highland watershed with various slope classes.

The RFD player was assigned a task to maintain forest area above threshold level of 40%. Likewise, the LDD player should try to promote soil conservation practices in the vulnerable area to minimize soil erosion.

At the initial stage of the game, each farmer received a different amount of cultivated plots allocated on varying slopes. The number of given plots and their location to each player were designed corresponding to the actual agricultural land characteristics in Maehae. Each farmer received a different amount of initial cash according to the given status to invest in crop cultivation. Each yearly time step, the individual farmer could freely allocate different crops to the given plots. Each farmer was allowed to open new plots according to the respective strategies.

During the game, the RFD player had the right to withdraw new opened plot in the next time step. The aim of this was to see coordination and negotiation that may occur during the game among individual farmer or farmer group and RFD players. LDD tried to monitor the plots that were prone to erosion and tried to convince the plot owner to accept soil conservation practice. If the owner agrees to do so, there will be trade-off on the 25% lost in crop production of that plot.

Once farmers finished allocating the crops, three climate cards representing Good, Normal and Low rainfall conditions were randomly drawn by a player and announced in public. This affected crop production and soil erosion of the plots. Then, product price ranked by good, medium, and low, was randomly chosen. At the end of each time step, farmers' household income balance was concluded. Lastly, the moderator calculated and announced the amount of overall erosion and remaining forest area to all players. This aimed at encouraging RFD and LDD players to actively play their roles for the next gaming session.

In the evening and the day after the game sessions, players were interviewed individually at home. The interview issues covered comparison of the player's real life with the game, reasons for the role that the player performed during the game, perception, and experience of other key stakeholders' roles, and general context of the Maehae watershed.

3.1 Results from the games and further exploration

A collective manner of trying to compromise with RFD and LDD was shown in both games. Forest area declined and soil erosion increased during the beginning steps and then moved to a steady stage toward the end of the game (Figure 2). This contradicted to our pre-perception which expected that the one who plays the role of the poor farmer would exploit forest resource to claim more land to increase production that fulfills household needs. The interviews confirmed that 15 villages of Maehae watershed have been coordinating the forest conservation network for more than 10 years to manage and protect forest areas. Rules and regulations on forest resource accesses were set up and agreed upon for all members. One of the reason beside this was to lower the degree of forest law enforcement, since most of the agricultural area fall into forest reserved area. With the believe that the better performance on managing the forest would result in the less degree of enforcement and the more security in the right of using the land. Thus, this might influence the players' reflection upon the cooperation action in the game.

Furthermore, most of the players did not directly know the role of the LDD but they experienced some of the soil conservation practices implemented through RPF. However, collective decision-making on suppressing soil erosion has emerged during the game.

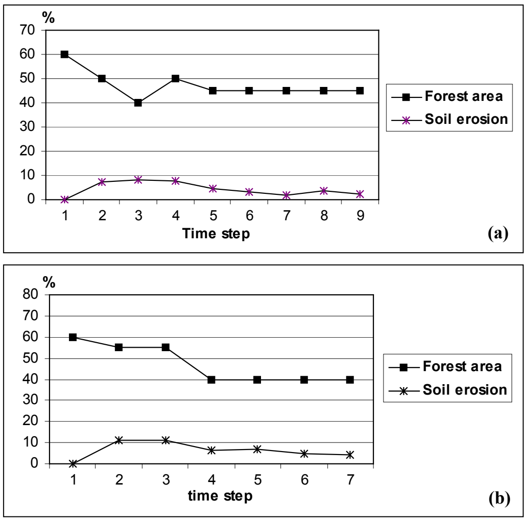

Figure 2: Forest area and soil erosion changes during the first (a) and second (b) role-play game.

The rules, steps, and atmosphere of the game could provoke players to react to situations individually and collectively. This allowed them to extend their vision and understanding beyond their existing scopes. The game made them perceive that there are multiple stakeholders taking action in the same system context with differing objectives. Furthermore, this also provided views on interaction between system components and consequences of inter-scale linkage between farm and watershed levels. It can be seen that these two RPG facilitated collective learning processes of players and provided the understanding on complex space-and-time dynamic processes through a simple exercise.

