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# Modelling Decision-making in Rural Communities at the Forest Margin

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The FLORES simulation model aims to capture the interactions between rural communities living at the forest margin and the resources that they depend upon, in order to provide decision-makers with a tool that they can use to explore the consequences of alternative policy options. A key component of the model is simulating how decision-making agents within the system (individuals, households and the whole village) go about making their decisions. The model presented here is based on an anthropological description of the rules and relationships that people use, rather than on the assumption that people behave in an economically optimal fashion. The approach addresses both short-term decision-making (primarily the allocation of labour to various activities on a weekly basis), and long-term strategic land-use planning, taking into account the variety of tenure and inheritance patterns that operate in real communities. The decision-making sub-model has been implemented in the Rantau Pandan (Sumatra) version of FLORES, using the Simile modelling environment.

**Keywords**: decision-making, simulation model, household, forest margin, Sumatra, Indonesia

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## INTRODUCTION

In many parts of the world, rural communities living at the forest margin face increasing hardship, and contribute to deforestation. In some regions, lifestyles that were previously sustainable are threatened by increasing population pressure, over-exploitation of natural resources, and other pressures that lead to reduced yields and increased exploitation of natural forest. In other regions, people encroach on virgin forest areas, either through transmigration schemes or by following loggers into the forest, to grow crops, often on land incapable of sustaining yields.

Many policy-makers are concerned with formulating policies to address the problems associated with the conversion of forest to agriculture. Government agencies concerned with rural development, national and international agricultural research agencies, and non-governmental research organisations are all confronted with these challenges. For some, the primary concern is to formulate policies to improve rural livelihoods, by promoting more productive and more sustainable practices. For others, the main concern may be deforestation, conservation of biodiversity, to the reduction of carbon emissions. Often, both aims are served by maintaining the forest.

It is difficult to formulate effective policies. Because the systems involved are complex, with multiple interactions between biophysical and socio-economic components, the consequences of taking any particular action are not easy to predict. Tools are needed to help policy-makers anticipate the likely consequences of proposed actions. Such tools should allow evaluation of alternative policies, so that initiatives with a desirable profile of positive and negative impacts can be adopted.

Forest Land Oriented Resource Envisioning System (FLORES: Vanclay 1998, 2003) is intended to be such a tool. It aims to model the dynamics of and the interactions between the biophysical and socio-economic components of rural communities living at the forest margin and largely dependent on the land around them. The biophysical components include the land itself, crops, forests and their products, and other plant and animal species. The socio-economic components include the demographic and economic aspects of human communities.

The ‘glue’ that binds the biophysical and socio-economic components together is human decision-making at the local level. People make decisions about clearing, weeding, planting, fertilising and irrigating crops, all of which have obvious consequences for the biophysical components. In turn, the decisions that people make are influenced by the performance of the biophysical components (e.g. crop yields), together with their socio-economic context. A key component of FLORES, therefore, is the modelling of this decision-making process.

FLORES differs from other models of village-scale land-use systems in its fine-scale temporal and spatial resolution, its detailed representation of the socio-economic sub-system, and its emphasis on a simulation approach (Vanclay 2003). Some models concentrate on the selection of individual patches of land on an annual time base. For example, Wilkie and Finn (1988) modelled *shamba* (forest clearing) selection in swidden agriculture in Zaire, while Thornton and Jones (1995) modelled agricultural land-use patterns resulting from farmers’ choice of crops. A number of authors have adopted an optimisation approach, using a mathematical programming approach either for the whole system, or for the farmer’s decision-making component. For example, Fawcett *et al.* (1997) used a multi-objective optimisation approach to explore agro-forestry options for Ghana, while Vosti *et al*. (1999) reported on a model which combines an economic optimisation model of farmer's behaviour with simulation of crop dynamics. A third approach deals with farmers as decision-making agents, using Multi-Agent Systems (MAS) as the basis for simulating the behaviour of and interactions between farmers (e.g. Antona *et al*. 1998, Rouchier and Bousquet 1998).

This paper examines the approach adopted in the Rantau Pandan version of FLORES to model human decision-making in rural communities at the forest margin. It provides an overview of FLORES, summarises key concepts, canvasses the modelling of both long-term (strategic) and short-term (week-by-week) decision-making, and sets out the approach to include key aspects such as land tenure, inheritance, negotiations over the acquisition and disposal of land, and long-term planning. Finally, the implementation of the decision-making model is described, and its future development is discussed.

