From conceptual model to implementation model

Piloting a multi-level case study in Cameroon

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RÉSUMÉ. Cet article présente une application de l'approche de modélisation multi-échelle à base d'agent en s'appuyant sur un modèle spécifique (NMDC) pour décrire et modeliser une classe de problèmes environnementaux. Le modèle NMDC permet à l'expert du domaine de décrire le domaine d'application sous-jacent en termes de concepts environnementaux et ne nécessite pas de compétences techniques spécifiques, ni de détails de mise en oeuvre. Nous montrons comment l'outil TiC (Tool-in-Context) associé développé à partir du modèle NMDC peut aider l'expert du domaine à décrire dans un langage naturel (spécifique) le problème environnemental. Cette description est la base pour l'outil TiC de générer un outil de simulation. A travers cet outil, nous transformons le langage spécifique en code multi-agents NetLogo, facilitant ainsi un premier prototype de l'application pouvant être utilisé par l'expert de domaine. Enfin, nous appliquons cette approche pour expliquer et analyser le processus de déforestation autour de la réserve forestière de Laf et discuter du prototype résultant de notre approche.

ABSTRACT. This paper presents the application of a Multi-Level Agent Based Model technology through a Natural Model based Design in Context (NMDC) to describe and model a class of environmental problems. NMDC allow training domain expert to design a conceptual model for a concrete environmental problem. This model describes the underlying application domain in terms of environmental concepts and neither requires specific technical skills nor involves implementation details. We show how the associated TiC (Tool-in-Context) develop through NMDC can help the domain expert to describe in semi-natural (specific) language the environmental problem. This description is the basis for TiC to generate a simulation tool. On the base of this, we transform the specific language to NetLogo agent based code, thereby facilitating an early prototype application to be used by the domain expert. Finally, we applied this approach to explain and analyze the process of deforestation around the Laf Forest Reserve and discuss the prototype resulting from our approach.

MOTS-CLÉS : Multi-Echelle, Modèle à Base d'agent, Langage Specifique, Problèmes environnementaux

KEYWORDS : Multi-Level, Agent Based Model, Specific Language, Environmental Problems

1. Introduction

The analysis of the environmental problems such as the management of natural resources presents the causes that are closely linked both physically and socially [2, 6]. Exploring the physical causes shows that they are due to ecological factors which can be for example the harsh droughts, heavy rains, etc. These factors are more or less static and hardly vary over the time. As for social causes, they are directly related to the population. They result from the combined actions of different actors on the management process of a set of resources such as water, land, money, labor force, availability of work and techniques of work. We can thus see in this situation a strong dynamic of causal parameters. The collection, analysis and exploitation of information in this case to understand the phenomena and propose a solution to the environmental problem is not always easy.

Multi Level Agent Based Model and simulation are increasingly used nowadays as an appropriate tool to represent processes of social interaction at many levels between several autonomous agents (actor or group of actors) and dynamic resources taking into account the social, economic and environmental constraints see [9, 1, 15]. The aim is to integrate in a single model the knowledge and/or operating rules from different levels of analysis considered by the system designer. As an example, Belem et al., [3] presents an Organization-Role-Entity-Aspect (OREA) model. It is an organizational model for multi-scale and multi-formalism description of complex systems based on the assumption that one issue in complex system simulation is to integrate multi-scale and multi-formalism representation. It is applied in implementation of a generic model for carbon dynamics simulation in West-African Savanna and shown its effectiveness in (1) organizational approach for representing the global and local level and (2) Discrete Event System Specification (DEVS) formalism for multi-formalism representation. Smajgl [19] argues that facilitating a learning experience for decision makers by employing participatory modelling and explicitly considering multiple tiers of governance can effectively contribute to achieve sustainable outcomes. Decision makers operate on different scales and respond to decisions made on other scales. Futhermore Kyle et al., [17] assesses the importance of spatial scale in long-term for land use modeling. Apply in the Midwestern United States in three levels of spatial aggregation, and three climate change mitigation scenarios, it shows that the level of spatial aggregation influences the magnitude but not the direction of land use change in response to the modeled drivers, and in the examples analyzed, increasing spatial resolution reduces the extent of land use change. Further work on the same subject can be found in [12]

These works show various approaches for data collection, system design and integration of the data in the system. A common feature is however that the actual work is usually done by a domain expert (e.g. social scientist, environmental scientist) which is then delivered to a computer modeler to integrate the data and ideas in the model that should be developed. This basically one-way communication may cause hard-to-trace inconsistencies between the various steps in the chain (from theory to meta model, from meta model to data

collection, from rough data to interpreted data, from data to model and so on). Moreover, a lack of two-way interaction may result in missed opportunities, e.g. more efficient data collection or more explicit theory. The development and programming solutions offer a very little abstractions and highly technical methodological support often limited to domain expert.

The aim of our work is to strengthen bridge-building tools between the two worlds (domain experts and ICT in this case) in the form of a meta model accessible from both sides. This work presents the application of a Multi-Level Agent Based Model through a Natural Model based Design in Context (NMDC) (see [16]) to model environmental problems and generate a simulation tool. It is based on the Problem-in-Context and Action-in-Context framework ([6]) to describe and explain agent motivations and cooperation.To better illustrate through a showcase, we modeled and explained the process of deforestation and analyze scenarios for a more rational management of the space around the Laf forest reserve located in the drylands of North Cameroon. It allows the modeler to focus on the social causes of environmental problems, taking into account the biophysical processes. Multi-level aspects are introduced through the AiC concept as well.

In this paper we make a distinction into a general approach for the problem area and its application for an actual problem (see Figure 1) and restrict ourselves to the lower level of this figure.
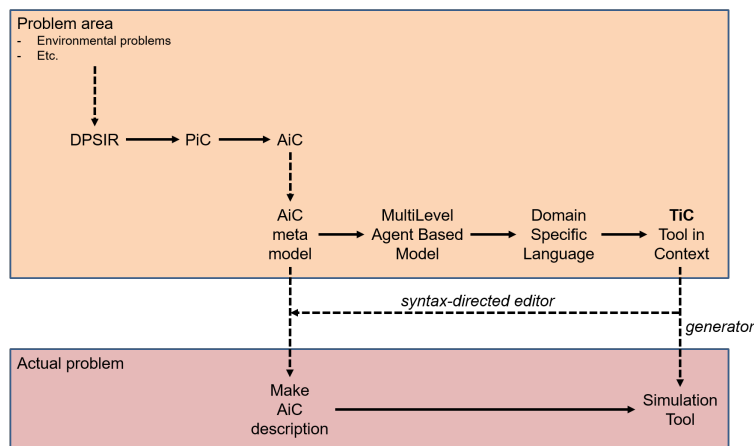

Figure 1 – The various levels of abstraction and application

The layout of the paper is as follows. In Section 2 the Action-in-Context model is introduced. Then in Section 3 we describe the Laf Forest Reserve case, and show how this can be seen as an AiC problem. In Section 4 we populating the Laf Forest Reserve AiC conceptual scheme. We continue in Section 6 and we derive the Laf Forest Reserve

conceptual model, and transform it to a simulation tool. In Section 7 we demonstrate the simulation tool, and study some Laf-specific question. We conclude in Section 8 with some conclusions and suggestions for future work.

2. The AiC Conceptual model

Problem-in-Context (PiC) is a framework, proposed by De Groot [6] to analyze, explain and solve environmental challenges. PiC makes the normative side of environmental problems explicit and adds much more detail to their social causes. Figure 2 gives the essentials.
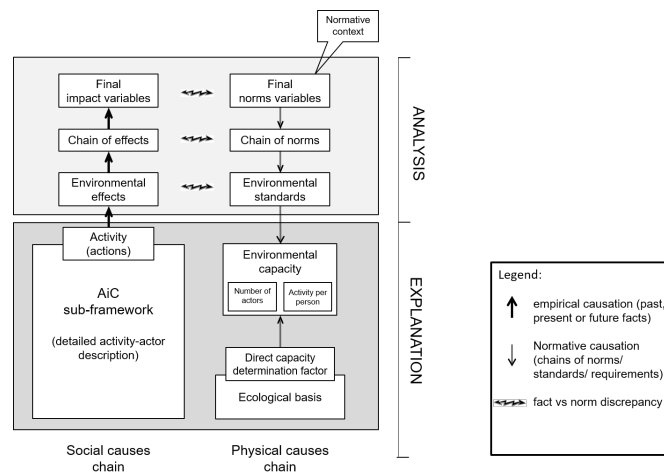

Figure 2 – Problem-in-Context framework (PiC), adapted from [6]

In its problem-analytical part, PiC contains two parallel causal chains. The left one is factual, and indicates which human activities cause environmental effects and onwards to impacts on society (called 'final variables'). The other chain is normative, running from desired societal goals (e.g. poverty alleviation or biodiversity conservation) to environmental standards and further downward to human activity prescriptions ('environmental capacity'). These two chains are connected in a comparative manner, e.g. factual poverty compared to poverty alleviation goals, environmental facts compared to environmental standards and factual versus prescribed activities, defining the environmental problem at these different levels in the double chain.