On the researcher's side, RPG helped verifying previous perceptions by allowing players to react toward given rules and environments. Individual decision-making in the game was clarified during the interview, thus adding to the researcher's knowledge. One of the important outcomes from RPG was the emergence of a collective manner which stemmed from individual decision-making to tackle common problems; for instance, players tried to suppress soil erosion and maintain forest area under the given threshold.

After the two game sessions and interviews, the related issues arising during the game, individual interview, and group discussion were further investigated. The actual crop choice and allocation were determined by multi-factors, for instance the plot slope. However, water availability, which is an important factor, has not been covered in the games. Some key informants in different villages were interviewed to attain their representation toward the dynamic changes in forest, land, and water resources. Before ending the interview, each of them was asked to express the uncertainty and scenario.

4 FROM GAME TO MODEL DESIGN

The two role-playing games conducted with local stakeholders effectively provided knowledge, behavior, and decision rules in using and managing land and forest resources of the players. These are only part of system properties and characteristics, and may not exclusively represent all the complexity of the Maehae system. Nevertheless, this improved learning capacity of players to understand the links between individual action and consequences that impact the watershed system dynamics. Thus, they were prepared for the further participatory MAS modeling processes.

4.1 Model analysis and conceptual diagram

The structure, rules and given environment applied in the games, resulting from the games and interviewing were analyzed to develop a conceptual model in the form of UML diagrams. The conceptual diagram was designed to be simple and understandable. Therefore, it can be used as a means of facilitating collaborative work among disciplines to make the model well describe and represent the study system.

The UML class diagram in figure 3 illustrates the structure of the conceptual model, which was transformed from the role-playing games. Each graphic box represents a description of objects having a similar structure and behaviour. *Farmer*, *ForestOfficer* and *LandManager* classes in the diagram represent farmer, RFD and LDD agents in the games respectively.

The *LandCell, LandusePlot*, *Farm*, and *Watershed* represent piece of land (or minimum land unit), agricultural plot, farm and watershed areas respectively. Lines linked between these classes and other components mean possible associations and relationships among them. A *LandusePlot* is aggregation of many *LandCell*s. Each *LandCell* is covered by particular *LandCover* either *Forest* or *Crop*. Therefore, the watershed is seen as an area with many pieces of land with different land cover types.

A *Farmer* can see all *Watershed* areas and know all *Crop* types. A *Farmer* may own at least one *LandusePlot* in his/her *Farm*. In each year, the *Farmer* chooses crops, which are *Paddy, UplandRice, Vegetable, Orchard*, or may leave the plot fallowed (*NoCrop*). Then, the *Farmer* allocates a crop to every *LandCells* in each *LandusePlot*. A *Farmer* may interact with *LandManager* and *ForestOfficer.*

At each year, rainfall condition will be varied, which is based on *climateState*. Likewise, crop products' prices will be determined by the *Market.* During cropping season, erosion in each LandusePlot may occur according to *LandCover*, LandusePlot's slope and *climateState.* Level of erosion then, can be derived from *ErosionTable*.