## FLORES MODELLING OF RURAL COMMUNITIES

### Key Concepts

The FLORES approach to modelling rural communities is based on the following key modelling commitments:

- The socio-economic side is modelled in terms of individual 'agents'. Typically, these correspond to households, although the approach allows for agents to be individuals within the community, and/or a body (such as the village council) that takes decisions at the level of the whole village. These agents have various fixed and dynamic attributes, corresponding to key socio-economic parameters and variables, and are capable of making decisions about their resources.
- The biophysical side is modelled at the level of land-use 'patches', corresponding to fields or clearings in the forest (typically about 1 ha in size). The actual location of a patch and its boundaries in co-ordinate space may or may not be represented. Spatial divisions within a patch (e.g. in a spatial agroforestry system) are not explicitly represented, though the proportion of an area represented by different crop types can be.
- There are tenure relations between agents (individuals, households, villages) and patches, defined flexibly enough to represent a range of tenure systems. Thus, it is much broader than simple 'patch ownership', and can include temporary rights, rights to exploit only some products within a patch, and communal rights.
- There are flows of information between households and patches, in both directions. The information flowing from household to patch reflects the decisions made by households about the patch. Principally, this corresponds to the amount of labour allocated to various activities on the patch. The information flowing from patch to household corresponds to information about the state of the patch that the household can make use of in arriving at decisions, along with other information (such as crop yields) that feed into the household socio-economic component.

- The modelling approach is numerical simulation, using a fixed time step (typically, a weekly time step). This distinguishes FLORES from other models which adopt an optimisation approach (e.g. Fawcett *et al*. 1997), and from simulation models which use a longer time step (e.g. Thornton and Jones 1995). Nevertheless, FLORES enables individual components of the system – such as decision-making by individual agents – to be modelled using an optimisation approach.

Figure 1 shows the overall architecture of the FLORES model.

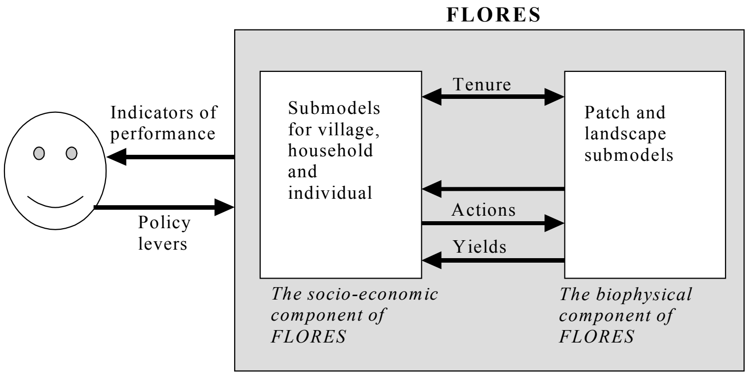


**Figure 1.** Overall architecture of the FLORES model

**Implementation of FLORES in Simile**

Simile (Muetzelfeldt and Taylor 1997, 2001) was chosen for the implementation of FLORES because the FLORES team considered that it satisfied more of the requirements than other potential approaches. First, the visual nature of this modelling environment increases the extent to which various contributors to FLORES development can participate in the process of model construction and can 'read' the model design decisions made by others. Second, its ability to handle basic system dynamics concepts (stocks and flows) makes it straightforward to implement the many standard biophysical models cast in these terms. Third, it has powerful features for representing the complex disaggregation, object-orientation and relationships required for FLORES: multiple patches, dynamically-varying numbers of households, a hierarchy of households within villages, and tenure relations between households and patches. Fourth, it can generate highly-efficient executable versions of complex models (in compiled C), essential for a model intended to deal with the interactions within and between hundreds of households and thousands of patches. Finally, all interfacing aspects can be customised (through programming in the interpreted scripting language, tcl/tk), making it possible to engineer interfaces to GIS and displays specific to the requirements of FLORES.

**The FLORES Process**

FLORES is not just a model, but a methodology that reflects a commitment to an open, inclusive and transparent approach to the modelling of complex socio-econobiophysical systems. Vanclay (1998) set out the conceptual framework for this approach, and a prototype proved that it was feasible to use Simile for this work (Muetzelfeldt and Taylor 1998). Subsequently, a DFID-funded workshop was held in Bukittinggi, Sumatra, to design a version of FLORES for the Rantau Pandan area of Jambi province in Sumatra (Vanclay *et al*. 2003). Five teams were charged with producing working sub-models of crops, forests and household decisions. These sub-models were then combined into a single, integrated model. The workshop model was later extended to incorporate a link to a GIS, and enhance the decision-making model to include long-term, strategic decision-making.