Focusing on the social explanation of problematic human activities, PiC further contains the AiC sub-framework. The sub-framework AiC is depicted in some more detail in Figure 3. It focuses on the empirical explanation of the Activity (actions) element in PiC.

Going upwards in the figure, the arrows indicate the causal direction. The direction of the explanation, amounting as it does to repeatedly asking the why-question, therefore runs downward in Figure 3.
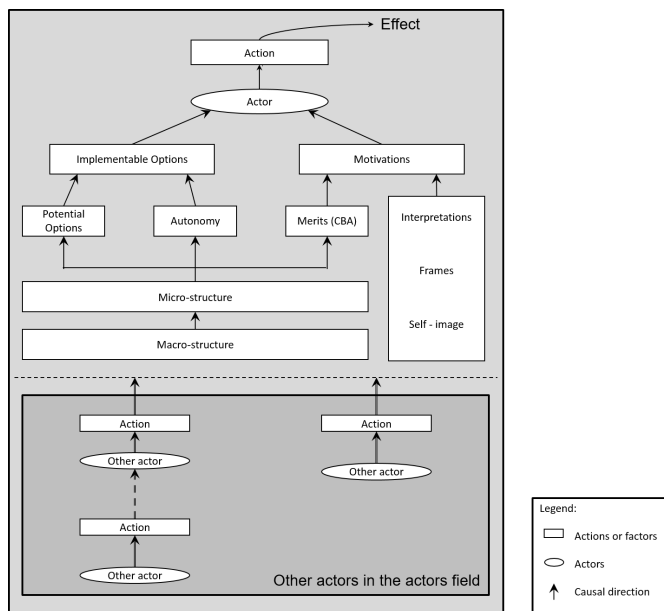

Figure 3 – The AiC framework

For any action, AiC shows the actors involved and their options and motivations related to this action. Options are defined as what the actor can do (alternative courses of action), and motivations are the actor's reasons that come into play for choosing one or another option. This allows AiC to explicitly represent the process of actors' decision-making that integrates economic factors, political context and sociocultural perceptions (the merits of the action and the subjective interpretation of these merits).

The AiC conceptual model is displayed in Figure 4 in the style of the modeling technique Object Role Modeling (ORM) (see [10], [11] and [23]). In ORM, an application domain (also referred to as universe of discourse) is modeled as a so-called information grammar that describes the basics of the conceptual language used in that domain. An ORM diagram is a graphical representation of that grammar. The information grammar not only describes the structuring of the information, but will also describe constraints on how the structure may be populated.
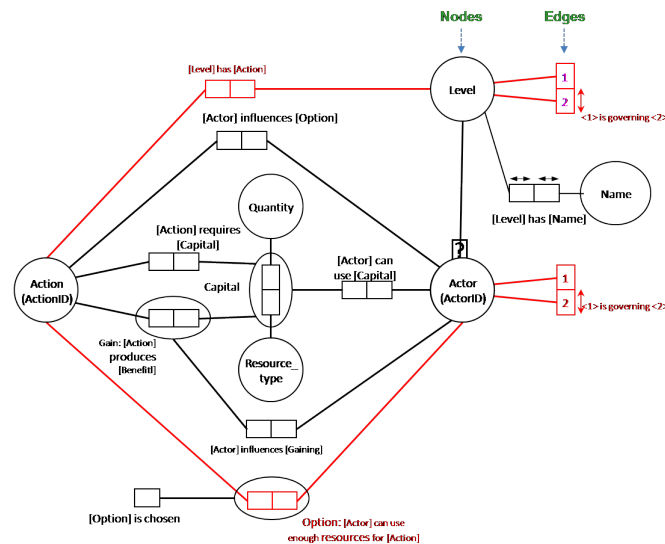
Figure 4 – The AiC Metamodel

2.1. The approach

In [16] it is shown how the AiC metamodel can be transformed into a simulation tool for problems that are described in terms of the AiC metamodel. The resulting tool is called Tool-in-Context (TiC). This tool supports the domain expert in formalizing the actual domain in terms of elementary (semi-)natural language sentences as they are required by the AiC metamodel. These elementary sentences describe a population of the AiC metamodel. TiC generates from this population a concrete simulation tool.

In this paper we first show how an informal problem description can be transformed into a problem description conforming to the AiC metamodel. Our point is that the domain expert will have better access to the AiC formalism, since it consists of (semi-)natural language sentences. Consequently, the domain expert is only required to be able to restructure the sentences from an informal description into the more restricted semi-natural formal from the AiC metamodel.

3. Problem analysis of the Laf Forest Reserve case

A study was done in the field with a multidisciplinary team composed of researchers from the Dschang and Yaounde universities and IRAD (Institute of Agricultural Research and Development) as well as extension agents from PNVRA (National Programme for Vulgarization and Agricultural Research). Meetings of 25-40 persons were held in the villages to discuss land use and develop the participatory map [5]. Using the conceptual

structures of PiC/AiC [6] to first analyze the problem and then build the actors fields, 45 people participated in three focus groups. The participants included all stakeholders involved in the management or use of the forest reserve : farmers, local wood traders, chief of village, district delegate and wood trader from Maroua town. Furthermore several field visits were made afterwards to meet the different actors in order to complement the information and actually adapt the model to local situation.

The Laf village area is located in the Diamare plain at 45 km south of Maroua in North Cameroon (see Figure 5) between $10°14'$ and $10°18'$ north latitude and $14°23'$ and $14°30'$ longitude. The area covers by Laf Forest Reserve is around 5000 ha. This reserve was created in 1940 with the aim of promoting natural reforestation and enforcing methodically the work of reforestation. The climate in this area is semi-arid with precipitation around 900 mm/year, concentrated from June to September. The soil consists of hydromorphic clay, locally called Karal. Its moisture retention capacity and relative fertility favours the growth of open dryland forest, but is also attractive for the cultivation of sorghum, locally called *mouskwari*.
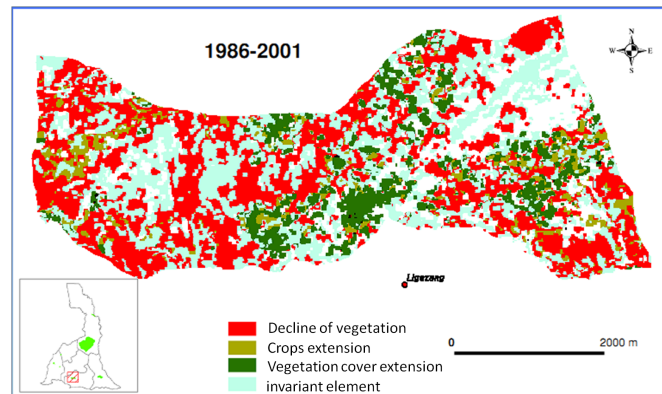

Figure 5 – Dynamics of land use in Laf Forest Reserve [20]

Until the 1970s, the Laf Forest Reserve was still endowed with important ligneous resources [8]. Forest protection by the state has been very weak, causing insufficient constraining of village practices such as firewood extraction and sorghum field expansion in the forest area. These practises will lead to a both qualitative and quantitative degradation of the forest cover, continuing the trend that was already visible in the period 1986-2001 from land use change analysis by [20] using remotely sensed data (Figure 5).

Interviews with villagers indicated that the expansion of agriculture into the Laf Forest Reserve was in fact only part of a larger-scale expansion over the whole village area. This expansion primarily is not caused by population growth or land increase per household, but by degradation of existing fields, resulting in their abandonment and the creation of

new fields in still 'fresh' (grassland or forest) areas. Farmers also pointed at the role of the firewood merchants from Maroua town, who buy firewood in the village with the intention to re-sell it on the urban market.

