CHAPTER X

THE BAN MAK MAI AGENT-BASED MODEL

An ABM is a computational model that allows for the simulation of actions operated by autonomous entities (called "agents"), interactions among multiple agents and between the agents, and the virtual environment where they are located. From components interacting at the lower (micro) level of a MAS, system properties emerge at a higher (meso) level. Individual agents, whose knowledge and perceptions are limited, are presumed to be acting according to what they perceive as being in their own interest (Axtell, Andrews et al., 2003). Agents in an ABM may experience learning, adaptation, and reproduction (Bonabeau, 2001).

In the field of computer science, the research on MAS refers to game theory, complex systems, computational sociology and evolutionary programming. The idea of agent-based modelling was developed as a relatively simple concept in the late 1940s since it required computation-intensive procedures (Gilbert, 2008). A further step was made when the mathematician John Conway introduced the well-known 'Game of Life' operated by tremendously simple rules in a virtual world in the form of a 2-dimensional checkerboard (Conway, 1970).

ABMs are nowadays widely used to investigate how basic micro mechanisms generate macro structures (Epstein and Axtell, 1996). With such a perspective, relations and descriptions of general/system variables are replaced by an explicit representation of the micro features of a system usually considered in a discrete space-time (Gross and Strand, 2000).

The BanMakMai (BMM model) ABM was developed with the CORMAS (Common-pool Resources and Multi-Agent Systems)[15] platform, which was specifically developed to deal with renewable resource management. It uses Smalltalk object-oriented language under the VISUALWORKS environment (Bousquet, Bakam et al., 1998; Green Research Unit, 2003). CORMAS provides the developer with a built-in facility that includes a set of pre-existing entities and agent control procedures, and different types of interface to visualize simulation results.

[15] CORMAS and source code of BMM model are available at http://cormas.cirad.fr.

Through the above mentioned collaborative modelling process, the BMM model was co-constructed to achieve a representation of the reference domain shared by all the participants in the modelling process, including researchers. A sense of co-ownership of the BMM model therefore emerged as a result of the collaborative model construction process. The description of the BMM model, and its verification and validation are presented in this chapter.

10.1. The Challenge of Describing an ABM

Describing the implementation of an ABM is often cumbersome: its structure, characterized by intertwined interactions and rule-based algorithms, is difficult to unfold. Compared to traditional equation-based models, ABMs are undoubtedly more difficult to describe, communicate and analyze. Traditional equation-based models are easy to communicate because they are formulated in the unambiguous and universal language of mathematics. Unlike mathematical models, computer simulation models such as ABMs have no standard language or protocol for communication, so published descriptions of ABMs are often hard to read, incomplete, ambiguous (without clear indication of rules and schedules), and therefore less accessible (Grimm and Railsback, 2005). Consequently, to reproduce an ABM from its published description remains problematic (Hales, Rouchier et al., 2003), which seriously questions the scientific status of such tools.

To help readers understand the structure of ABMs more easily, and enable them to re-implement such types of models, a standard protocol entitled Overviews-Design concepts-Details (ODD) has been proposed for the description of both individual-based models (IBMs) and ABMs (Grimm et al., 2006). IBMs differ from ABMs in that they generally model non-human entities interacting within an ecological system (Grimm et al., 2005), while ABMs often model human actors making decisions (Gilbert and Troitzsch, 1999). The description of the BanMakMai ABM below is, hence, based on the ODD protocol.

10.2. Description of the BMM Model

10.2.1. Overview of the BanMakMai Agent-Based Model

The first purpose of the BMM model is to inform readers about what is to be done with the model. Then, the low level state variables[16] of all entities (see Table 10.1) and the spatial and temporal scales outline the structure of the model. A UML class diagram showing the structure of the ABM completes this static representation (see Figure 10.1). Finally, all the processes that occur in the model are listed and indications about how they are scheduled are given in a UML sequence diagram (see Figure 10.4).

10.2.1.1. Purpose of the BMM model

The BMM model is a communication tool that is used by scientists and local RLR farmers to exchange knowledge about the interactions between land & water use and labour migration in the RLR environment of lower northeast Thailand and integrate that knowledge into local practices.

10.2.1.2. State Variables and Scales

The BMM model is made of five key interacting entities: Individual (Member), Household, Village, Rice, and Water tanks. Individuals (Members) and Households are rule-based agents representing local rice farmers from Ban Mak Mai village. In the BMM model, the heterogeneity of the household's aggregating member agents, whose age, gender, marital status and migration experience are different, depicts the diversity of existing farming households as they exist in reality.

The age of an individual (Member entity) influences its labour status and role (dependant, farmer, or migrant) while gender, marital status and migration experience influence an individual's decision to migrate or not. The age and the migration experience of an individual change over time. Figure 10.2 shows the relationship between the age and labour status (role) of an individual. The performance (area per day) of an individual performing the Farmer role also depends on the individual's age.

[16] Low level state variables cannot be deduced from other state variables because they are elementary properties of model entities. For example, individuals might be characterized by age, gender, location etc.

The algorithm simulating the decision of an individual member to switch its role to migrant is described below in the "details" section of this chapter.

Table 10.1 List of parameters classified by entity indicating their default values and sources.

Entity	*Parameter*	*Default value*	*Unit*	*Source & main tool used*
Individual (Member)	Minimum age of farmer villagers	15	years	Field workshop based on BMM model in 2007
	Maximum age of farmer villagers	65	years	
	Minimum age of migrant villagers	17	years	Authors' farm survey in 2004
	Maximum age of migrant villagers	45	years	Field workshop based on BMM model in 2007
	RLR transplanted area	0.16	ha/day	
	RLR harvested area	0.08	ha/day	
	RLR transplanted area by young farmers	0.16	ha/day	
	RLR transplanted area by old farmers	0.08	ha/day	
	Age threshold for RLR transplanting	50	years	
Household	Beginning of RLR nursery establishment	the Royal Ploughing Day	day	Field workshop based on RPG1
	Average annual net income per household	20,000	baht	NSO, 2007
	Average farm input cost excluding labour cost	3,750	baht/ha	OAE, 2007
	Average annual consumption expenditure	9,600	baht/per capita	NSO, 2007
	Paddy for self-consumption	350	kg/person/year	Authors' farm survey in 2004
	Daily rainfall threshold to initiate RLR nursery establishment	30	mm	Field workshop based on RPG3
	Daily rainfall threshold to start transplanting	20	mm	
	Daily rainfall threshold to stop harvest for one day	10	mm	
Village	Daily wage at RLR transplanting	120	baht/labour	Field workshop based on BMM model in 2008
	Daily wage at RLR harvest	150	baht/labour	
Rice	Minimum daily rainfall of a wet day at nursery stage	10	mm	Field workshop based on ABM2
	Duration of dry spell for water stress to occur in RLR nurseries	12	day	Field workshop based on ABM1
	Average RLR paddy yield in Ubon Ratchathani province	1,970	kg/ha	OAE, 2007
	Age of RLR seedlings ready for transplanting	30	day	Field workshop based on RPG1
	Duration of transplanting after rice seedlings reach 30 days	21	day	Field workshop based on ABM2
	Last week to establish RLR nurseries	3rd week of July	week	Field workshop based on RPG1
	Last week for RLR transplanting	2nd week of September	week	
	Starting date for harvesting of glutinous rice (RD6)	10th November	day	Bureau of Rice Research and Development, 1999
	Starting date for harvesting of non-glutinous rice (KDML105)	21st November	day	
	Maximum harvesting date to get high quality paddy	1st December	day	Field workshop based on BMM model in 2007
	Maximum harvesting date to get fair quality paddy	10th December	day	
	Farmgate price of high quality paddy	18	baht/kg	Thai Rice Mills Association, 2008
	Farmgate price of fair quality paddy	12	baht/kg	
	Farmgate price of low quality paddy	9	baht/kg	
	Water quantity needed to establish a 0.04 ha RLR nursery	80	m^3	Field workshop based on BMM model in 2007
	Water quantity needed to supply a 0.04 ha RLR nursery	40	m^3	
Water Tank	Depth of water storage tanks (farm ponds)	3	m	Authors' farm survey in 2004
	Height of ponding tanks (paddy fields)	20	cm	
	Minimum depth of water level needed in water storage tanks as percentage of water storage tank depth	10	%	Field workshop based on RPG1
	Daily volume of water deducted from a ponding tank by the soil-plant system	10	mm	BMM model calibration