**The Biophysical Component**

The biophysical component of FLORES was developed largely by three teams at the Bukittinggi workshop. Their work resulted in 10 sub-models, summarised in Table 1. There are two main points to note:

1. Some sub-models apply at the patch level, and some at the landscape level. In the former case, the sub-model can have a separate instance for each patch: e.g. crops, trees, soil water and pest dynamics are modelled separately for each patch. In contrast, biodiversity and vertebrates are modelled at the landscape level.
2. Some sub-models have multiple instances to represent more than one type of NTFP, crop or pest, with the differences types accommodated by different parameter values.

In most cases, the dynamics of the modelled component is represented in system dynamics terms. Thus, an animal population may be represented with a compartment for the number of animals, with flows for reproduction and mortality. Crop growth is represented by a number of interlinked compartments for crop biomass in various parts (e.g. root, stem and grain). In other words, an orthodox approach has been adopted for modelling the biophysical components.

## DESIGN OF THE DECISION-MAKING COMPONENT

This section focuses on the design of the decision-making component in the FLORES model, while the following section examines how the design was implemented in the Simile modelling package. This section is based on an analysis more fully reported in Haggith (1999).

**Key Assumptions**

Some key assumptions are needed before the task of designing a human decision-making model can commence. These extend the key commitments that apply to FLORES itself.

- Decision-making can be modelled using a set of rules and relationships, rather than through an assumption that humans behave optimally.

- Decision-making involves a perception-response loop: perception of the current state of the system (both socio-economic and biophysical); and an associated response (e.g. as labour allocation to various activities).
- Decision-making about land use involves three types of 'agent', i.e. village, household and individual.

**Table 1**. Biophysical sub-models in FLORES

| Sub-model | Team | Level | Description |
|---|---|---|---|
| NTFP | biodiv | patch | Simulates abundance of each of several NTFPs in each patch using three life stages ('young', 'mature', 'old') for each NTFP. |
| Trees | forest | patch | Simulates forest dynamics in terms of tree volume and tree stem density for each of two species types (pioneer and shade-tolerant) on a per-hectare basis. Also calculates top height and dead wood. |
| Jungle rubber | forest | patch | Models dynamics and yield of rubber trees inter-planted in forest patches, as numbers of plants in four life-stage categories. |
| Plantation rubber | forest | patch | Simulates dynamics and yield of rubber grown as a plantation tree crop, in terms of number of plants in four life-stage categories |
| Crop | crop | patch | Models the dynamics of up to five crop-like plants. Currently used for wet and dry rice, and two weed species. |
| Water | crop | patch | Simple one-compartment for simulating soil water dynamics. |
| Nutrients | crop | patch | Simple one-compartment simulation of soil nutrient (N) dynamics. |
| Pests | crop | patch | Calculates patch-level abundance of two 'external' pests (pigs and monkeys, simulated in the 'animals' sub-model below); and simulates the within-patch dynamics of two insect pests of crops. |
| Animals | biodiv | area | Simulates dynamics of six vertebrate species, four of biodiversity interest plus two pests (above), on a total-area rather than patch-level basis, since these are mobile species. |
| Biodiversity | biodiv | area | Calculates an index of biodiversity by aggregating patch-level information on species abundance and forest state. |

Notes: 1)'Team' refers to the team of experts used to develop the sub-model at the Bukittinggi workshop. *biodiv*: biodiversity, NTFPs and animals team; *forest*: trees and forest team; *crop*: crops, soils and pests team.
2) 'Level' indicates whether the sub-model has a separate instance for each patch, or has a single instance relating to the whole of the modelled area.
3) The term 'simulate' is used to signal the fact that the sub-model is modelled in System Dynamics terms, i.e. with compartments (state variables) and flows. The term 'calculate' is used to signal the fact that the sub-model contains only equations and has no state variables.

- Land tenure, a key FLORES commitment, involves more than simple 'ownership'. It can operate at all three levels (village, household, individual), and can change dynamically (e.g. through inheritance or purchase).
- Decision-making has both short-term (weekly) aspects and longer-term (strategic) aspects. Short-term decision-making is at the household level, and is primarily concerned with labour-allocation to various activities, most of which relate to land units over which the household has some tenure right. Strategic decision-making is concerned with making choices at infrequent (yearly) intervals which set the scene for short-term decision-making.

**Strategic Decision-Making**

A specification for the basic strategic decision-making model includes employment, land-use intensification, and a wider range of strategic choices. The basic strategic decision model involves five phases:

- population and household dynamics, involving calculations relating to reproduction, marriage and death, and household formation;
- application of land tenure and inheritance rules, say on death or on the creation of a new household;
- choice of new strategic options, such as to buy or sell land, or to emigrate;
- land re-allocation; and
- land-use planning, involving decisions about change in land use (e.g. clearing) and preparation of the annual work-plan.