Methodologically, the analysis of problem of the Laf Forest Reserve resulted in the decision to model the whole village area rather than only the forest reserve area itself. Substantively, it became clear that the two basic land use activities in the village, sorghum cultivation and firewood extraction, were both unsustainable. The firewood was over-extracted and the sorghum cultivation, as farmers themselves also indicated, was in great need of intensification, especially fertilization either through chemical fertilizer or through more labour-intensive practices, e.g. geared towards manure production, collection and application.

Figure 6 – Field work in Laf Forest Reserve. *Images a, b ,c show the current status of the Laf Forest Reserve. We observe advanced deforestation and increase of mouskwari crop cultivation in the forest reserve. Images d, e, f show an interview with the wood merchants. And finally images g, h, i show a stakeholder meeting*(Kameni Pictures 2014)

3.1. The analysis of the problem of the Laf Forest Reserve following the PiC framework

In this section we refine the PiC framework from the previous subsection for the Laf Forest Reserve to further elaborate on the activity component of the PiC framework (See Section 2, Figure 2) As for the decision-making of the farmers and wood merchants, it became clear from our investigations that for the activities discussed here (firewood extrac-

tion and mouskwari cultivation), short-term income is the overriding interest. Therefore we decided to drop the 'interpretations' element in the AiC framework (see Figure 3 and to focus instead fully on economic utility.

Referring to Figure 7, combining the farmers' and the forest reserve's goals, we have the following :

Three final norms variables :

FV-1 Forest and biodiversity goals
FV-2 Sustainability objectives
FV-3 Farmer's welfare objectives

The environmental effects :

EE-1 mouskwari cultivation
EE-2 woord extraction

The environmental standards :

ES-1 More fertilizers, more labour
ES-2 maximum wood extraction

Based on these variables, the following causal chains present themselves (Figure 7).

Referring the normative context (the right side of Figure 7), the final norms variables lead to the following chains, that we discuss via the causal relations provided in Figure 7

- *No decline of the forest reserve* is derived as a normative consequence of goals G-1 (forest and biodiversity) and G-2 (sustainability).
- *Subsistent food security and cash revenue* is a normative consequences of goals G-2 and G-3 and the environmental standard ES-1 (more fertilizers and more labour).
- *No new forest clearing* is a normative consequence of *No decline of forest reserve* and environmental standard ES-1.
- *No spread of degraded areas* is a normative derivation from Subsistence food security and cash revenue
- *No forest quality decline* is a normative derivation from *No new Forest clearing* and *No decline of the forest reserve*.
- *No land degradation* is a normative derivation from *No spread of degraded areas* and *No new forest clearing*.
- More fertilizers, more labour is a normative derivation of No forest quality decline
- Maximum extraction (environment capacity) is a normative derivation of No land degradation.

Concerning the actual context (the left side of Figure 7) we have the following causal chains, that we also describe by their elementary causal relations as provided in this figure.

- With current technologies and over time working the land, actions A-1 and A-2 cause land degradation. After subtraction of basic needs (food security), working the land causes revenue.
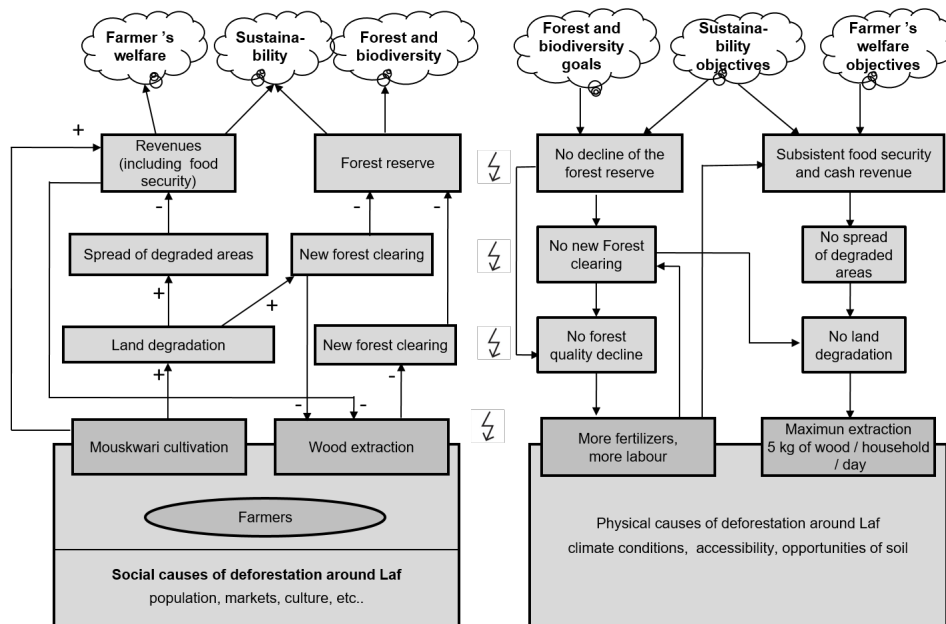
Figure 7 – Analysis of the environmental problem in the Laf Forest Reserve. *Left and right are facts and norms, respectively. Factual causal chains run primarily up towards the final variables (farmers' welfare etc.). In bold are the most important output variables of the model. The pluses indicate positive relations (more of A, then more of B) ; the minuses indicate the inverse*

- Land degradation causes a spread of degraded areas. Combined to the farmers need to keep up food security and revenue, land degradation will also cause new forest clearing.
- New forest clearing adds arable land and starting degradation process. Combined with prices cutting trees, new forest clearing causes revenue.

Previous studies [13, 8] and field observations reveal that needs wood are not respected, as well as food and conservation objectives are not met.

In order to make our model as realistic as possible, many quantifications of these causal relations were elicited by interviews with villagers and informants or obtained from literature (e.g. on local prices, years it takes for soil to degrade under the present land use practice, the regrowth rate of the forest, the time it takes to get firewood to Maroua and so on).

3.2. The social explanation of the problem of Laf Forest Reserve following AiC framework

We start from Figure 8 that illustrates the social causes of the deforestation processes around the Laf Forest Reserve. This figure also highlights the impact relations between the activities of *wood merchant*, the *authorities* of the forest administration and the options and motivations of *farmers* practicing deforestation. The main reasons for deforestation are (1) creating sorghum fields and (2) the need to increase earning through the sale of firewood. The choice of this latter option is favored by the high demand for wood and motivated by the cost of corruption (authorization uncontrolled cutting) and the importance of income derivatives from this activity. According to Figure 8, the main activities / actions of farmers
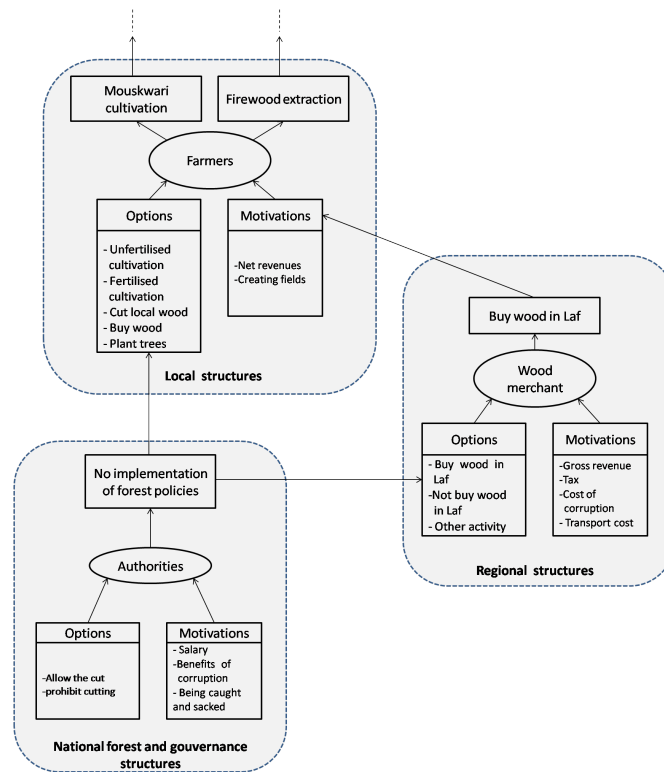

Figure 8 – The social causation submodel of the environmental problem in Laf Forest Reserve. *Drawn lines denote modelled actors (farmers as a primary actor, wood merchant as secondary actor and government as a tertiary actor). Options and motivations are depicted as connected to structures (systems) on three scale levels : local, regional, national*

at the local level are 'Mouskwari cultivation' and 'Firewood extraction'. These activities are motivated respectively by the search for revenue and the creation of new fields to provide for famine problems. Furthermore, after discussions with the farmers there are also other possible activities for the peasants that we call here options (unfertilised cultivation, cut local wood, ..). Similarly, at the regional level, the main activity of wood traders is 'buy wood in Laf'. This activity is motivated by the search for net income (= Gross revenue - taxes - transport cost - cost of corruption). Just like peasants, wood merchants, also have an option list (buy wood in Laf, other activity, ...). Finally we have the authority actor who operate at the national level. Their main activity is the 'no implementation of forest policies', this being motivated by its net income (= salary + the cost of corruption).