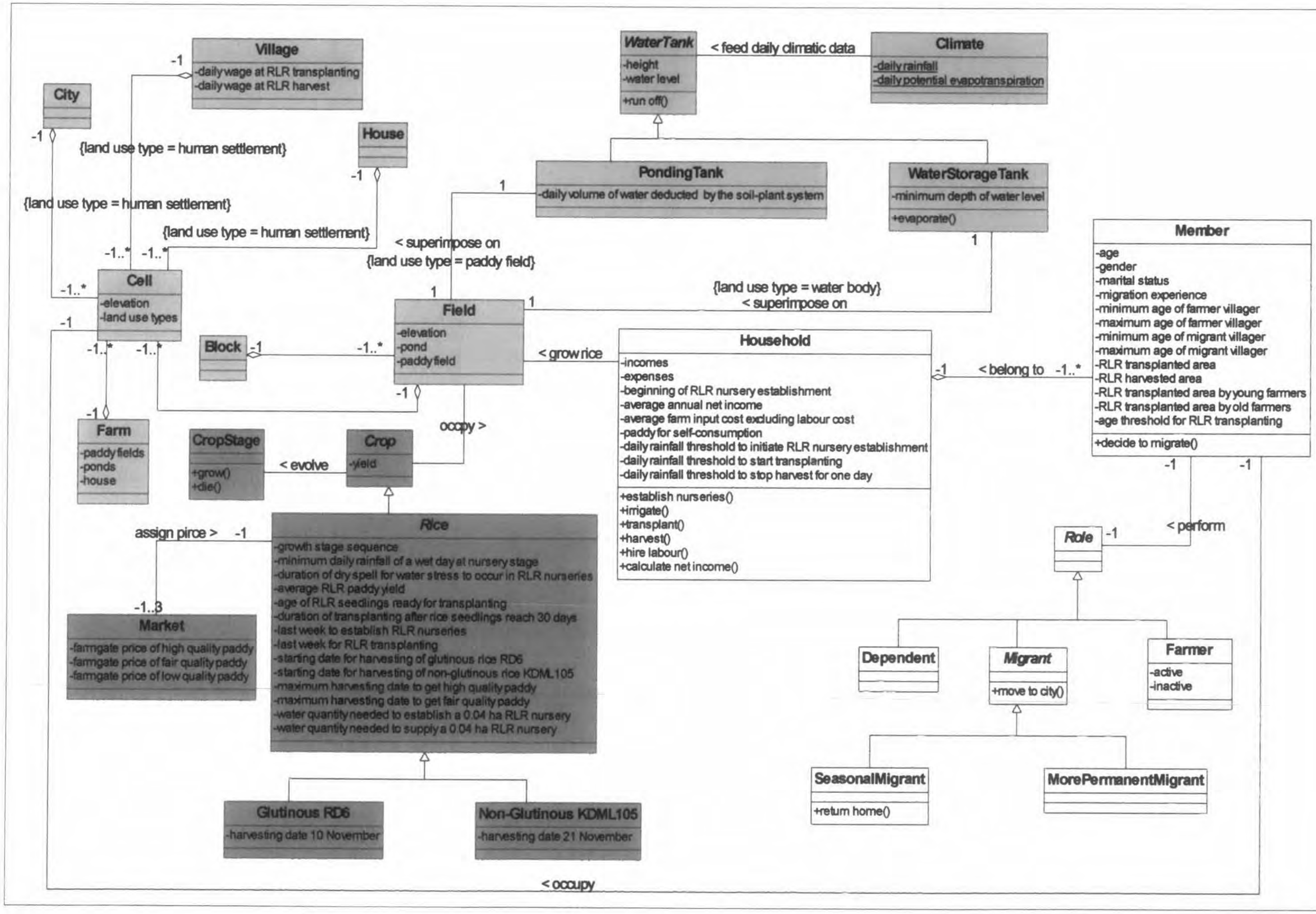


Figure 10.1 Structure and interlinked components of the BMM model represented by a UML class diagram showing the attributes and methods associated to each entity.

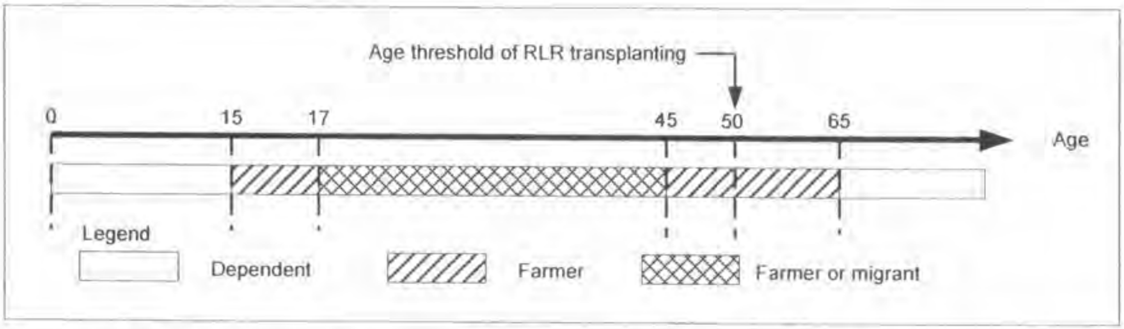


Figure 10.2 Relationship between the age of individuals and their labour status.

The Household entity, made of individual members, is a key decision-maker in the BMM model. All main RLR-producing activities are decided at this entity level by considering the need for and the availability of water whenever it is relevant (for instance there are thresholds of daily rainfall to start the nursery bed, to start transplanting and to pause harvesting; see Table 10.1). State variables embedded in this entity include average farm input cost (used in the calculation of income generated from rice sales), average annual net household income (used in the migration decision algorithm), and annual area of paddy for self-consumption.

The Village entity is an aggregation of household agents functioning as a registration desk where all potential farm workers are listed for hiring. The daily wages for transplanting and harvesting rice are also defined at this level. The Rice entity comprises two photo-sensitive late-maturing varieties: glutinous (RD6 variety) for self-consumption, and non-glutinous (KDML105 variety) rice for sale. The key dates and durations related to the successive phases of the RLR-based cropping system (seedling stage, transplanting, harvesting) are presented in Figure 10.3. For instance rice seedlings can be transplanted once they are 30 to 51 days old. After 51 days, the rice seedlings are too old for transplanting.

The lack of water at critical points of the cropping calendar (establishment and maintenance of nursery beds, start of transplanting) results in partial (maintenance of nursery bed) or complete (establishment of nursery bed and start of transplanting) failure. To facilitate the comparison of simulation scenarios, the yield is set to a constant value of 1,970 kg per ha (Office of Agricultural Economics, 2007). Three different selling prices of late maturing rice variety are set to represent a delay between maturity and harvest: the faster the harvesting is completed, the higher the quality of the paddy (see Table 10.1). The three different prices of rice also take into account the effect of the duration of harvest on the quality of paddy. The volumes of water needed to establish a nursery and to alleviate any drought effects, and the time constraints of rice-growing practices at each rice growth stage are also low level variables (see details in Table 10.1).

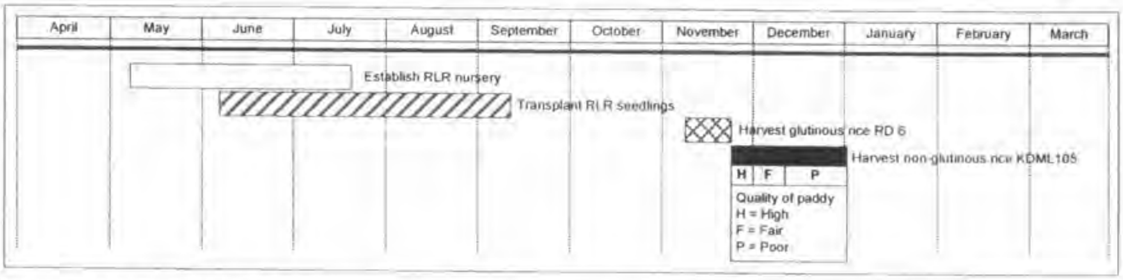


Figure 10.3 Rainfed lowland rice (RLR) cropping calendar in the BMM model.

In the BMM model, Water tank entities are either paddy field ponding tanks (20 cm deep) or farm pond storage tanks (3 m deep). The water level in the tanks is updated on a daily basis by adding the rainfall and subtracting the evaporation read from external data files (see below in the "input" section in this chapter). When the water level exceeds the height of a water tank, the overflowing water is shared among the lower level neighbouring water tanks (run-off). Additionally, an estimated constant volume (10 mm per day) is subtracted from the ponding tanks to account for water used by the soil-plant system. A minimum water level (estimated at 10% of storage capacity) is needed in the ponds. Otherwise a household cannot operate the irrigation function.