*Phase 1*: *Population and household dynamics*

Decisions about child-bearing could be influenced by a number of factors including family and village circumstances, and government family planning policies. Currently, in the absence of detailed information, it is assumed that the 'decision' to have a child is in fact random, for women of child-bearing age.

Mortality is modelled stochastically, and is currently a function only of age, though there is scope for including other factors such as poverty.

Simulating marriage involves selection of criteria of suitability for the wife, or husband, or both; these differ between cultures. The model enables various criteria to be specified, then chooses at random if there is more than one suitable partner. For the Rantau Pandan context, the conditions are that both male and female must be aged 15-25, unmarried, and be 'friends' (where friendship is defined in terms of friendship between their parents).

A new household is formed when a married couple satisfy specific criteria, which vary between societies, normally in terms of number of children and land endowment. For the Rantau Pandan model, a new household is formed immediately on marriage. A household disbands when it is reduced to one person.

*Phase 2*: *Land tenure and inheritance*

Land tenure is fundamental to land use (Meek 1957, Fortmann and Bruce 1988, Colchester and Lohmann 1993, Alcorn 1996, Diaw 1998), and there are many forms of tenure relationship. To reflect this, and to permit the exploration of the role of tenure in more depth, an expressive notation for tenure information has been developed. It is capable of handling quite sophisticated relationships.

A key concept is the tenure register. This is a (notional) register of all the tenure relationships within a village, and consists of a number of records. The following information is recorded:

- the holder, grantor and location of the tenure right;
- whether it is permanent or temporary, when it starts, and its seasonality;
- its security (*de jure* or *de facto*) and transferability; and
- the resource to which it applies and any limit on labour that can be used.

These details can for example, represent the fact that Village 3 has granted to individual 106 a permanent, transferable, *de jure* right to undertake any activity in, and to take any resource from, patch 66 during weeks 40 to 50.

However, a record can also be a general rule, which will apply to all instances of a particular category. This is far more parsimonious than having every record separately, and also ensures a closer correspondence between information coming from local people and the way it is represented. An example specific to the Rantau Pandan situation captures the custom that pigs may be hunted at any time of year with no limit but not from forest plots considered to be sacred.

> Tenure (H, V, P, permanent, _, 1...52, defacto, pigs, hunting, _, non-transferable) **if** household_in_village(H, V) **and** not sacred(P).

where H, V and P stand for some household, some village, and some patch of land, respectively.

Tenure is annulled or transferred when population or household membership changes, or through decisions to buy or sell land, according to a culturally-specific set of rules. For example:

- on death of an individual, heritable tenure rights are transferred, while temporary or non-transferable rights are annulled;
- a new household gains usufruct rights to village commons;
- household rights are lost when a household disbands or emigrates; and
- time-limited tenure rights are checked annually.

Inheritance of tenure rights involves two stages: finding heirs; and distributing the rights across the heirs. Inheritance rules are culture-specific, involving factors such as gender, the number of kin that can inherit, and what to do if someone dies without heirs. In Rantau Pandan, inheritance is gender-aligned (same-sex inheritance), all kin at a given level can inherit, and the village acquires tenure rights of a person dying without heirs. Tenure rights are distributed across heirs by a simple algorithm, sharing out rights uniformly across heirs.

*Phase 3*: *Choosing strategic options*

Simulating a strategy involves four stages:

1. identification of needs;
2. assessment of current state (resources and memory);
3. determining level of satisfaction with current livelihood; and

4. choosing a strategy from various options.

Needs are assessed in terms of the annual subsistence requirement for an average household, expressed as an economic unit known as 'dosh' (Daily Ordinary Subsistence per Household; Haggith and Prabhu 2003). It is adjusted according to household size and composition, so that a larger household would need a greater amount of dosh, as would an average-size household with a higher proportion of adult men. This 'full belly' subsistence economics model (Angelsen 1996) can then be adjusted if it is considered that the household has aspirations greater than subsistence level.

Assessing the current state involves calculating a household's land endowment (i.e. the total area of all patches to which they have tenure rights); its labour pool (weighted for children and elderly members); and its economic reserves (expressed as 'dosh'). Economic reserves are assumed to include food stores (rice), construction materials (poles harvested from the forest) and any cash on hand. Collectively, these economic resources are known as a household's 'wealth'. In addition, the household 'remembers' its previous performance, in terms of income over the past year, including yield from its patches of land.

The household then determines whether or not it is satisfied with its current situation. Many alternative theories can be (and have been) proposed about the conditions under which a household deems that it is 'satisfied' with its current performance. It is assumed that a household is satisfied if the previous year's income plus some proportion ($k$) of its 'wealth' is greater than its needs. The parameter $k$ is culturally determined, reflects a household's propensity to draw down on its reserves if needed, and can be set by users.