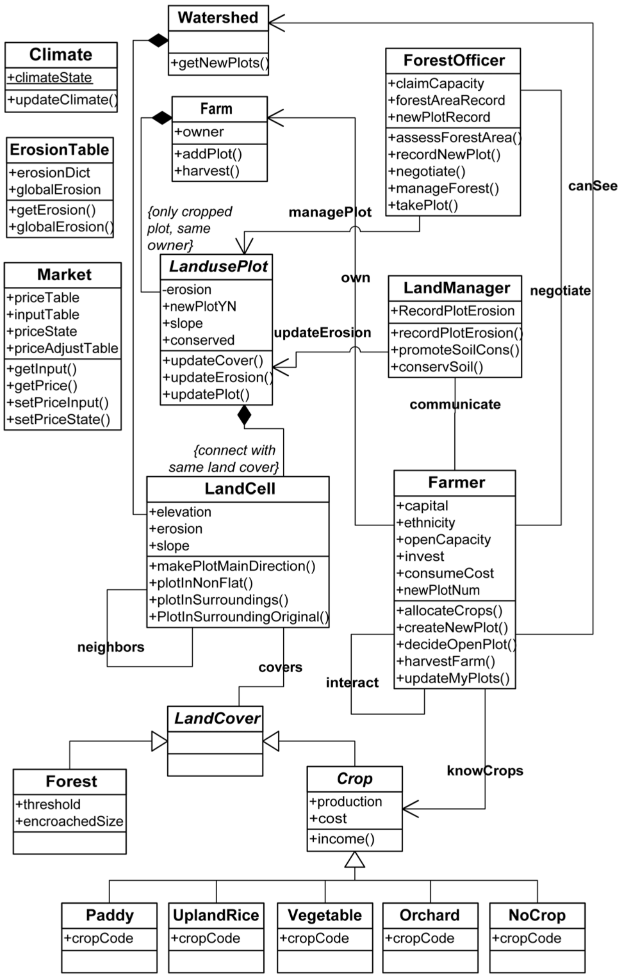

Figure 3: The UML diagram transformed from role-playing game.

4.2 Model dynamics and activity diagram

Dynamics in the game were illustrated using UML dynamic diagram. The diagram describes activities and interaction of agent class based on behavior and decision made under given rules and environment. In this study, the sequence diagram was used to represent and describe the sequence of tasks and actions applied in the games. This will determine processes that model scheduler activate the model entities in each yearly time step as shown in Figure 4.

At the beginning of this sequence of watershed dynamics, the model *Scheduler* will send the message *manageForest* to the *ForestOfficer,* then he will firstly *assessForestArea* by monitoring the whole *Watershed* area focusing on new *LandusePlot* (using *getNewPlots* method). If the remaining forest area declines to the given threshold (it was 40% in the game), he will try to reclaim the plots. Therefore, he goes *negotiate* with the *Farmer* who owns that new *landUsePlot*. If he succeeds in negotiation, then he will *takePlot* from *Farmer* and reforest the plot (through *updateCover* method) to increase the forest area.

Likewise, *LandManager* will *recordPlotErosion* occurring in cultivated plots, and aggregate the total soil erosion of the whole system. If the amount of soil erosion is near to or exceeds the threshold level, he may promote *SoilCons* to convince Farmer to implement *soilConserv* in order to suppress soil erosion.

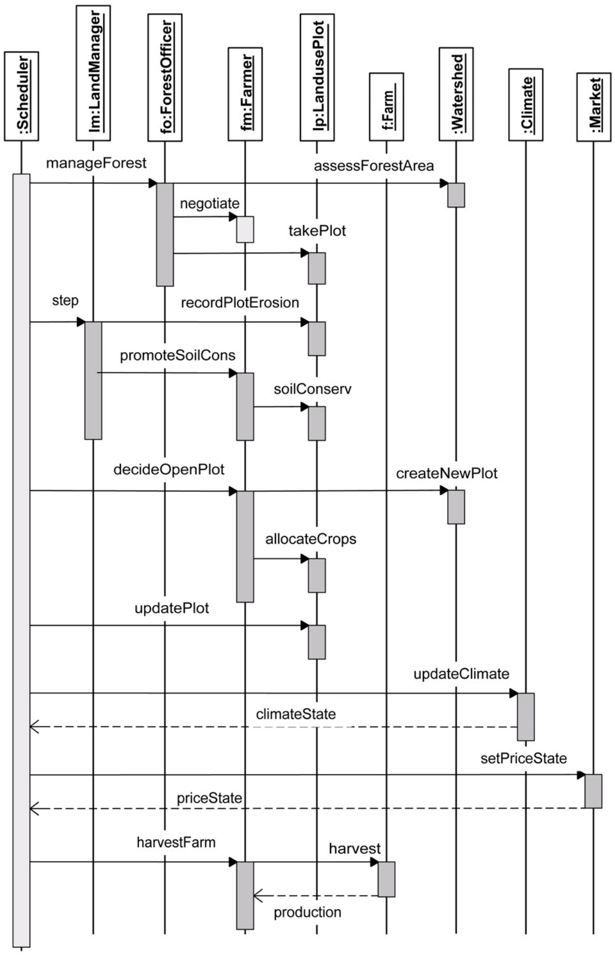

Figure 4: A simple UML sequence diagram representing major dynamic processes.