The spatial resolution was set to 0.04 ha (one *'ngan'*, a traditional Thai measurement of area), and is represented by a cell (the smallest homogeneous spatial unit of the model) on the BMM interface. Elevation ranges from 97 to 133 meters and represents a regular slope from lower to upper paddies. To represent a typical portion of a RLR ecosystem, 2 small (3.6 ha) and 2 large (7 ha) farms are plotted. Each farm is made of a collection of paddy fields in sizes ranging from 0.28 to 0.96 ha.

The BMM model is a discrete time step model. A daily time step was chosen because in reality, participating rice farmers adjust their decisions according to climatic conditions on a daily basis. However, to some extent this model is also eventdriven since occurrences of water stress during the nursery stage trigger household agents' reactions. The time horizon was set to 5 years to enable an assessment of scenarios simulating diverse climatic situations to be carried out while limiting the impact of demographic change: within such a relatively short period of time, the reproduction and mortality of individual members, which are not the focus of this model, are not taken into account.

10.2.1.3. Process Overview and Scheduling

A simple hydro-climatic process aggregating rainfall, evaporation, run-off and soil-plant consumption is run on a daily basis to update the water levels in all water storage tanks and to determine water availability for rice cropping. The operations related to rice production are also considered on a daily basis by the household agents. Figure 10.4 shows the sequence of farming activities throughout a crop year that was set to start on the first of April. The key successive farming activities are as follows: establishment of RLR nurseries and production of seedlings, transplanting, and harvesting. After RLR harvest, each household computes the results of the rice season. This updated household income and the presence of dependants in the household is taken into account when each member makes migration decisions during the dry season.

10.2.2. Design Concepts

This section intends to specify how concepts such as stochasticity, adaptation, fitness (objective) and interactions are addressed in the BMM model. The BMM model is purely deterministic. Randomness would be inconveniently confusing when the main objective of the model is to enhance communication among participants.

Household agents are able to memorize daily rainfall conditions and therefore detect the occurrence of water stress in nurseries when the last effective rainfall occurred more than 12 days ago. Additionally, in agreement with the objective of managing rice production and paddy quality, household agents adapt to labour constraints and can hire extra farm workers at transplanting and harvesting if needed (they are able to anticipate the need).

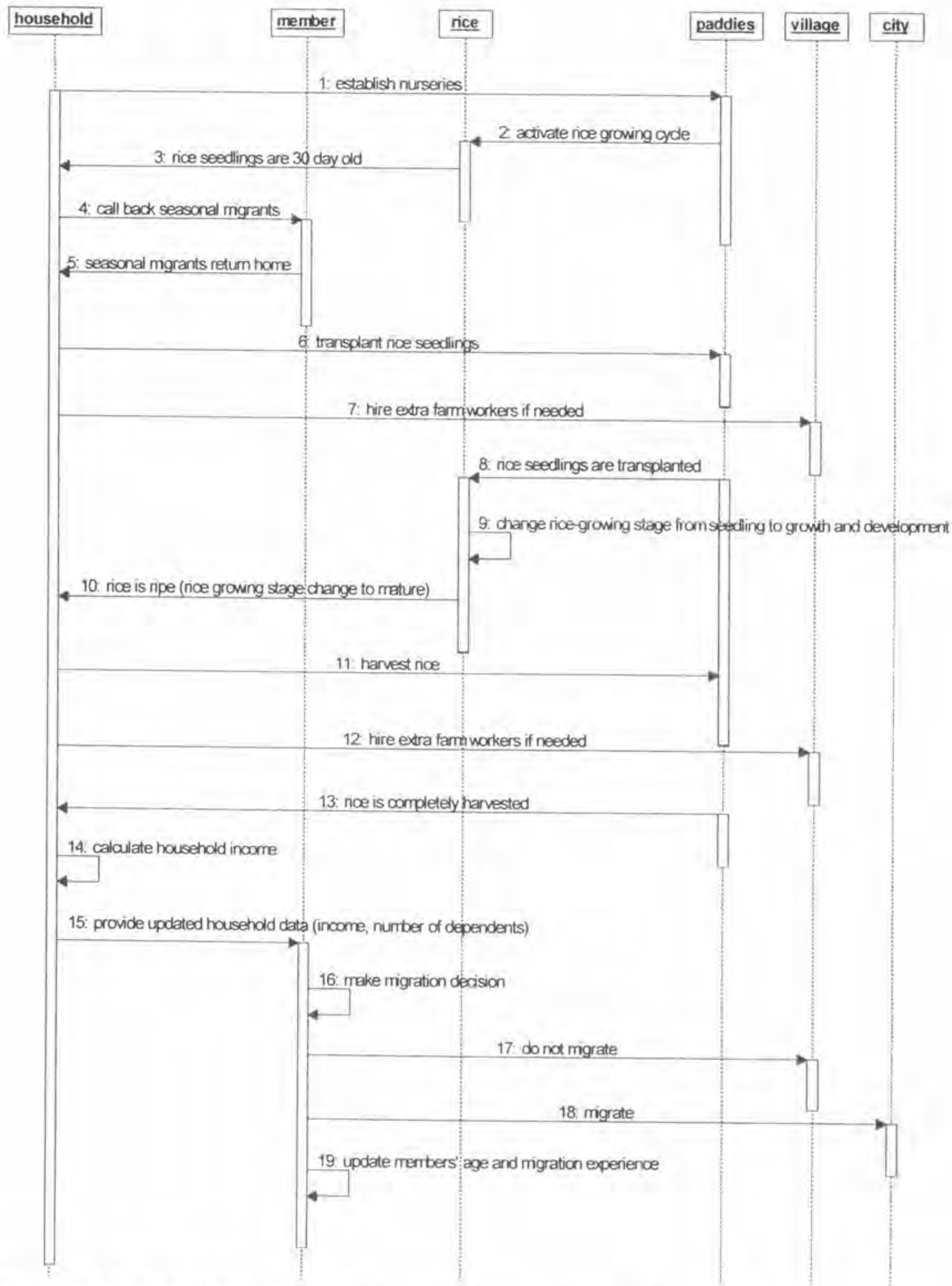


Figure 10.4 Scheduling of the BMM model operations during a crop year represented by a UML sequence diagram.

The BMM model integrates three aggregated social levels: individual, household, and village. A list of farm workers available for hiring is updated at the village level, and made accessible to all household agents. The household agents directly interact in the process of hiring extra farm workers.

Observation of visual outputs is an essential feature of collaborative modelling: for the farmers to be able to comfortably follow a simulation, a set of specific interfaces were developed. To facilitate the understanding of the chronology of a simulation, an interface depicting the traditional calendar was displayed week after week with the corresponding rainfall distribution (Figure 10.5). It also displays the dates of key ceremonies used as milestones by the farmers, such as the Royal ploughing ceremony in early May and the Thai New Year on the 13th of April. Rainfall information is also updated on a daily basis, illustrated in the right corner of the simulation interface (close to household A2).

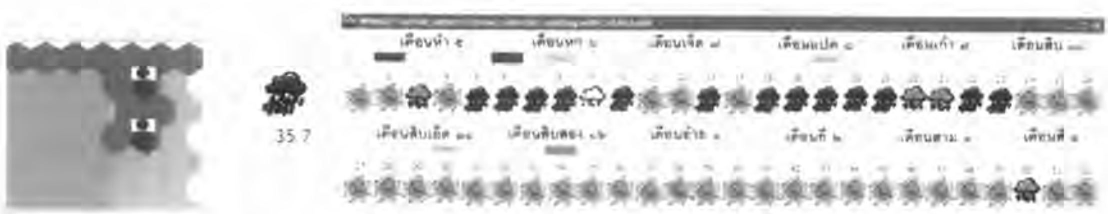


Figure 10.5 Display of rainfall conditions on a daily basis (left) and weekly basis (right) on the BMM model main interface.

Water levels in farm ponds are also displayed on the BMM main interface to facilitate discussion and assessment by participating farmers (Figure 10.6). Other types of spatial settings are constant, and are used to indicate the role of their occupants (dependant, farmer, or migrant) via the use of different coloured pictograms.

To visualize what is happening at any time step of a simulation in a way that makes sense to the participating farmers, the interface representing the space includes other elements. As shown in Figure 10.6, roads are located at the highest elevation, next to upper paddies, while lower paddies are close to a natural stream located at the lowest elevation. Additionally, to allow for the visualization of the labour status of individual members by deduction from their locations, human settlements are also represented: one house per farm (location of dependent members), one village (location of unoccupied farmers) and one city (location of migrants).