If a household is not 'satisfied', then it has three options, i.e. acquire land, dispose of land or migrate. The current rules, reflecting the Rantau Pandan situation, are:

1. a household chooses the option of *migrating* if it is landless and if its needs have not been met for the last $n$ years (where $n$ is a parameter set by users);
2. a household chooses the option of *acquiring land* if it has a household labour surplus and if it does not have an uncleared patch; and
3. a household chooses the option of *selling land* if it has some land and either it has a deficit of household labour, or its needs have not been met for the last $n$ years.

The last two options involve the household in placing bids or offering land in the land market.

*Phase 4*: *Land re-allocation and the land market*

Plots of land may be offered for sale by the village or by individuals. It is recognised that communities differ in their ability to manage the land over which they have control. A key issue is the likelihood of common land being made over to individuals. Social factors are important, namely the existence of external forces, such as state granted concessions to external parties (SKEPHI and Kiddell-Monroe 1993, Miyamoto *et al*. 1999); a lack of recognition by the state of common pool resource management at the village level (particularly if coupled by a strong state recognition of land claims by individuals; Angelsen 1995); and, crucially, the strength of the village institutions and their ability to enforce their rules and protect the common land (Agrawal 1994). Weak community institutions are often reflected by an increase in spontaneous clearing or unsustainable harvesting leading to degradation of the forest resources (Agrawal and Yadama 1997).

Two parameters, set by users, are designed to enable a distinction to be made between different types of village community:

- *commons-insecurity* represents the proportion of common land to which a village has *de facto* rights only, and which is subject to take-over by an external party; and
- *strong-community* is a boolean parameter[2] that can be set by users for each village. It has the value 'true' if the community enforces its rules effectively (e.g. by appointing forest guards) and 'false' otherwise. Agrawal (1994) offers empirical evidence that this is a significant factor in forest loss.

The situation when *strong-community* is false and *commons-insecurity* has a value of 1 would make the land effectively open-access, a situation likely to lead to the 'tragedy of the commons' (Hardin 1968).

The Rantau Pandan case assumes that, if there is an oil-palm plantation nearby, then *commons-insecurity* is high; and if *strong-community* is false then a village is likely to offer plots of land for sale to individuals (Miyamoto *et al*. 1999).

As seen in Phase 3, individuals may make a strategic decision to dispose of plots of land. They may also bid for land offered for sale by the village or by other individuals. A simple market mechanism is proposed, in which offers and bids are paired randomly. In effect, this is a first-come, first-served system. Any left-over plots on offer remain unsold; any remaining bids remain un-met. Currently, there is no pricing mechanism, but this is envisaged for a future extension of this model.

*Phase 5*: *Land-use planning*

Land-use planning is done by the household, and involves the following stages. First, the household chooses an overall land-use strategy. There are four choices for the Rantau Pandan situation (Tomich *et al*. 1998):

1. if a household is landless, then their strategy is 'forest dependence';
2. if a household has less than 3 ha of land, including an old rubber plot, then they adopt '*sisipan*' (gap-planting rubber in established forest plots);
3. if the household has more than 3 hectares, of which half is '*sawah*' (rice paddies), then they adopt a 'rice specialist' strategy;
4. otherwise, they adopt the default strategy, rotational rubber agroforestry, occasional '*ladangs*' (forest clearings), and rice growing.

Second, a 'norm table' is selected for the chosen strategy. A norm table specifies the proportion of labour allocated in each of the four labour classes (child, man, woman, senior), each of eight activities, and each of 12 months. The eight activities are clearing, perennials, cultivation of annual crops, forest work, protection, husbandry, leisure and other. The last two are non-spatial activities. The norm table approach

[2] A boolean parameter can take only two values, usually true or false.

draws heavily on the fact that data of this type are routinely collected during anthropological surveys. It is therefore a empirical approach to modelling labour allocation and while lacking a causal basis, is unlikely to be wildly wrong.

In some cases, an owner of forest land will decide to clear a patch during the coming year. A set of rules are used first to decide whether a patch will be cleared, and then what use should be made of it once it has been cleared. For the Rantau Pandan situation, a decision is made to clear if the patch is an old, unproductive rubber plot and the household has not chosen *sisipan*; if it is a newly-acquired commons patch; or if a household is 'not satisfied' and has surplus labour. The patch is used for *sawah* if it is next to a river, otherwise it is used for rubber.