From all this information, the decision-making processes of the actors involved in the Laf process are follows :

3.2.1. Farmer decision

The state of the farmer consists of attributes such as the number of persons per family, the number of children going to school, occupation, some of its problems to solve and its initial capital . These attributes will allow the actor's farmer to define its different goals to achieve during the year. In the decision module, the farmer makes choices between the options based on its goals. For example in the case of Laf, the agent chooses to cut and sell wood in the presence of wood trader at the expense of agriculture. The investment in each activity depends of the labor available to each household.

In the list of options, the agent chooses an action depending on the priority assigned to this action. The priority being profit maximization and goal satisfaction, a simplified version of the algorithm of farmers' decision is the following (see Algorithm 1)

3.2.2. Wood trader decision

The wood traders' decision consists of maximizing their profit compared to the expenditure incurred in obtaining the wood. Initially they have capital to enable them to buy the wood in the village and then pay the various costs to enable delivery until its sale, including the costs of loading and transport in Maroua town . The priority being profit maximization, the algorithm of wood traders' decision is very simple (see Algorithm 2).

3.2.3. Authority decision

The authority actor is a civilian servant of the government. Its main role is to 'prohibit cutting' in the Laf Forest Reserve . For this reason he receives from the government a monthly salary which we will note (S). However the authority allows the cut, and from this, he can capture nice Corruption Benefit on top of his salary that we note (CB). However, being corrupted also carries a certain risk, that could be modelled as the probability to be sacked because of corruption, we call the probability (PR). What happens if you are sacked ? You loose your salary. So, the negative side of being corrupted is $PR * S$. The algorithm of Authority decision is the following (see Algorithm 3).

Algorithm 1 Farmer decision

1: *function DecisionFamer (Agent a)*
2:     *Variable :*
3:          *EX : Expenditure for the family*
4:          *IV : Investment for works (fertilizer, tools, ...)*
5:          *MC : Money obtained from the sale of crops*
6:          *MW : Money obtained from the sale of wood*
7:          *NR : Net Revenue*
8:          *CT : Cost of transport for Maroua*
9:     *NR := MC + MW - IV ;*
10:    *if $NR < EX$ then*
11:       *if wood trader present then*
12:          *– wood extraction*
13:          *– Update MW*
14:       *else*
15:          *– wood extraction*
16:          *IV := IV + CT*
17:       *end if*
18:    *else*
19:       *– Invest for works*
20:       *– Mouskwari cultivation*
21:    *end if*
22:    *return*
23: *endfunction*

Algorithm 2 Wood trader decision

1: *function DecisionWoodTrader (Agent a)*
2:     *Variable :*
3:          *CLW : Cost of Laf Wood*
4:          *BLW : Benefit of Laf Wood*
5:          *PWP : Purchase of wood Price*
6:           *SC : Shipping Cost*
7:           *CC : Cost of Corruption/Tax*
8:     *CLW := PWP + SC + CC ;*
9:     *if $CLW > BLW$ then*
10:       *– choose other activity*
11:    *else*
12:       *– Buy wood in Laf*
13:    *end if*
14:    *return*
15: *endfunction*

Algorithm 3 Authority decision

1: **function** *DecisionAuthirity (Agent a)*
2:        ***Variable* :**
3:             *S : Salary*
4:             *CB : Corruption Benefit*
5:             *PR : Probability to be sacked*
6:             *NR : Net Revenue*
7:             *RC : Revenue with risk of corruption*
8:        *RC := S + CB - $PR * S$;*
9:        *NR := RC - S ;*
10:      **if** $NR > 0$ **then**
11:           *– Allow the cut*
12:      **else**
13:           *– Prohibit cut*
14:      **end if**
15:      **return**
16: **endfunction**

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4. Populating the Laf Forest Reserve AiC conceptual scheme

Our approach is as follows, we group the actors according to their level. So we see 'farmer' as a group name for individuals (actors) who are acting as farmers. Basically we describe the properties of the actors as properties for the levels. The actual actors will act according to the rules described for their level. In the simulation TiC, we will assume that the actual actor properties are statistically described. So for example, we may indicate that the farmer is to be disposed of some money supply. Then the simulator will provide each actor of that level (each actual farmer) with an actual money supply according to a normal distribution with mean value the level money supply, and some variance to be specified.

4.1. Capitals

The resource is all the assets and capabilities available to an actor or needed by an action to be run. In our application, the following resource types are distinguished :

1. Resource_type 'CFAF'.
2. Resource_type 'Time'.

4.2. Levels

Level is a social category and physical environment. Following Figure 8, we distinguish 3 levels of actors. Levels are involved in the following fact types :

- *fact type*: Level POWERSET OF Actor.
  Handled by simulator, the TiC simulator will generate actors for each level.
- *fact type*: Level has Name.

1. Level has Name 'farmer'.
2. Level has Name 'wood merchant'.
3. Level has Name 'authority'.

We will use the unique level names as standard name for levels (rather than the set of its set of constituent actors).

- *derived fact type*: LET Level is governing Level BE Level containing Actor is governing EACH Actor in Level.

4. Level 'authority' is governing Level 'wood merchant'.
5. Level 'wood merchant' is governing Level 'farmer'.

4.3. Actors

The actors are all social entities acting individually or collectively. According to the Laf Forest Reserve description (see Figure 8) we distinguish the following specializations of actors :

1. Farmer IS Actor in Level having Name 'farmer'.
2. WoodMerchant IS Actor in Level having Name 'wood merchant'.
3. Authority IS Actor in Level having Name 'Authority'.

Note that these specializations form a conceptual basis for the object type Actor. Next we describe these subtypes.

4.3.1. Farmers

Farmers are involved in the following fact types :

- *fact type*: Actor can use Capital.
  Farmers start with some initial capital. This is described by :

  1. Farmer can use $n1 - $n2 : '' of 'FCFA'.
  2. Farmer can use of $t1 - $t2 : '/week' of 'hours'.

  The actual values of $n1, $n2, $t1 and $t2 are simulation parameters that are set by the domain expert upon starting a simulation session. The actual farmers then will get a start capital according to some normal distribution function as set by the domain expert.

- *derived fact type*: LET Option BE Actor can use enough capitals for Action.
  The population of this sentence type is derived from the actual action requirements and actor disposition. Assuming their initial capital suffices, the following would be derived :

3. Farmer can use enough capitals for 'mouskwari cultivation'.
4. Farmer can use enough capitals for 'firewood extraction'.
5. Farmer can use enough capitals for 'unfertilized cultivation'.
6. Farmer can use enough capitals for 'fertilized cultivation'.
7. Farmer can use enough capitals for 'cut local wood'.
8. Farmer can use enough capitals for 'buy wood'.
9. Farmer can use enough capitals for 'plant trees'.

- *derived fact type*: ChosenOption IS Option with highest benefit. An option is proven beneficial, when (1) no other action can bring more profit and (2) no action with the same profit is higher appreciated by the actor. For the farmer, the following two options are chosen during the start of the simulation session. Both the government and the wood merchants will try to influence this choice.

10. Option ('firewood extraction', Farmer) is chosen.
11. Option ('mouskwari cultivation', Farmer) is chosen.

- *fact type*: Actor influences Gain.

12. farmer influences profit of 'firewood extraction' in 'positive' direction.
13. farmer influences profit of 'mouskwari cultivation' in 'positive' direction.

4.3.2. Wood merchants

Wood merchants are involved in the fact types involving actors as follows ;

- *fact type*: Actor can use Capital.
  Also merchants start with some initial capital. This is described by :

1. WoordMerchant can use $n1 - $n2 : '' of 'FCFA'.

The actual values of $n1 and $n2 are simulation parameters that are set by the domain expert upon starting a simulation session.