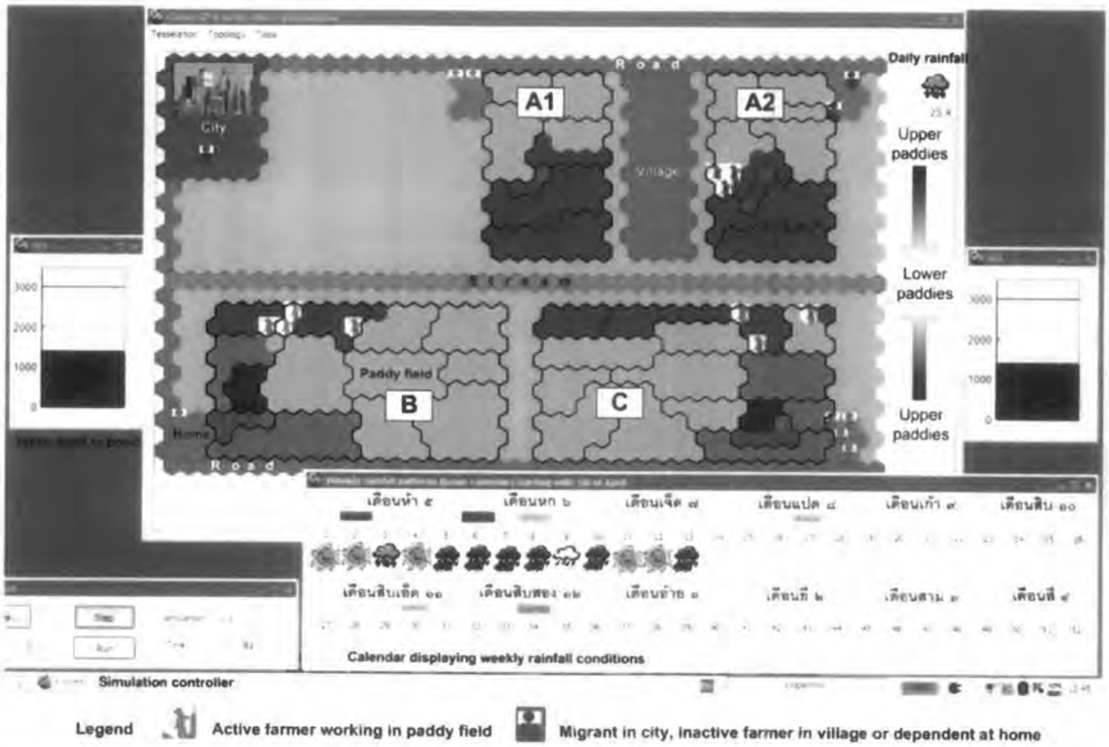
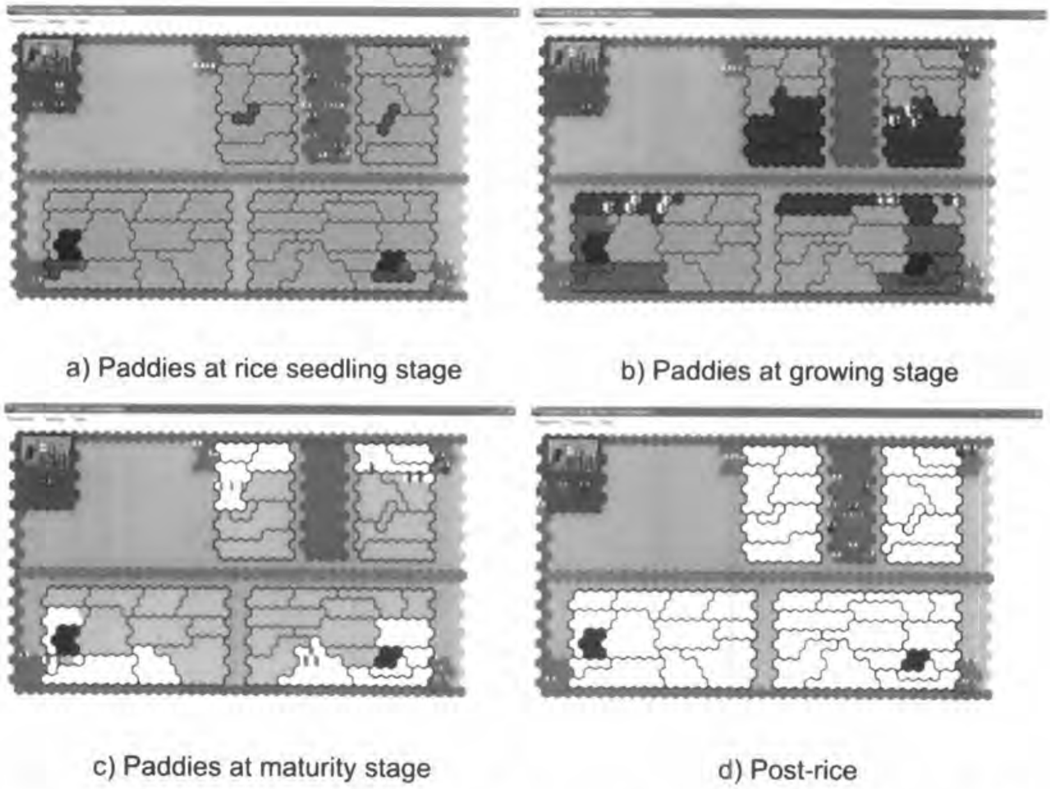


Figure 10.6 Spatial configuration of the BMM model representing two small farms (A1 and A2) and two large farms (B and C) during rice transplanting, and water level in farm ponds updated daily during simulation run.

The visualization of paddy fields changes according to the stage reached by the rice crop. For instance, during rice establishment, a light green colour indicates fields planted to glutinous rice (RD6) while dark green refers to non-glutinous rice (KDML105). Once the rice is ripe, yellow is used to indicate that it is ready to be harvested. Each growth stage is associated with different colours on the simulation interface at different times of the simulated crop year (Figure 10.7).



a) Paddies at rice seedling stage b) Paddies at growing stage

c) Paddies at maturity stage d) Post-rice

Figure 10.7 Display of paddy fields on the BMM interface during simulation of a rice cropping year.

10.2.3. Details

The last part of the ODD protocol aims to provide enough details so that the model can be re-produced from scratch. The details are grouped into three sections: initialization, model input, and sub-models.

10.2.3.1. Initialization

As I experienced some difficulty in meeting the model's purpose when introducing the 11 households and their actual means of production (participants were just concerned with the household initialized in their situation, looking for perfect similarities between the representation of their farm and their actual conditions), a simplified initialization to have only four virtual farms was designed. Two households (A1 and A2) represented type A farmers (the majority of farming households found in the study area) while types B and C were represented by households B and C respectively (see Figure 10.6 and Table 10.2). Beyond the farm size, the land/labour ratio to represent each main farm type according to the results of my on-farm survey and farmer typology was taken into account. The characteristics of each individual member were chosen to represent the heterogeneity of family members living in a household (Table 10.3). The initial water level in ponds was set to 0 cm.

Table 10.2 Characteristics of simulated households at initialization.

Household	*Farm size (ha)*	*Pond volume (m^3)*	*Family labour*			*Family dependent*
			Farmer	*Seasonal migrant*	*More-permanent migrant*	
A1	3.3	no pond	3	1	0	2
A2	3.3	no pond	3	0	1	2
B	6.5	7,200	2	0	0	1
C	6.5	4,800	2	1	0	4

Table 10.3 Characteristics of individuals from each household at initialization.