The *Farmer* who needs more cultivated land to increase household product and capital may *decideOpenPlot* and *CreateNewPlot* in the *Watershed* area. When the cropping season starts, the *Farmer* will choose and *allocateCrops* to the *LandusePlot*s.

Crop *production* of the *Farm* will vary according to *climateState*, and erosion that may occur in the plot. At the end of season, the Farmer will *harvestFarm*, and sell products. The *income* from crop product will vary depending on the market *priceState*.

This sequence diagram does not provide the detail of all message and actions because the purpose is to express only the basic order of operation series that will be implemented in the model simulation. The next step is to associate each operation to another UML activity diagram to explain the internal steps and processes.

The example activity diagram shown in Figure 5 elaborates order of activities and entities involved in *manageForest method* of the *ForestOfficer* class.

These UML diagrams representing the main sequences and activities of entities are very useful during discussion among multi discipline researchers and modelers. It started by simple sequence diagram, then analyzed into detail of each activities to understand and clarify all processes before hands on programming the model codes.

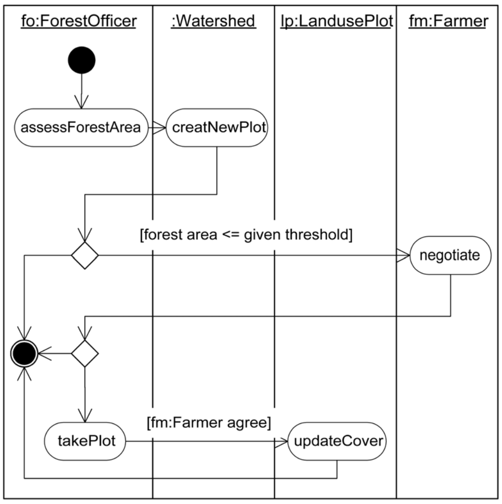

Figure 5: An example of UML activity diagram of *manageForest* method of the *ForestOfficer*.

5 FORMULATING CORMAS MODEL

A prototype computerized MAS model has been formulated based on these conceptual diagrams using Cormas platform [Bousquet et al , 1999b] to reproduce phenomena in the role-playing games. Cormas provides programming environment specifically designed for interaction between natural and social dynamics in the context of common-pool resource management. Stakeholders or players in the games, or agent classes in the UML conceptual diagrams were formulated as 'Social entities' in Cormas (Figure 6). The agents' have capabilities to situate in environment, move, communicate and perform actions. The predefined functions in Cormas can facilitate formulation of these agents, their characteristics (attributes) and possible actions (methods).

The environment entities: *LandCell*, *LandusePlot* and Farm in UML were create as 'Spatial' entities in Cormas. The *LandCell* is elementary level entity, *LandusePlot* is aggregation of *LandCell* and it is one of components in the *Farm*. Thus, these entities are associated to each others. The 3D model was transformed in to Cormas spatial grid, which is composed of 135x106 elementary *LandCell*s. The visualization of this spatial grid (point of view) can be manipulated using various colors to represent specific attribute of the *LandCell*. For example in Figure 7, the point of view is 'elevation' attribute of the LandCell, which formulates topographic landscape of 3D model in the game representing typical watershed landscape in northern Thailand. The white rectangles are *LandCell* with *LandCover* type *NoCrop*. These represent the plots allocated to farmer player at the beginning of the games.