- *derived fact type*: LET Option BE Actor can use enough capitals for Action.
  The population of this sentence type is derived from the actual action requirements and actor disposition. Assuming their initial capital suffices, the following would be derived :

2. WoodMerchant can use enough capitals for 'buy wood in Laf'
3. WoodMerchant can use enough capitals for 'Not buy wood in Laf'
4. WoodMerchant can use enough capitals for 'Other activity'

- *fact type*: ChosenOption IS Option with highest benefit. An option is proven beneficial, when (1) no other action can bring more profit and (2) no action with the same profit is higher appreciated by the actor.

5. Option ('buy wood in Laf', Merchant) is chosen.

- *fact type*: Actor influences Gain.

    6. WoodMerchant influences 'output' of 'buy wood in Laf' in 'positive' direction.

4.3.3. Authority

Authorities are involved in the fact types involving actors as follows ;

- *fact type*: Actor can use Capital.
  Also authorities are assumed to start with a bounded initial budget :

    1. Authority can use Capital $n1 - $n2 : '' of 'FCFA'.

  The actual values of $n1 and $n2 are simulation parameters that are set by the domain expert upon starting a simulation session.
- Derived fact type LET Option BE Actor can use enough capitals for Action.
  The population of this sentence type is derived from the actual action requirements and actor disposition. We assume that the government has enough capital to finance the actions intended policies, leading to the following options :

    2. Authority can use enough capitals for 'allow the cut'.
    3. Authority can use enough capitals for 'prohibit cutting'.

- *derived fact type*: ChosenOption IS Option with highest benefit.
  Chosen is the following option :

    4. Option ('no implementation of forest policy', Authority) is chosen.

- *fact type*: Actor influences Gain.

    5. Authority influences 'input' of 'no implementation of forest policy' in 'negative' direction.

4.4. Actions

An action is a unit of behavior on which an actor has to make a decision. Finally we focus on the actions, and specify what they require and what they produce.

- **We have the following actions :**
    – Farmer related actions :

    1. Action 'mouskwari cultivation'.   5. Action 'cut local wood'.
    2. Action 'firewood extraction'.   6. Action 'buy wood'.
    3. Action 'unfertilized cultivation'.   7. Action 'plant trees'.
    4. Action 'fertilized cultivation'.

– Wood merchant related actions :

1. Action 'buy wood in Laf'.
2. Action 'no buy wood in Laf'.
3. Action 'other activity'.

– Authority related actions :

1. Action 'no implementation of forest policies'.
2. Action 'allow the cut'.
3. Action 'prohibit cutting'.

- **The requirements for these actions are specified by fact type** Action requires Capital. We mention some of them :

1. 'mouskwari cultivation' requires [Capital] : '/hectare/year' of 'CFAF'
2. 'mouskwari cultivation' requires 4-9 : 'hours/day' of 'Time'
3. 'firewood extraction' requires : 'hours/week' of Time
4. 'unfertilized cultivation' requires : other cultivation technology and fallow.
5. 'fertilized cultivation' require [Capital].
6. 'buy wood' requires [Capital] 10 - 20 : '/ kg' of 'CFAF'.
7. 'plant trees' requires [Capital] and 2-3 : 'hours/day' of 'time'.
8. 'no buy wood in Laf' requires other activity to earn money.
9. 'other activity' requires [Capital].
10. 'no implementation of forest policies' requires cost of corruption.
11. 'allow the cut' requires cost of corruption.
12. 'prohibit cutting' requires Salary.

- **The products of these actions are specified by fact type** Gain : Action produces Resource. We mention some of them :

1. 'mouskwari cultivation' produces 112,500-168,750 : '/year/hectare' of 'FCFA'
2. 'firewood extraction' produces 10000-15000 : '/month' of 'FCFA'
3. 'unfertilized cultivation' produces 43,300-60,250 :'/year/hectare' of 'FCFA'.
4. 'fertilized cultivation' produces 112,500-168,750 : '/year/hectare' of 'FCFA'.
5. 'buy wood in Laf' produces 200,000 : '/month' of 'CFAF'.
6. 'plant trees' produces good conservation.
7. 'no buy wood in Laf' produces other activity.
8. 'other activity' produces cash.
9. 'No implementation of forest policies' produces 3,000 : '/month/wood merchant' of 'CFAF'.
10. 'allow the cut' produces 3,000 : '/month/wood merchant' of 'CFAF'. + Salary with risk to being caught and sacked
11. 'prohibit cutting' produces good management of forest and Salary.

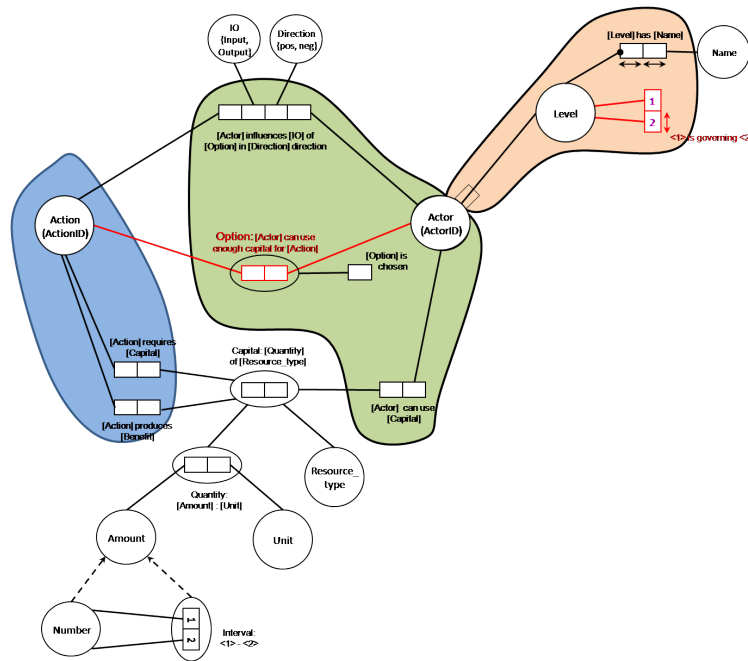## 5. The relational population of Laf Forest Reserve

Figure 9 – Grouping the AiC Metamodel

We summarize the conceptual population of the AiC metamodel as described in the previous section. The relational data representation is derived from the grouping as shown in Figure 9. This is the data representation as used internally in TiC. We will discuss the resulting relations stepwise, and show how the conceptual population is represented in the relational scheme. (See section 5.1, section 5.2, section 5.3) .

5.1. Actors

First we overview the resource types that are considered (CFAF and Time). These resource types are used in Table 1 and Table 2. The actors are represented by the following relational structure :

R1. Actor (ActorID,
                (can use (Quantity, Resource_type))*,
                (influences ((ActionId), (Quantity, Resource_type)))?,

> (*is governed by ActorID*)**?**,
> (*has option (ActionId)*)*****,
> (*has chose (ActionId)*)**?**)

Tableau 1 – Actor table

ActorID	can use	options	choice	influencing
Farmers				
...	- [Capital] : FCFA - [Capital]/week : time	- firewood extraction, - mouskwari cultivation, - unfertilized cultivation, - fertilized cultivation, - cut local wood, - buy wood, - plant trees	- firewood extraction, - mouskwari cultivation	- input, positive : firewood extraction - input, positive : mouskwari cultivation
Merchants				
...	- [Capital] : FCFA	- buy wood in Laf - no buy wood in Laf, - other activity	- buy wood in Laf	- output, negative : buy wood in Laf
Authority				
...	- [Capital] : FCFA	- allow the cut, - prohibit cutting	- allow the cut	- output, negative : allow the cut

5.2. Actions

The actions are represented by the following relational structure :

> **R2.**   Action (ActionID,
> (*requires (Quantity, Resource_type)*)**?**,
> (*produces (Quantity, Resource_type)*)**?**)

Tableau 2 – Actions table

ActionID	requires	produces
Farmers		
mouskwari cultivation	[CFAF/50kg]/hectare/year	1500 kg /hectare/year ≡ 168650 CFAF
firewood extraction	15 /hours/week Time	100,000-150,000 /month CFAF
unfertilized cultivation	Other technology(Fallow)	> 1700kg / year
fertilized cultivation	50 kg of intrant / hectare	> 1700kg/year
cut local wood	Time	< 15000/month of CFAF
		more time for mouskwari cultivation
		good conservation
buy wood	[Capital]	more time for mouskwari cultivation
plant trees	Time	good conservation
Merchants		
buy wood in Laf	[Capital]	200,000 /month of CFAF
no buy wood in Laf	other activity	[Capital]
other activity	[Capital]	[Capital]
Authorities		
allow the cut	Cost of corruption (3.000/wood merchant/month of CFAF)	cost of corruption + Salary
prohibit cutting	Salary	good conservation + Salary

Actions in bold are actions that define the current situations in the village. These actions have been implemented in the model based on the information collected in the field during interviews with actors. Other actions are those proposed by domain expert to the actors in field to improve the current situation. These actions are implemented in the model based on the information provided by domain experts and literature.