Household	*Name*	*Gender*	*Age*	*Marital status*	*Migration experience*
A1	M1-1	Male	55	Married	Yes
	M2-1	Female	55	Married	No
	M3-1	Female	30	Married	Yes
	M4-1	Male	25	Single	Yes
	M5-1	Female	10	Single	No
	M6-1	Male	8	Single	No
A2	M1-2	Male	55	Married	Yes
	M2-2	Female	52	Married	Yes
	M3-2	Female	32	Married	Yes
	M4-2	Male	29	Married	Yes
	M5-2	Female	10	Single	No
	M6-2	Female	6	Single	No
B	M1-3	Male	50	Married	Yes
	M2-3	Female	45	Married	No
	M3-3	Male	5	Single	No
C	M1-4	Male	50	Married	No
	M2-4	Female	45	Married	No
	M3-4	Male	30	Married	Yes
	M4-4	Female	14	Single	No
	M5-4	Male	12	Single	No
	M6-4	Male	5	Single	No
	M7-4	Female	2	Single	No

10.2.3.2. Input

Daily rainfall and potential evapotranspiration (PET) data used in the model to vary the climatic conditions affecting agents' decisions to establish rice nurseries, transplant and harvest, were obtained from the regional meteorological centre located in Ubon Ratchathani province. The same set of 5 years (1991-1995) was used for all simulation experiments. This set was selected because they are the most recent successive 5 years with complete daily rainfall and PET data. Figure 10.8 shows the accumulation of daily water balance each year determined by daily rainfall subtracted by daily PET. This daily water balance inputs indicate water availability retained in farm ponds. The price of rice was set based on information obtained from the Thai Rice Mills Association (Table 10.1).

10.2.3.3. Sub-models

The sub-models correspond to the key activities practiced by local farmers during the rice production cycle. In the BMM model, once the selection of rice varieties to be grown has been made, the cycle starts and ends with rice post-harvest activity including updating Household and Member variables and labour migration.

At the beginning of a simulation run, rice varieties are selected. Depending on land per labour ratio, either a single or two rice varieties are produced. If the ratio is lower than 2 ha, only KDML105 variety is grown. Otherwise, two rice varieties (RD6 and KDML105) are planted. However, this ratio may change over time as family members update their labour status every year. The area planted to varieties for self-consumption depends on the needs of all household members.

Nursery establishment

The location of nurseries is set such that, as in the reality, it is neither far from the house nor from the pond (when it exists); higher places are better for water control. When there is no pond, the nursery is located in the middle of the farm.

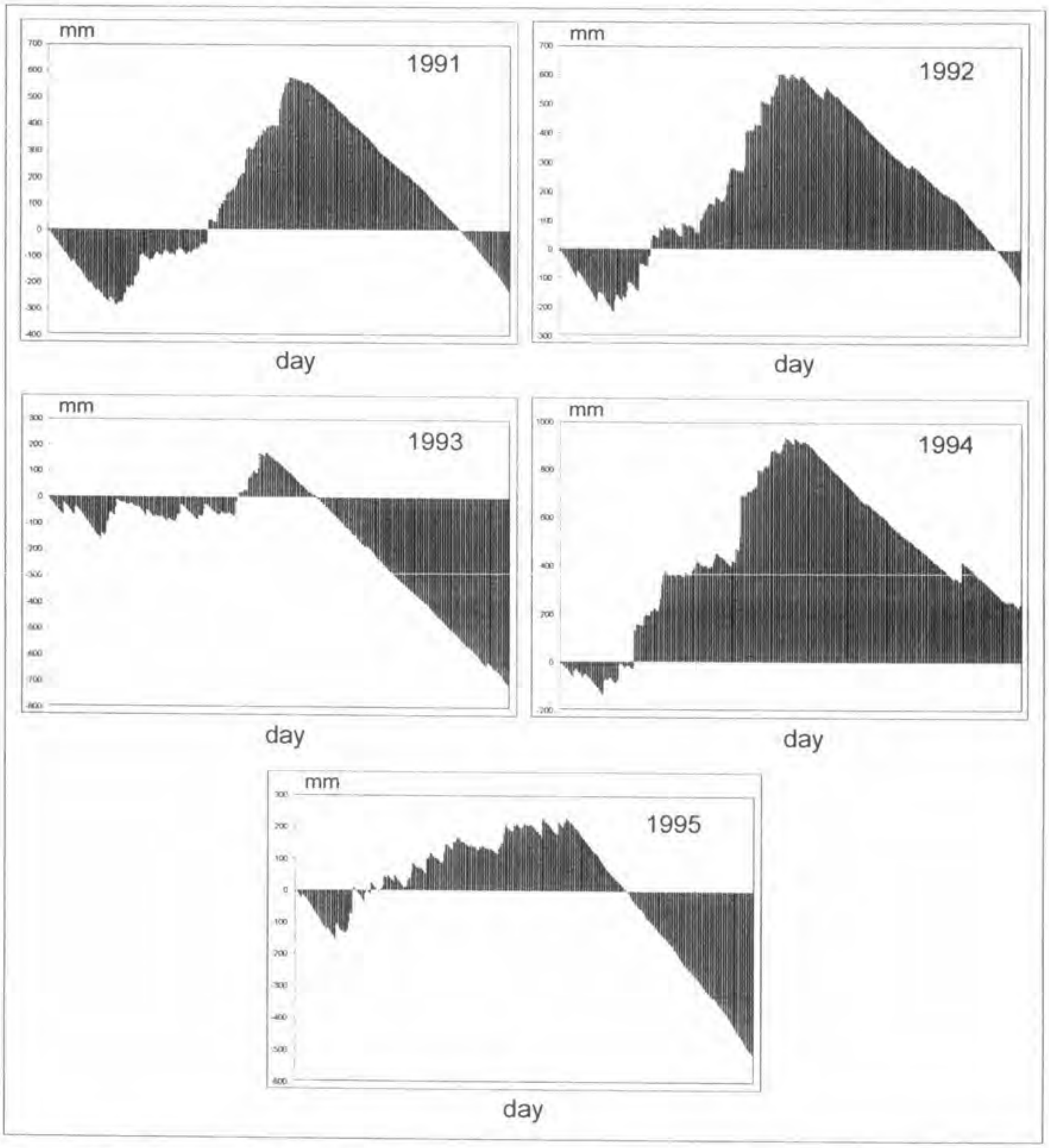


Figure 10.8 Accumulation of daily water balance input (mm) for water availability in farm ponds used in the BMM model.

The annual RLR production cycle begins in the second week of May, after the Royal ploughing ceremony held in Bangkok. From that date on, if the quantity of daily rainfall is higher than 30 mm, a nursery is established (Table 10.1). If the quantity of daily rainfall is lower than this threshold, water from the pond can be used for nursery establishment (80 m^3/ha), provided the water level is above 10% of the pond's depth (Figure 10.9). This activity takes only one day, and must be performed before the 3rd week of July (limit date for nursery bed) to ensure that rice being produced has enough time to accumulate biomass needed for the target yield. This activity is visualized on the simulation interface as light and dark green cells for RD6 and KDML105 varieties respectively (Figure 10.7a).

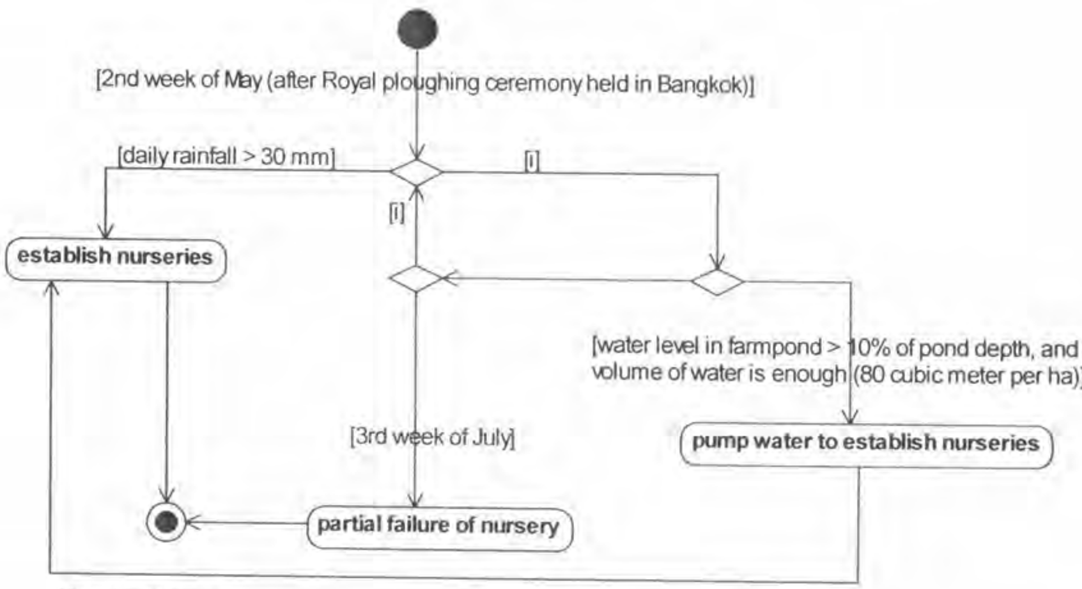


Figure 10.9 Algorithm for the establishment of a rice nursery bed in a UML activity diagram.