The third stage involves choosing crops for cultivated land. Currently, this merely reflects the allocated state of each patch (*sawah*, dry-rice, vegetables, rubber). In future, a greater range of options will be introduced.

Finally, a work plan is produced, specifying how the household will organise its labour for the coming year. This is driven by the norm for the chosen land-use strategy, modified to take account of major activities due to be carried out (e.g. land clearance) and of activities that are part of the norm but are impossible for the household (e.g. cultivation activities for a family with no suitable land). To modify the norm into a plan for the year, proportions of time allocated to one activity type need to be reallocated to other types. As elsewhere in this specification, a heuristic approach is proposed. For the Rantau Pandan area, the following rules are used:

- If the household plans to clear a forest patch, then 100% of male labour, 50% of female labour and 20% of child labour are re-allocated from other activities to 'clearing' in month 5, and 50% of male labour in month 6; and
- If the household has no land of type 'rubber', then allocate 50% of time of all age groups to cultivation and 50% to forest activities.

This concludes the modelling of strategic decision-making. Each household is now in a position to enter the weekly simulation cycle.

**Possible Extensions to the Basic Strategic Decision-Making Model**

The analysis that was undertaken to produce the original specification also specified several model extensions, which considerably broaden the range of strategic options. These include:

- *Introducing intensification of production*. Households whose level of satisfaction is low might wish to intensify production by, for example, adding inputs such as fertiliser to their crops. This requires extending the strategic options open to a household, with a rule that depends on the household economic resources ('dosh') available for spending on inputs.
- *Introducing employment*. Another strategic option for improving a household's decision is to find paid work or to hire extra labour. This extension involves extending the definition of satisfaction, reflecting the situation where a household has either surplus or insufficient labour, adding new strategic options, adding a labour market, and handling wages.
- *Introducing land leasing and refining the land market*. The model currently has no mechanism for handling the rubber share-tapping agreements

prevailing in Rantau Pandan, whereby one individual negotiates the right to tap rubber on land owned by someone else, paying a share of the rubber as 'rental'. In addition, poor households can gain temporary access to common land for cultivation. Together, these rights are referred to as leasing. To handle the distinctions between leasing and buying, a number of extensions to the model are needed. Firstly, an extended rule is needed for the release by the village of common land for sale or for rent. Secondly, households need to distinguish buying and selling land from leasing-out or taking a lease in their strategic options. Thirdly, the land market needs to handle both situations. Finally, in the weekly sub-model, yields may need to be shared with other households.

**The Weekly Cycle**

In comparison with the annual cycle, the weekly decision-making procedure is a much simpler affair. Its task is to determine how much labour is allocated to each activity on each patch (or just to each activity for the non-spatial activities) in the current week. This information is then used as an input to various parts of the biophysical part of the FLORES model. There are essentially three parts, i.e. perception, action, and handling yields.

*Perception of possible activities*

The determination of what activities are possible on each patch for which the agent has tenure rights is handled by a set of rules. The rules have the general form:

> activity A is possible on patch P if conditions expressed in terms of attributes of patch P are true

In the norm tables, each activity type is an aggregate of several specific activities. For example, 'cultivation' is an activity type which covers the various specific seasonal activities required to grow a crop, such as sowing, weeding and harvesting, while 'forest work' is the aggregation of a range of activities which may or may not be seasonal, such as fruit collecting, logging or hunting. In contrast, the perception of what activities are possible is at the more specific level (e.g. 'sowing' as opposed to 'cultivation').

Altogether, there is a rule set of some 20 rules specially formulated for the Rantau Pandan area, in consultation with anthropologists who have worked in the area. The rules are of course expressed formally so that the computer can process them, but the following examples in English accurately reflect the types of rules used:

- *Slash-clearing* is possible on a patch if the patch is forest or rubber and week is between 16 and 24.
- *Gap-planting* of rubber is possible on a patch if the patch has rubber and its productivity is low.
- *Weeding* is possible on a patch if the patch is growing a crop and crop-stage more than 2 and weediness less than 0.5

*Action*
The time specified in the adjusted norm table for each activity is allocated across all the plots for which it is possible for that household. This is done by simply dividing the time up across the plots. There are two qualifications to this. First, an activity is not undertaken on a particular patch if it would involve less than some amount of time (set by the user). Second, an activity is not undertaken if it is perceived to be unnecessary, e.g. time will not be spent on pest protection if it is perceived that there are no pests.

*Handling yields*
At each time step, certain activities (e.g. harvesting, fruit collecting) may result in yields from patches. These can be accumulated in household stores, and their value is calculated in 'dosh'. These resources are used by the household at a rate determined by household composition.