5.3. Levels

Levels are recorded according to the following relational structure :

R3. Level (<u>LevelID</u>,
           (has member (ActorID))*,
           (is governed by ((ActorID))*)?)

6. The resulting Laf Model

6.1. The Laf computational model

This section describes how the Laf conceptual model can be transformed into a more specific computational model that is used as the basis for designing the Laf domain-specific language. The goal of domain specific languages is to narrow the gap between the application domain and its implementation. Therefore such languages must satisfy (see [18]) :

1) conceptual proximity : the domain concepts must be proximal to their corresponding language concepts

2) representational proximity : the representation of concepts in the application domain is proximal to the representation in the domain specific language.
Domain specific languages are commonly represented by a meta model that describes the relevant concepts in the application domain and their relations. We describe how the AiC conceptual scheme of Laf developed and described in terms of ORM in Section 3 can be systematically converted into a computational model using Xtext format description.

In [16], it is shown that the grammar derived from the AiC conceptual model using Xtext grammar information [7], [25] is the following :

```
grammar org.xtext.AIC with org.eclipse.xtext.common.Terminals
generate aIC "http://www.xtext.org/AIC"
import "http://www.eclipse.org/emf/2002/Ecore" as ecore
AIC_SPECIFICATION_RULE returns Model:
   'Model_AIC'
   '{'
     ('ModelVariable' ':' (Variable+=ID',')*)?
     (Level+=LevelRule)*
   '}';
EInt returns ecore::EInt:
   '-'? INT;
EString returns ecore::EString: STRING | ID;
LevelRule returns Level:
   'Level' (LevelID=EString)? '('(iAttribute+=ID)*')'
   '{'
     ( (actors+=ActorRule))*
     ('is-governed-by' ':' (actor+=ActorRule)*)?
   '}';
ActorRule returns Actor:
   'Actor' (ActorID=EString) '(' iAttribute+=ID ')' '{'
     ('can-use''('quantity+=EInt','resource_type+=EString')')*
     ('influences''('action+=ActionRule','quantity+=EInt','resource_type+=EString'))?
     ('is governed by' ':' actor+=ActorRule)?
     'has-option' ':' (action+=ActionRule)*
     'has-chose' ':' (action+=ActionRule)?
   '}';
ActionRule returns Action:
   'Action' (ActionID=EString) '(' (iAttribute+=ID)* ')' '{'
     ('requires''('quantity+=EInt','resource_type+=EString'))?
     ('produces''('quantity+=EInt','resource_type+=EString'))?
   '}';
```

Where the rule Variable use for declaring global variables or parameters of the model and the rule EInt for generating the numerical type.

```
1  ModelAIC
2  { ModelVariable: day_in_month, day_in_year, ..., weekdays, firewood_price,
       sorgho_price,fields_karal,sorgho_production_per_ha, hour_begin1, hour_end1,
       hour_begin2,...,
3    Average_revenue, population_grow_rate,karal_Area, wood_per_ha, limit_area, ...
4  Level Laf ()
5  { Actor Farmer (number Amount Unit Resource_type)
6    { can-use(Amount,Resource_type)
7      has-option :unfertilized_cultivation fertilized_cultivation Plant_trees
           Cut_local_wood buy_wood
8      has-chosen :
9        Action Cutting_wood ()
10         {requires(Amount,Unit,Resource_type)
11          produces(Amount,Unit,Resource_type)
```

```
12                        }
13          Action Mouskwari_cultivation ()
14          .....
15        influences(cutting_Wood,Ipositive)
16        is-governed-by : Wood_Merchands Authotities
17      }
18      Actor Wood_Merchands (number Amount Unit Resource_type)
19       {can-use(Amount,Resource_type)
20        has-option :no_buy_wood_in_Laf other_activity
21        has-chosen :
22          Action Buy_wood ()
23          {requires(Amount,Unit,Resource_type)
24           produces(Amount,Unit,Resource_type)
25          }
26       influences(buy_wood_in_Laf,Onegative)
27       is-governed-by : Authotities
28       }
29      Actor Authorities (number number Amount Unit Resource_type)
30      { can-use (Amount,Resource_type)
31        has-option :allow_the_cut corruption sensitize apply_the_laws prohibit_cutting
32         has-chosen :
33           Action no_implementation_of_forest_policy()
34           {requires(Amount,Unit,Resource_type)
35            produces(Amount,Unit,Resource_type)
36           }
37        influences ( no_implementation_of_forest_policy,Ipositive)
38        is-governed-by :
39      }
40     }
41    }
```

Listing 1 – Code snippet of the Model of Laf deforestation process obtained from the developed language domain

From the language generated by the grammar above we get our Laf computational model in listing 1. As shown the grammar, this editor with tools that offers Xtext manages spaces, carriage returns and tabs.

6.2. Introduction to the TiC environment

6.2.1. Syntax-driven editor support

As can be seen from listing 1, our syntax-driven editor is aware of the keywords of the corresponding AiC language and where to place them. It knows about all the grammatical constructs, and it includes nice tools such as syntax coloring, code completion, and validation. The editor also includes rules that express constraints that could not be expressed from the AiC metamodel. These rules are implemented with XTend Language (see [24]). These constraints concern especially the uniqueness of the actors groups identifier(the name of an Actor (ActorID) is unique), the the uniqueness of action name, the governance relations between actor group (an actor or level can not govern itself) and the uniqueness of some general parameters.

The editor also provide Outline View facilitating navigation through the program code and Quickfix to correct some errors that may occur when editing the program.

6.2.2. Main functionality of the TiC simulator

1) Modify sentence types : for example to implement a new policy for the authorities.

2) Modify the distribution parameters for auto-generated object types. For example, the number of farmers, or the property that farmers dispose of.

3) Transforms the domain concepts in the target language while keeping the logical construction of these concepts.

4) Generates a general structure of the model source code.

6.2.3. The TiC simulator user interface

Listing 2 show the general scheme of the generated NetLogo [21, 22] code of Laf model from the AiC model. We observe in this figure an early implementation of the Laf model characterized by processing of parameters, creating different classes of agents, creating the body of all the functions and procedures that define the actions of the agents, the initialization of simulation environment, and a general scheme for the main program. As we see, there remains only to user to complete the code functions and procedure according to the agent's goals.

```
1   globals
2   [day-in-month day-in-year month-in-year month-text year months hour-in-day day-in-
        week weekdays-text weekdays
3    firewood_price sorgho-price ... cost_daily_labor number_of_hectar_work_per_day
        Average_revenue population_grow_rate...
4   ]
5   breed[Levels Laf ]
6   Levels-own[ ]
7   breed[Farmerss Farmers]
8   Farmerss-own[number-Farmers Amount-Farmers Unit-Farmers Resource_type-Farmers ]
9   breed[Wood_Merchandss Wood_Merchands]
10  Wood_Merchandss-own[number-Wood_Merchands ...]
11  breed[Authoritiess Authorities]
12  Authoritiess-own[number-Authorities ...]
13  directed-link-breed[is-governed-by Govern]
14  to can_use_of_Farmers[Amount Resource_type]
15  ;to completed by user
16  end
17  ....
18  to go
19  ask Farmers[
20  ;to completed by user
21  ]
22  ask Wood_Merchands[
23  ;to completed by user
24  ]
25  ask Authorities[
26  ;to completed by user
27  ]
28  ; Call the plot functions here if necessary
29  tick
30  end
```

Listing 2 – Snippet of NetLogo generating code

The TiC tool offers the user two big advantages :

Data consistency from data collection phase to the code generation is therefore carried out by the domain expert. The data transfer of one competence to another is no more useful. This reduces data loss.

Gain in time since code is generated directly from the conceptual model.