Irrigation water requirement for the maintenance of a nursery was defined through two thresholds: a daily rainfall threshold to define a dry day, and a number of successive dry days (12) needed to cause water stress in rice seedlings (Table 10.1). A water stress triggers a household to operate water pumping (40 m^3/ha). The seedlings in nurseries require 30 days to be ready for transplanting. Seedlings may become too old (over 51 days) for transplanting when a long dry spell occurs. Participating farmers said that water from the pond could only be used during the nursery phase, and not for transplanting. In case of water stress during the nursery stage or too long a period before transplanting, a 2nd nursery establishment needed to be established (Figure 10.10). According to the participants' suggestion, the algorithm takes into account when a 2nd nursery is needed, 1/3 of the whole nursery area will be resown because local farmers have never experienced a complete nursery failure.

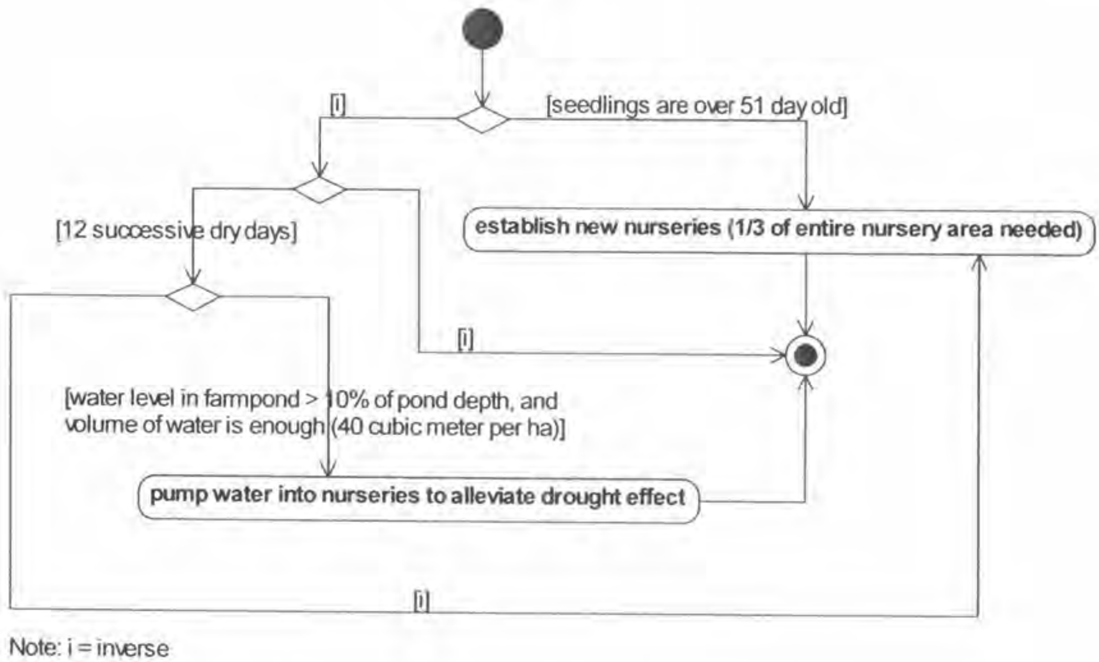


Figure 10.10 Algorithm for the maintenance of a rice nursery in a UML activity diagram.

Transplanting

Once rice seedlings are 30 days old and ready for transplanting, Rice entity sends a message to the household agent who checks whether or not the daily climatic conditions are suitable for transplanting (daily rainfall higher than 20 mm). The last date for transplanting was set to September 15; after that date the duration of the RLR vegetative phase would be too short to achieve satisfactory yields. In case this situation could not be avoided, some paddies would remain without rice. Once a household starts transplanting, its seasonal migrant members return home to take part in this activity. Additionally, a household can compute if additional workers are needed to be able to complete transplanting on time. Once a household has completed transplanting, no more rice activity will be done until November. Thus, farmers belonging to such households are located in the village area, ready to be hired by other households who have not completed transplanting yet (Figure 10.12).

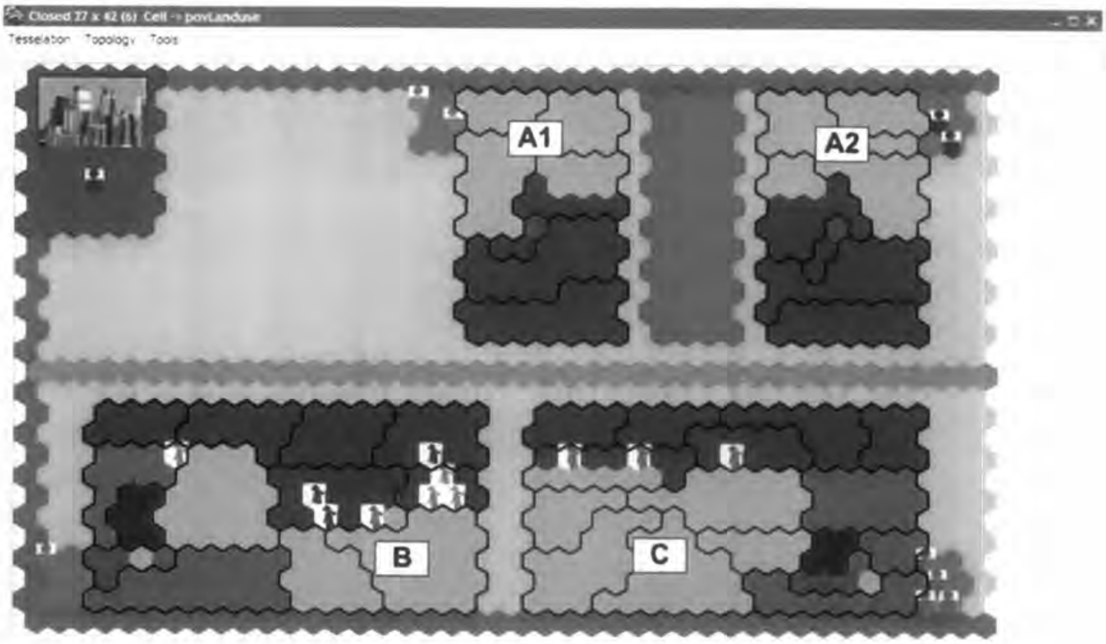


Figure 10.11 Members of household A1 and A2 being hired by household B during transplanting of KDML105 variety on the BMM model interface.

Participants were requested to transplant the RD6 variety first if it was produced. The transplanting of the RD6 start from the upper paddies downwards to the lower ones and its paddies has to be close to a house (or temporary storage hut). Because this RD6 rice variety is harvested earlier, the KDML105, which is growing, must not block the path to deliver RD6 paddy back to the storage hut.

The KDML105 variety is transplanted from lower paddies upwards to upper ones to ensure enough water for this farm gate rice. Water is collected at lower paddies and usually increases rapidly to upper paddies in August when rainfall is high and the water table is rising close to the ground.

Harvesting

Farmers return to the paddies to harvest at fixed dates defined in table 10.1. These dates correspond to the harvest time of these photo-sensitive late-maturing rice varieties. For the RD6 variety, the harvest time is set to the 10th of November and 10 days later for the KDML105 variety. In the BMM model, harvesting stops if the daily rainfall is more than 10 mm. Farmers will let the rice dry for one day after a wet day before restarting the harvest. The number of days it takes to complete the harvest is important in determining paddy quality, resulting in different prices that affect household income generated from KDML105 sales, which in turn influences migration decisions. Hiring labour could therefore be considered as a necessary practice for all farms to accelerate harvesting, so that this activity can be completed before the 1st of December to ensure the highest paddy quality (Figure 10.13). The recruitment of hired labour is often competitive in this period, resulting in a higher daily wage than during transplanting (see Table 10.1).

Participants requested rice to be harvested in the model from upper paddies towards lower ones. This practice is carried out in reality to avoid poor paddy quality because of high moisture. While rice is harvested, paddies will gradually dry out from upper to lower areas.

Labour migration

Once rice harvest is completed, two key operations are made in sequence. First, households update their household net income and members update their age, and migration experience. Then household members can decide whether or not to migrate. The household income is generated from rice sales and wages earned during rice production. The farm expenses are calculated based on farm inputs used. This household income will be updated. The annual household net income is computed as follows: (income from rice sales + wage received) – (farm inputs cost + labour cost + household expenditures). The level of updated household net income affects the selection of migratory patterns decided by members in the household.