## IMPLEMENTATION OF THE DECISION MODEL

Figure 2 shows the main sub-models for the implementation of the full decision model in Simile. The full diagram has many variables, with influence arrows between them: Simile enables one to control the level of detail shown in model diagrams, and here most of the variables and influences have been suppressed for clarity. In addition, the biophysical components of the patch model have not been shown, since the emphasis here is on the decision-making model.

The following conventions have been used. A shaded box (light or dark grey) represents an 'object' in the real world. There are objects for village, individual, household, patch of land, and tenure record. Note that the nesting of objects indicates a hierarchy in which one is contained within the other. Thus, it can be seen that a village contains individuals, households and tenure records. Individuals are not placed inside households because that makes it more difficult to handle switching of an individual from one household to another (e.g. after marriage).

Note that the boxes denoting objects have two types of border. Village and Plot have multiple borders, like a stack of cards. In Simile, this denotes that there are several (possibly many) of them, and that this number is fixed. Individual, household and tenure records have a double border. This again denotes that there are several of them, but that the number is potentially variable, as individual instances can be created and destroyed. For example, individuals can be born or die; and households can be formed or disbanded.

A white box represents a 'relationship' between objects. There are a number of relationships between one individual and another (e.g. sibling, father, friend). There are also two relationships between different types of object: the household membership relationship between an individual and a household; and a tenure acquisition relationship between a person and the tenure right that the person has acquired.

Undifferentiated boxes (such as 'Weekly Labour Allocation' and 'Possible Activities') denote sub-models whose task is solely to perform some calculations.

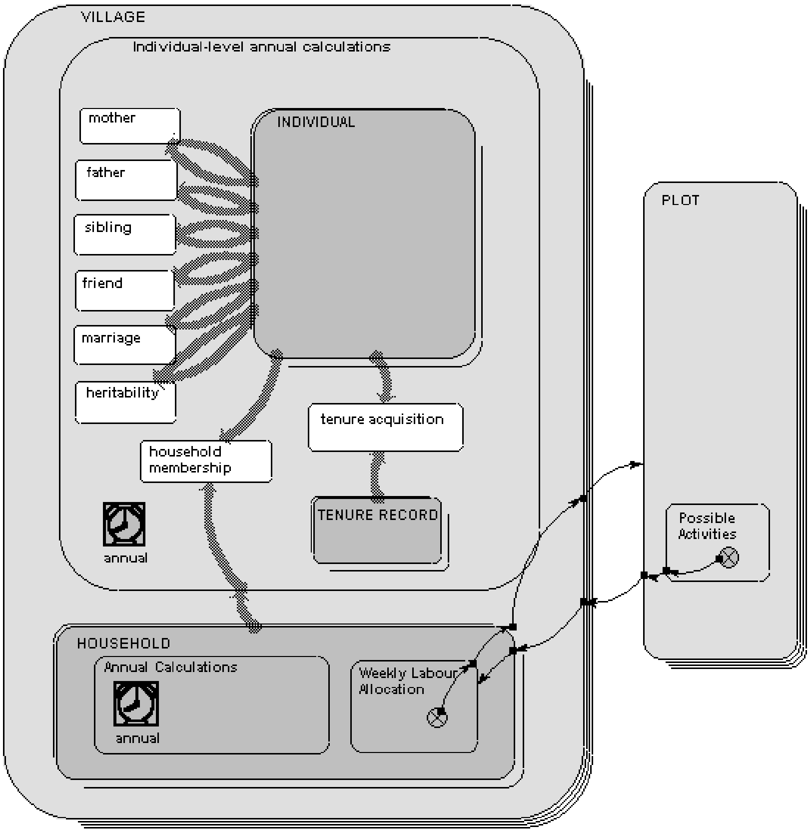


**Figure 2**. The top-level components of the decision-making model

The thin arrows going from the household labour allocation to plots, and from plot possibilities to household labour allocation, indicate the principal flows of information between the decision-making and the biophysical parts of FLORES. Although there are of course many items of information flowing in both directions, Simile enables multiple values to be packaged up as a single complex data structure, and transferred from one part of the model to another. Here, labour allocation is in effect a three-dimensional structure (household, activity, plot), while the set of possible activities has two dimensions (plot and activity).

Two sub-models contain an alarm-clock symbol[3]. By default in Simile, all calculations are undertaken every time step, as specified in the 'Run Control' window (for FLORES, this is weekly). The alarm-clock symbol enables the modeller to specify when calculations should be performed for the sub-model and those that it contains. Here, the alarm-clocks are set to execute the individual-level and household-level strategic decision-making calculations once per year, while household labour allocation and plot dynamics occur on a weekly basis.