For a more detailed description of the TiC tool (See [14])

7. Simulation and discussion

Figure 10 – Validation of the simulation model with the different actors in Laf

In the previous sections we have shown how the conceptual description of the Laf Forest Reserve domain was entered in TiC. In this section we show some simulations that were made with TiC after the Laf Forest Reserve description was entered. We describe 3 simulation sessions, that we refer to as scenario 1, 2 and 3. In scenario 1 we study the current situation in Laf Forest Reserve. In scenario 2 we focus on a conservation measure (PR=0.9, high risk of being caught in case of corruption) by moving the wood merchants in village. Since the controllers (authority) will prevent the cutting and sale of wood. Finally in scenario 3 we investigate a sustainable effort.

Each edit session starts with some basic decisions, one of them being a decision about the granularity of time. In each of the sessions we choose that the system clock tick

corresponds to one day. We take into account the typical characteristics of agricultural life. The agricultural activity is concentrated in the months May - January, a period of 9 months. The other months are months of extreme drought (no agricultural activity) in which logging operations are intensified. Furthermore we take into account the daily period that one person can work in the farm in one day, the number of months of intensification of cutting wood and the quantity of wood any family can cut at the day during these periods. So a curve is plot at any 360 ticks corresponding to one year (one tick equals to one day).

The preliminary results of the implementation and testing of the simulation model illustrate the interest of the approach proposed in this article. A participatory map developed with local residents of the village has been digitized and integrated in NetLogo to perform simulations in a realistic environment (Figure 11). The simulation consist of three scenarios and tested the system behavior with respect to these scenarios. The village has about 1,000 households growing at 2% per year [4]. For reason of calculation time, we used an initial population of 20 households (Figure 10), growing same 2% per year. This is important for the interpretation of the simulation curves.

7.1. Scenario 1 : The current situation in Laf Forest Reserve

In this scenario a simulation is made by taking into account the presence of farmers, wood traders, and authorities (with PR=0 no punishment risk on corruption) in the village. The aim is to observe the actual situation that prevailed in Laf Forest Reserve. Concerning the farmers, their income is calculated by adding the earnings from the sale of wood and those obtained from the mouskwari harvest ; 1600 kg of wood are extracted on one hectare and the price of 1 kg varies between 8 FCFA and 16 FCFA. Also between 1000 and 1560 kg of mouskwari are collected per hectare. The price of one kg mouskwari varies between 100 and 125 FCFA / kg. For each family, we considered an average money spending per day depending to the number of persons in the household. Also the cultivated area by a family depends on the number of person in the family. Land of mouskwari used for six consecutive years without rest turns to degraded land.

Concerning the wood trader, income is calculated taking into account the purchase price of the wood in the village (see price /kg above), the shipping cost of wood in Maroua which price of 1 kg varies between 2.5 FCFA and 5 FCFA. Also taking into account the cost of the tax and the cost of corruption (varies around 1000 FCFA per month) and finally the selling price on the major market in Maroua where 1 kg fetches between 12 FCFA and 30 FCFA, depending on the season. In one sub-scenario, the tax/cost of corruption was set increased to 19.5 % of the selling price, thus investigating the effect of better policy implementation (higher cost of corruption and/or improved tax collection).

7.2. Scenario 2 : Conservation measure

This scenario takes place under the same conditions as Scenario 1 but without the wood trader, because these are hunted by the authorities who prohibit the sale of wood. The absence of the wood traders in village requires an additional resource to farmers to

go and sell their wood in the nearest city to 45 km (Maroua). The clearing of forest for the creation of the new fields has a cost (in time and money). Because in scenario 1, the farmers could create Mouskwari field directly in deforested areas (no cost of clearing). But with the absence of wood merchants, wood extraction is scarce because there is no buyer on site. So, to create a field, we have to clear the wooded area ourselves.
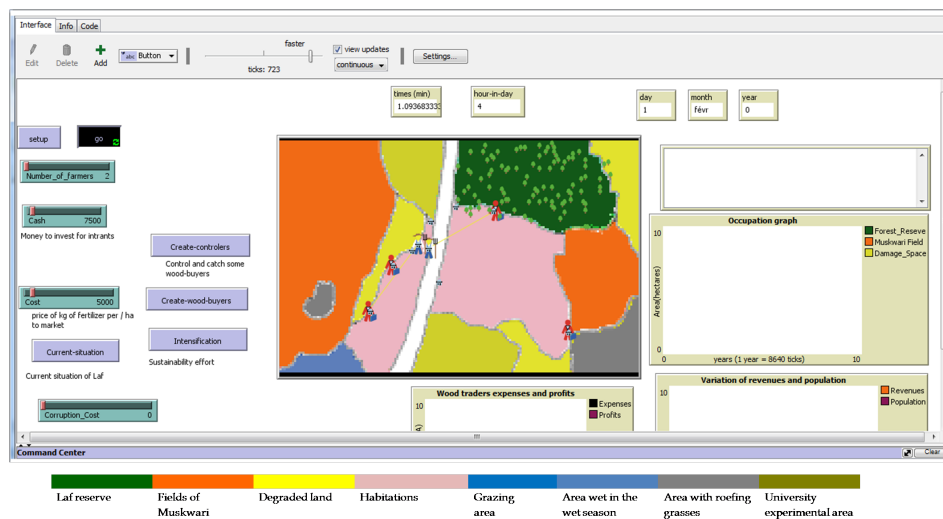

Figure 11 – Simulation interface

7.3. Scenario 3 : Sustainable effort

In this scenario farmers make efforts to maintain soil fertility. Money obtained from wood sales is used to buy fertilizer and/or pay for labour needed for manure management, which is modelled as increased yields and maintained soil fertility. A hectare of Mouskwari uses on average a bag of 50 kg of fertilizer that costs on average 20 000 FCFA. The average cost of labor is 1000 FCFA the day for 5 hours of work. For the rest, we are in the same conditions as Scenario 1. Thus the farmers will cut wood if their mouskwari income does not buy enough fertilizer to fertilize his fields

7.4. Discussion of the simulation results

Next we discuss the outcomes of the simulations in the above scenarios. Figure 11 shows the initial simulation interface.

7.4.1. Scenario 1

The simulation of Scenario 1 (Figure 12) confirms the current trends in the village of Laf Forest Reserve [8]. We note continuous degradation of arable land and a decline of the forest reserve in the first 50 years. The intrusions to the Laf Forest Reserve reserve is more intense at the 100 model years caused by the wood traders in place in village. The deforestation facilitated the installation of the new fields quickly by reducing the cost of forest clearing of which was to lay out the farmer to be able to create his new field. All this results in fast degradation of land (see yellow curve 6530 ha). We note that the incomes of farmers decline over the years. Furthermore we observe an increase in revenues of the wood trader ; this is explained by that the trader can invest more in buying wood due to his accumulating capital, and sell in on the insatiable market.

At 100 years (Figure 12), we note a significant extinction of the forest reserve and a total extinction of mouskwari fields, the forest area passes to 700 ha (contrary to 5000 ha initially), and a higher area of degradation (6530 ha). This is explained by the fact that intrusion in the reserve generates much firewood to sell.

The sub-scenario with improved policy implementation (i.e. higher cost of tax/corruption for the merchant) is depicted in (Figure 13). We see that after a certain number of years (20 model years), the wood trader withdraws from the market after accumulating many losses.

7.4.2. Scenario 2

As in scenario 1, at the 50 first years, we note a continuous degradation of arable but with a slower degradation of the forest that scenario 1. This is explained by the fact that in scenario 2, an additional resource is necessary to the farmers to be able to sell their wood (money of transport and time), which reduces wood cutting of certain farmers not having time or money to go to sell downtown. At 100 years (Figure 14), we note a total extinction of mouskwari fields and a low degradation of the forest reserve, the forest area passes to 4300 ha (contrary to 5000 ha initially), and a degradation of the grounds which is to 5500 ha (better than the scenario 1). So we see here a good conservation of the forest but the income level is not maintained.

7.4.3. Scenario 3

In Scenario 3 (Figure 15), we see an initial increase in the space of mouskwari fields, and a slight decrease in the degraded space. The farmers cut trees and sell to buy fertilizer and/or labour to try to restore soil and maintain their harvest. The incomes remain stable until the forest area declines. Forest extinction will be arrived at after around 200 years.