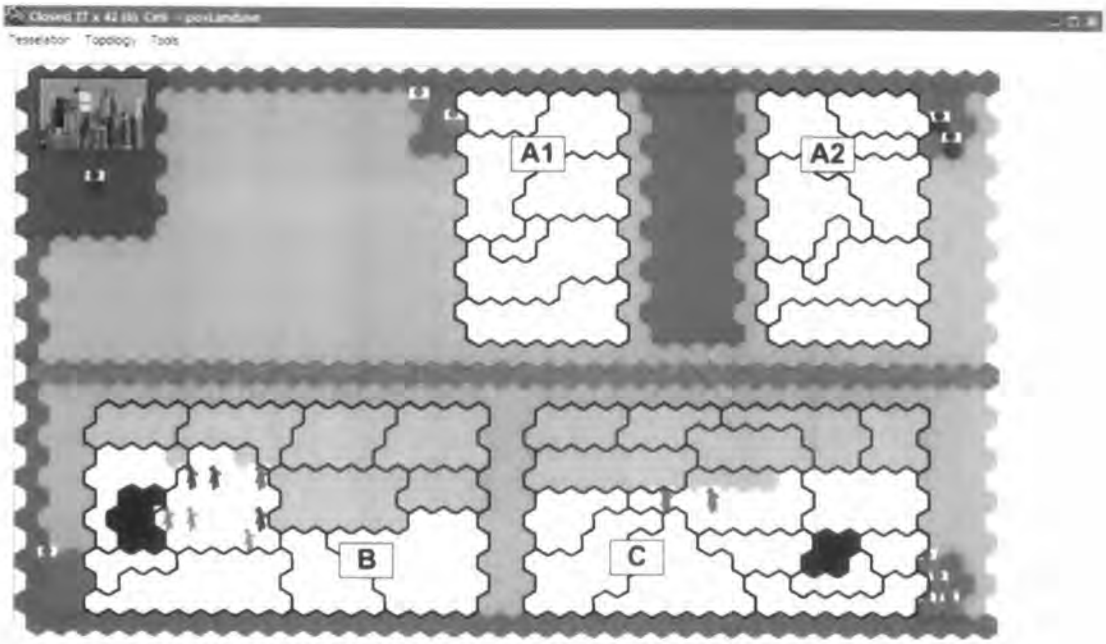


Figure 10.12 Members of household A1 and A2 being hired by household B during harvesting of KDML105 variety on the BMM model interface.

The migration decision involves multi-level factors from individual to village levels. Individual characteristics of members are considered as well as their household's social and economic status to determine whether they migrate during the dry season (seasonal migrant), migrate to the city without returning home to produce rice (more-permanent migrant) or do not migrate (Figure 10.13). An important social constraint is the presence of the elderly or/and children (dependant) who need to be looked after by an adult member. During the participatory simulation workshops, we could not reach an agreement about the minimum amount of annual net income needed for farmers to stay at home. This criterion is clearly different among the participating farmers. As a result, I decided to use the average annual net income for Northeast Thailand (20,000 baht per household) defined by the National Statistical Office (NSO) in 2007. At the end of a simulation, migrants will move to the city. However, household B did not have any migrants because two of its workers (45 and 50 year old respectively) were too old to migrate while the other one was only a 5 year old.

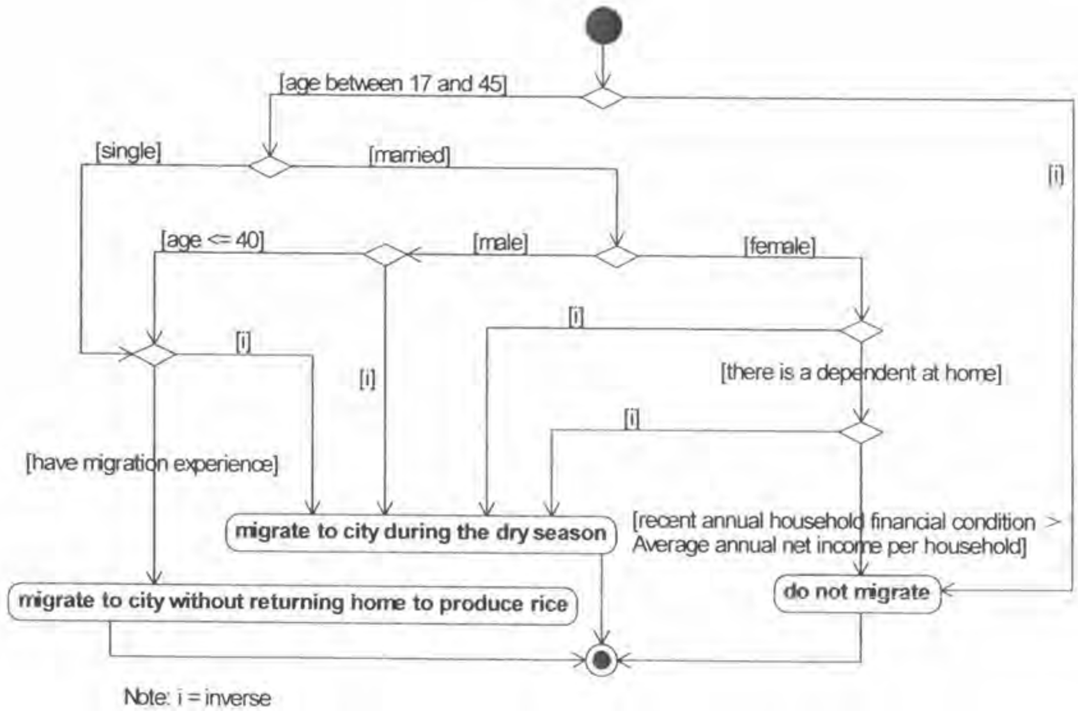


Figure 10.13 Algorithm representing individual decision to migrate or not in a UML activity diagram.

10.3. Calibration, Verification and Validation of the BMM model

Calibration is any parameter's value used to adjust the model's outputs in correspondence to the expected values. This process is similar to adjusting a measuring instrument using a calibration standard. After the model has been constructed, one begins the model verification process of checking that it is correct (Gilbert, 2008). The verification process investigates that the simulation program implemented in an operational model correctly represents its conceptual model, and ensures that the model satisfies what it is designed to do (Banks, 1998; Ferber, 1999). Simply, model verification deals with building the model right (Balci, 1998).

Once an ABM model has been developed, it is essential to check its validity. Validation is a determinant of whether the conceptual model can be substituted for the real system for the purpose of experimentation (Banks, 1998). Model validation deals with building a right model (Balci, 1998). However, both theory and practices of validation are complicated and controversial. The issues are related to the various objectives purported by modellers, which imply different criteria for validation and the insufficiency of social empirical data, which is usually hard to quantifiably acquire to allow systematic validation (Troitzsch, 2004). It is important to recognize that my ability to validate a model directly depends on how much we already know about the system under study (Deaton and Winebrake, 1999). The calibration, verification and validation are carried out with several techniques to assess credibility at each stage of the life cycle of a simulation study (Balci, 1998). These processes are often iteratively carried out once the programmed model is implemented.

10.3.1. BMM model Calibration and Verification

Many models are difficult to verify because they are often compounded by random number generators resulting in different outputs in every run. Only the distribution of results can be anticipated by the theory (Gilbert et al., 1999). But that is not true in this case because the BMM model is purely deterministic. Therefore, the outputs of this model can be determined based on its initial inputs of selected parameters. Several verification techniques were used to accomplish the verification purpose including debugging[17], cause-effect graphing[18], and functional testing[19] (Balci, 1998).

During the BMM model's co-construction with participating RLR farmers, the 'debugging' was also consistently carried out. The cause-effect graphing to verify water balance in ponding and water storage tanks of the BMM model was also conducted. During the test, only the complex hydroclimatic processes were executed. However, various difficulties were discovered. In particular, many values belonging to unidentified parameters were used. Such difficulties impeded the model verification process. Consequently, I decided to simplify the hydrological processes (see details in chapter VIII). Instead of underground water losses, the water outflow caused by the soil-plant system (10 mm per day) was a calibrated value used to balance water availability in the ponding tank to sufficiently represent the water dynamics based on farmers' perceptions (see in Table 10.1).

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[17] Debugging is an iterative process whose purpose it is to uncover errors and misconceptions causing the model's failure and to define and carry out the model changes that correct the errors.

[18] Cause-effect graphing assists model correctness assessment by addressing the question of what causes what in the model representation.