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[3] This symbol is a relic of former versions, and no longer appears in Simile 2.0 or later, represents another construct being used to allow sub-models to operate on different time-steps.

This implementation closely follows the semi-formal specification given in the previous section. Every year, new individuals are created when married women of child-bearing age give birth, and die with a probability that is a function of age. Marriage involves pairing up eligible individuals of opposite sex with the age 15-25 who are 'friends' (defined as having parents who are friends). Heritability is calculated by following parent relationships up and down through successive generations, and used to allocate tenure rights on death. A married couple leave their previous households and forms a new one; a household disbands when it has only one individual left. The land market involves plots of land being offered for sale, and purchased by those wishing to buy. Households make strategic plans, which modify the norm table for labour allocation. Every week, the norm table is compared to the set of activities that are possible on each patch over which a household has tenure rights, and time (person days) is allocated to each activity on each patch.

## DISCUSSION AND CONCLUSIONS

The semi-formal specification of decision-making presented above is a unique attempt at formalising the way that real people, households and communities in rural areas behave, so that it can be used as the basis for computer modelling of this behaviour. Mathematical programming approaches based on the assumption that land-use decisions are made by a process of economic optimisation have far less scope for handling qualitative factors, such as people's rights to resources (tenure), and the empirical information available from anthropological studies about how people actually spend their time (social norms). Rouchier and Bousquet (1998) have, as here, adopted an agent-based approach, but that is largely restricted to one particular aspect of agent behaviour, negotiating the transfer of commodities between individuals, and has not, to date, attempted such a range of decision-making activities and to include both strategic and short-term aspects.

The approach lends itself to community-based methods for gathering information, such as Participatory Rural Appraisal. Local people can be asked to describe their annual work patterns, and how these would be modified in response to changing circumstances, as well as how they go about planning for the future. There is then a close relationship between what people say, and what is represented in the specification as (for example) rules or tables. The semi-formal specification can then be used to validate this analysis, by checking back with the same or other people

An ability to implement the semi-formal specification in Simile deserves consideration. First, it indicates that the semi-formal specification was in fact largely complete and unambiguous, something that would have been difficult to determine without implementing it. Second, it reflects well on Simile's capabilities that it was able, with few extensions, to handle complex modelling concepts for which it was not designed: concepts such as family relationships across multiple generations, the inheritance of tenure rights, and the trading of tenure rights in the open market. The initial goal was to see whether the model could be implemented in Simile, and indeed it can be.

However, there are two reasons for caution. Firstly, the model as implemented runs slowly, even when compiled. Some minor re-engineering (for example, limiting the number of generations searched to determine inheritance) could speed it up, but the number of relationships to be searched restricts the gains that can be made. This problem is serious because some calculations are quadratic or cubic with respect to the number of individuals or plots of land, creating problems in scaling up. Secondly, the way that the model is implemented makes use of some Simile features that are unfamiliar to most people, and this makes it difficult for them to see how the model has been formulated. This is to some extent inevitable, given the complex social relationships to be represented, but the possibility of developing a more intuitive graphical notation will be explored.

It is natural to consider whether it would be better to implement the model in some other environment. Would it run faster? More importantly, would it be more transparent? After all, the model specification, developed without consideration to implementation, is indeed complex, and there are few magic solutions when faced with such complexity. At this stage, the only way of answering this question is to attempt implementations using other technologies, something planned for the future.

**Future Directions**

The ultimate goal of FLORES is to make a contribution towards the elimination of rural poverty and the reduction of deforestation. This requires four achievements:

First, people must have confidence in the behaviour of the FLORES model. This involves checking the correctness of the rules and relationships in the model, and the behaviour of the whole model. Field work with local people in Rantau Pandan has indicated some adjustments to the model are warranted (Joshi 2000).

Second, the modelling approach must be applicable elsewhere, otherwise the large investment of money and human resources in FLORES cannot be justified. To this end, a FLORES Adaptation and Calibration (FLAC) package has been developed and tested (FLORES Society 2001), with the intention that other institutions should be able to develop their own local versions of FLORES with minimal outside help.

Third, the modelling approach must be transparent and flexible, allowing experts from a wide range of disciplines to contribute to model development and understand the model design decisions made by others. Simile is a major step in this direction, but there is still much to be done to ensure that the gap between conceptual model design and its implementation is kept to a minimum (Haggith and Prabhu 2003).

Finally, it is necessary that policy players actually make use of FLORES to explore policy options. This requires a commitment to a client-based approach, to ensure that FLORES can do what the client organisations actually require. This includes working with potential users to identify the policy levers and indicators of performance that are important to them, and how the simulation results should be presented in the most useful way.

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