7.4.4. Discussing the scenarios

Our scenarios are of course not realistic in the very long term. Farmers will not wait, for instance, till their food and cash production is at zero level and rather migrate to town or live off remittances from migrated children. If users are aware of these and other
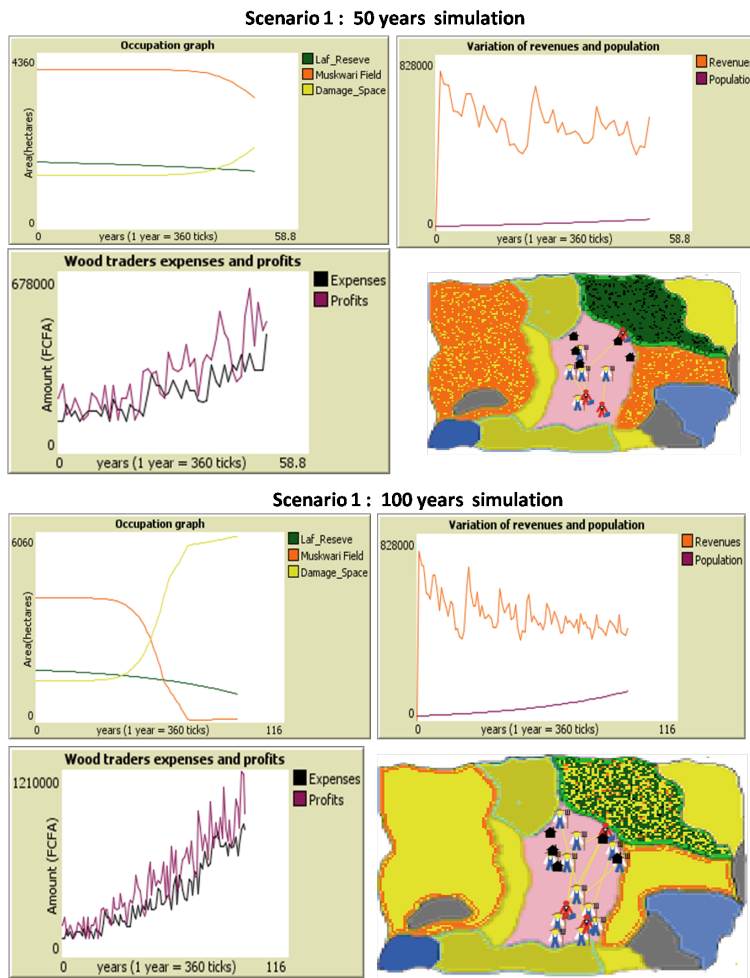
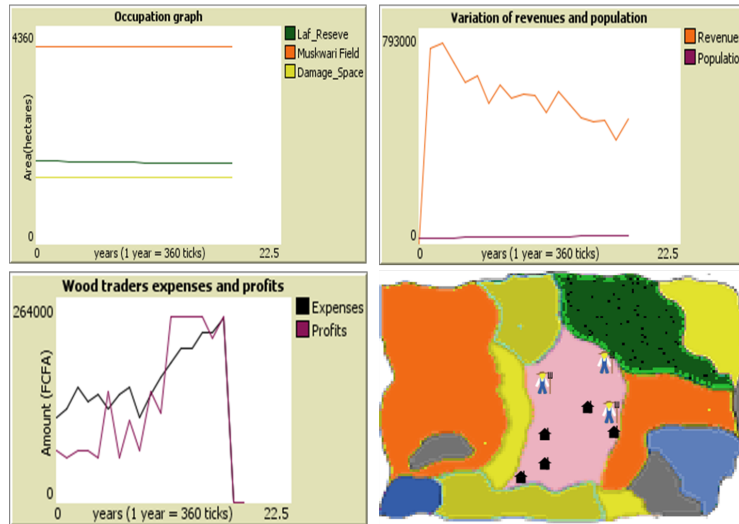Figure 12 – Simulation of Scenario 1 for 50 and 100 years

Figure 13 – Simulation Scenario 1 with tax fixed on 19.5 % of the selling price FCFA / month
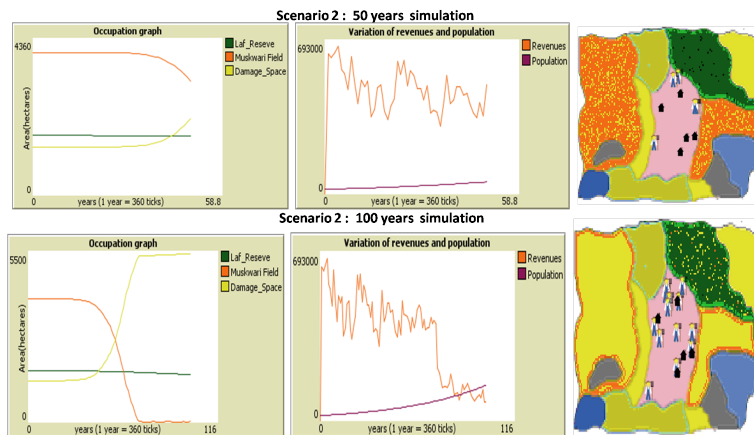

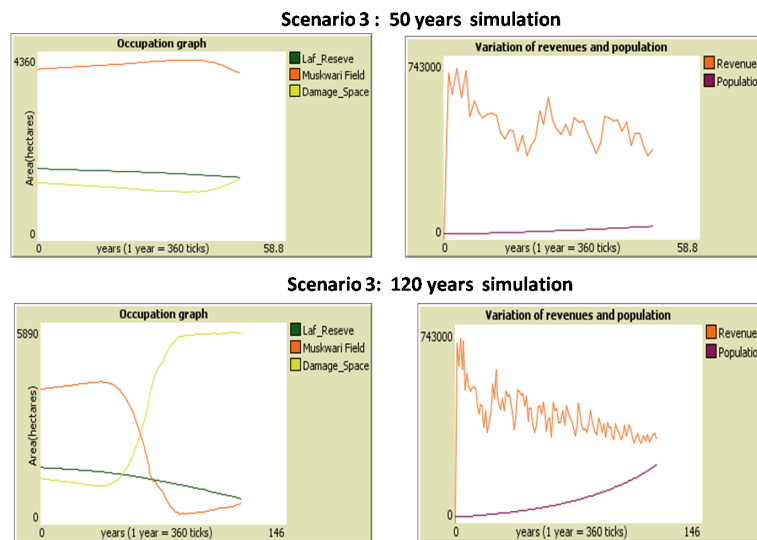Figure 14 – Simulation of Scenario 2 for 50 and 100 years

Figure 15 – Simulation of Scenario 3 for 50 and 100 years

limitations however, also simple multi-level models can be put to good use in participatory and policy-making work.

Comparison of the scenarios allows to recognize the important roles of the wood merchant as secondary actor in the deforestation and degradation in Laf Forest Reserve. Modelling this secondary actor also enabled to investigate the role of the authority as tertiary actor, in this case (non-)implementing forest and taxation policies. Because the authority actor was not modelled as a 'live' actor, we cannot explain why the government acts the way it does, and neither connect the government with possible higher-up actors such as international agencies.

On a more general level, we have seen how the Action-in-Context framework, and its actors field concept in particular, enables the modelling the local impacts of quite generic, higher-level phenomena and policy measures, market shifts, general subsidies or taxes, international pressures on government and so on. Which is exactly what multilevel models should do, focusing for instance on the design of effective policy measures.

8. Conclusion

This paper presented the application of the NMDC, a model-based development approach for designing ICT-based solutions to environmental problems. We show in this paper, how the associated TiC (Tool-in-Context) develop through NMDC can help the domain expert to describe in natural language the environmental problem.

Using NMDC, we logically and simply represented the deforestation process of the Laf Forest Reservethrough natural language using environmental concepts.

The TiC tool not only supports the construction of a simulation tool for concrete application domains, it also can be used as a syntax-directed editor that supports the domain expert in developing a concrete model. This allows the domain expert to develop a model-driven application without the need for advance ICT competencies, as is intended by Natural Model based Design in Context (NMDC).

Our approach effectively facilitates the systematic collection of information to explain and analyze the problem while providing a more relevant Multi-Level Agent Based Model (MLABM) that simulates the process taking into account the diversity of situations related to the process of actors decision-making at various levels, potentially from local to world systems.

Furthermore by allowing the domain expert to integrate the design phase through a specific language, our approach allows to maintain a good consistency of data in the different development phases and also allows gain in time by automating the various stages of implementation.

Our empirical test mainly focused on being a technical testing of practicability of the model at an early stage. More work will be required to expand the model to refine the empirical assumptions in order to improve both the multi-level character and model realism. We also plan to compare our approach with existing ones.

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