[19] Functional testing is used to assess the accuracy of model input-output transformation. It is virtually impossible to test all input-output transformation paths for a complex simulation model. Therefore, this technique aims to increase my confidence in model mode input-output transformation accuracy as much as possible.

Besides that, functional testing was carried out. A spreadsheet was produced and used to check: (i) the day that RLR establishment begins, (ii) the occurrence of water stress which triggers the irrigation function in the BMM model, and (iii) the day that run-off is operated (see Table 10.4). Under the same initial input values and thresholds, the simulated results of the BMM model were compared to the outputs generated by the spreadsheet. It was found that the BMM simulation provided the same outputs than those of the spreadsheet.

10.3.2. BMM model Validation

Similar techniques to model verification were used to achieve this task. Debugging and functional testing has often been conducted in the laboratory at the same time as the BMM model verification. However, in this ComMod experiment, the BMM model was commonly validated throughout its co-construction with participating farmers. Additionally, two techniques were used: the face validation[20] and turing test[21] (Balci, 1998).

Thanks to the principles of these techniques, the participating farmers are RLR grower experts who are knowledgeable about the RLR ecosystem under study. They observed the BMM simulations and analyzed the outcomes based on their mental models derived from their indigenous knowledge and experience. According to the iterative continuous loops of this collaborative modelling process, less differentiation between the BMM model and participants' mental models was identified. Likewise, the responses from participating farmers provided valuable feedback for correcting model representation. The BMM algorithms were then improved accordingly and the validity of model was gradually increased (see Table 10.5).

[20] Face validation is often carried out within a team of members and people knowledgeable about the system under study. The objective is to compare model and system behaviours under identical input conditions and judge if the model and its results are reasonable.

[21] Turing test is based on the expert knowledge of the system under study. Without identifying the simulations prior to its run, the experts are asked to differentiate between their mental model and simulation model.

Table 10.4 A spreadsheet produced to generate the outputs of 1986 to verify the BMM simulation outputs under the same value of parameters and thresholds, with the 18th of May highlighted for the beginning date of RLR nursery establishment.

Parameters' value input		day	1986							
			Accumulated water level in farm ponds (mm)	Accumulated water volume in farm ponds (m3)	Accumulated water volume in farm ponds is enough to build nursery? (m3)	Accumulated water volume in farm ponds is enough to mitigate drought? (m3)	Daily rainfall (mm) with highlight date to establish nursery	Water level (mm) in ponding tanks (paddies)	Water stress happens?	Run-off in paddies is operated?
Initial water level in farm ponds		Apr-01	118.30	189.28	NO	YES	23.40	108.30	NO	NO
100	mm	Apr-02	112.60	180.16	NO	YES	0.00	102.60	NO	NO
		Apr-03	107.00	171.20	NO	YES	0.00	97.00	NO	NO
Pond size		Apr-04	101.60	162.56	NO	YES	0.00	91.60	NO	NO
1600	m2	Apr-05	95.40	152.64	NO	NO	1.00	85.40	NO	NO
		Apr-06	87.60	140.16	NO	NO	0.00	77.60	NO	NO
Farm size		Apr-07	80.80	129.28	NO	NO	0.00	70.80	NO	NO
40	rai (0.16 ha)	Apr-08	76.20	121.92	NO	NO	0.00	66.20	NO	NO
		Apr-09	70.10	112.16	NO	NO	0.00	60.10	NO	NO
Nursery size		Apr-10	63.71	101.94	NO	NO	0.01	53.71	NO	NO
4	nagn (0.04 ha)	Apr-11	57.21	91.54	NO	NO	0.00	47.21	NO	NO
		Apr-12	51.01	81.62	NO	NO	1.50	41.01	NO	NO
Water volume needed to establish		Apr-13	46.21	73.94	NO	NO	0.00	36.21	NO	NO
320	m3	Apr-14	41.91	67.06	NO	NO	0.00	31.91	NO	NO
		Apr-15	34.91	55.86	NO	NO	0.00	24.91	NO	NO
Water volume needed to mitigate drought		Apr-16	30.61	48.98	NO	NO	0.00	20.61	NO	NO
160	m3	Apr-17	23.61	37.78	NO	NO	0.00	13.61	NO	NO
		Apr-18	17.81	28.50	NO	NO	0.00	7.81	NO	NO
Water staroge tank height (farm pond depth)		Apr-19	10.01	16.02	NO	NO	0.00	0.01	NO	NO
3000	mm	Apr-20	2.51	4.02	NO	NO	0.00	0.00	YES	NO
		Apr-21	0.00	0.00	NO	NO	0.00	0.00	YES	NO
Water to be kept in farm ponds		Apr-22	0.00	0.00	NO	NO	2.10	0.00	YES	NO
0	% of farm pond depth	Apr-23	0.00	0.00	NO	NO	0.01	0.00	YES	NO
		Apr-24	3.90	6.24	NO	NO	5.90	0.00	YES	NO
		Apr-25	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		Apr-26	5.20	8.32	NO	NO	11.90	0.00	YES	NO
		Apr-27	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		Apr-28	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		Apr-29	0.00	0.00	NO	NO	0.01	0.00	YES	NO
		Apr-30	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		May-01	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		May-02	0.00	0.00	NO	NO	0.90	0.00	YES	NO
		May-03	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		May-04	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		May-05	0.00	0.00	NO	NO	3.60	0.00	YES	NO
		May-06	0.00	0.00	NO	NO	0.00	0.00	YES	NO
		May-07	29.00	46.40	NO	NO	32.20	19.00	NO	NO
		May-08	61.80	98.88	NO	NO	35.70	51.80	NO	NO
		May-09	60.40	96.64	NO	NO	3.90	50.40	NO	NO
		May-10	54.70	87.52	NO	NO	0.00	44.70	NO	NO
Beginning of RLR nursery establishment		May-11	47.70	76.32	NO	NO	0.00	37.70	NO	NO
		May-12	40.80	65.28	NO	NO	0.00	30.80	NO	NO
		May-13	32.50	52.00	NO	NO	0.00	22.50	NO	NO
		May-14	24.30	38.88	NO	NO	0.00	14.30	NO	NO
		May-15	16.00	25.60	NO	NO	0.00	6.00	NO	NO
		May-16	28.20	45.12	NO	NO	19.10	18.20	NO	NO
		May-17	51.20	81.92	NO	NO	28.30	41.20	NO	NO
		May-18	95.00	152.00	NO	NO	50.30	85.00	NO	NO
		May-19	96.30	154.08	NO	NO	5.40	86.30	NO	NO
		May-20	101.50	162.40	NO	YES	10.30	91.50	NO	NO

Table 10.5 Feedback and parameter values from participating farmers used to validate algorithms of the BMM model.

Algorithm		*Feedback*	*Parameters and their values*
Crop establishment	RLR management	• Paddies with ponds: Nursery locates upper paddies near pond • Establishing nursery determined by accumulated daily rainfall, not measure soil moisture • Grow two varieties: - Glutinous rice (RD6): Transplant from upper paddies near house downwards to lower ones - Non-glutinous rice (KDML105): Transplant from lower paddies upwards to upper ones • Grow only one variety (KDML105): Transplant from lower towards upper paddies • Complete failure of nursery never happens • No water pumped from farm ponds for transplanting	• The ratio of rice nursery bed area to transplanted area is 1:40 • RLR transplanted area by young farmer: 0.16 ha/day/labour • RLR transplanted area by farmer older than 50 year old: 0.08 ha/day/labour • Pump water to establish a 0.04 ha RLR nursery: 80 cubic meters • Pump water to supply a 0.04 ha RLR nursery: 40 cubic meters • 1/3 of the whole nursery area will be resown if water stress occurs • Daily wage at RLR transplanting: 120 bath/labour
	Migration practices	• Migrant workers belonging to type A farming households return home when transplanting starts • Few farm workers migrate after transplanting	
Rice harvest and post-rice harvest	RLR management	• Stop harvesting and wait for a day if there is a heavy rainfall • Extra workers are not needed to harvest RD6 variety • Extra workers are hired to complete harvesting KDML105 variety as soon as possible to get high quality rice for high price	• RLR harvested area: 0.08 ha/day/labour • Daily wage at RLR harvesting: 150 bath/labour
	Migration practices		• Age of potential migrant: between 17 to 45 year old • Limited age to be a migrant worker for a male and married villager: older than 40 year old

Once the BMM model was validated by participating farmers to sufficiently represent their current situations, it was intended to be used for scenario exploration exercises. The use of the BMM model through the test of its sensitivity, field-based simulation and participatory analysis, and discovery of diverse scenarios in the laboratory is presented in the next chapter.