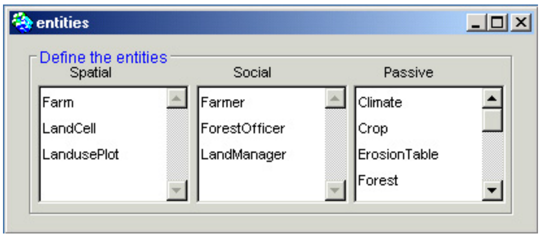

Figure 6: Entities in Cormas model

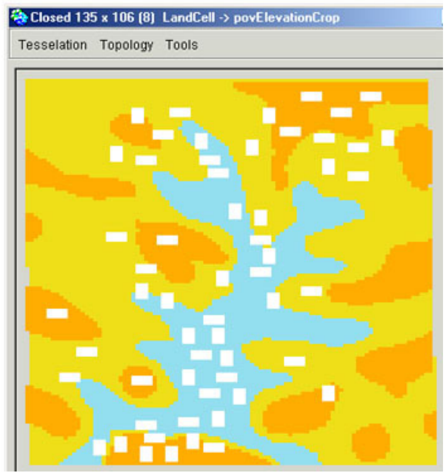

Figure 7: The Cormas spatial grid replicating 3D board with cultivated plots applied in the RPG.

Climate, Market, LandCover, types of Crop, and other auxiliary model components were assigned as "Passive entities", which can be accessed from other model elements. Behaviors and possible actions conceptualized in UML diagrams were programmed and embedded into these Cormas entities. The current version of this model can simulate and reflect some phenomena that occurred in the games such as choice and allocation of crops, fluctuation of climate condition and products prices, dynamics of soil erosion and forest area. Most of the dynamics in the model are based on the simple rules and parameters used in the game, which was not designed to cover the deep detail of this aspect. Therefore, at the current stage, it may not well represent the real complex dynamic of the Maehae system. The decision rules of exploiting forest for new plot derived from the games and interviews are still inconsistent. However, the model will be presented to stakeholders to be verified. Thus, this will guide to further investigation on these decision rules and parameters in the next research step. Then, the conceptual diagram will be modified and used for further Cormas model modification.

6 CONCLUSION AND PERSPECTIVES

This paper demonstrates a methodology of conducting participatory modeling regarding multiple stakeholders and common-pool resource management. The study started from formulating researchers' perception toward interest system through multi disciplines workshop and the use of UML diagram. This pre-conceptualization then, was verified by conducting role-playing game with stakeholders. At the same time, this RPG was used as a mean to convince stakeholders to participate and be involved in the modeling processes. The rules and condition applied to decision-making during the games and additional information could be derived during the games and the interviews. This work represents one of effort contributing to the joint use of RPG and computerized model to support collective resource management.

The UML diagram is a powerful concept and tool to integrate knowledge and efforts from social and natural sciences in order to understand and manage complex socio-agro ecosystem. It can be used to formulate the conceptual model, which is important in facilitating communication across disciplines, especially from the earliest stages of question formulation and research design (Heemskerk et al., 2003). It could bring together differing viewpoints to transform the Maehae watershed system into a conceptual framework representing a holistic view of the system. This common framework then, can guide and shape the further research activities. Moreover, during computerized MAS model design and formulating procedures, UML diagrams were important interface to explain and clarify the model between researcher and modeler.

In the field of social science, economics, and ecology, MAS modeling and simulation is increasingly becoming part of mainstream practice across many disciplines. In addition, there have been attempts to transfer knowledge from model to other modeler, none-modeler or between the models in order to understand and utilize the existing models (Hales et al., 2003). Thus, this study can be used as an example of participatory modeling methodology, which is transparent, understandable, and transferable for other scholars in this field.

However, it can be foreseen that the perception of stakeholders are different by nature, experience and discipline. One particular model may or may not reflect across these variations. A framework for implementing effective participatory modeling may vary among interest stakeholders. Thus, the challenge for further research steps is to develop and assess the combination of method, supporting tool and MAS model to facilitate the collective resource management in the highland watershed of Northern Thailand.

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