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MineSet:

Digitization of a board game to an interactive simulation for sustainable forest management in the Congo Basin

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Abstract

This work describes the adaptation of *MineSet,* a board game, into an agent-based model (ABM). The first part describes the *CoForSet* project from which this work stems. The geographical situation and the socio-economic context of the TRIDOM region in the Congo Basin are described. For this project, a board game called *MineSet* had been developed to support several activities. Co-designed with stakeholders, this game was one of the products of a participatory modeling approach, called *ComMod*. After the presentation of this approach and the context of *MineSet*'s development, the objectives and advantages of obtaining a digital version of the game are discussed.

The second part describes the structure and rules of the *MineSet* board game based on the UML formalism. The resulting diagrams provide an overview of the game and its functioning. They are also used to describe the parts of the conceptual model that need to be modified in order to obtain both an autonomous ABM and a new version of the game adapted for computers. The implementation options of this model and the resulting graphic interfaces are then described. In particular, the new simulator proposes three types of autonomous agents that mimic three player archetypes: "profit", "passive" and "pro-environmental" strategies.

The last part presents the results of the ABM. They are explained by considering each autonomous strategy one by one and then combining them. They are evaluated according to three indicators: 1) the generated economic benefits, 2) the environmental impacts (forest quantity and biodiversity) and 3) the social aspect estimated by the size of the populations living on the territory. These indicators are studied in relation to different parameters, such as the market prices for wood. Although some of the model's responses seem counter-intuitive at first, they turn out to be quite logical after analysis.

This adaptation of the board game into an ABM allows us to explore the simulations on various configurations over the long term, which is not possible with the classical game. But this work offers another original advantage: the interaction with the simulations. Like in video games, a player can control his avatar, which then becomes a simple agent without decision-making autonomy. Even better, the game can be configured by mixing avatars and autonomous agents. This digital *MineSet* can thus fit various situations, even when the number of participants changes during the simulation.

Acknowledgements

This internship offered me the opportunity to discover a new approach to natural resource management through participatory modeling. I would like to thank CIRAD for allowing me to do this internship, and in particular the “Forest and Society” Unit which received me in its premises. I would like to thank in particular Hélène Dessard, my supervisor, without whom this work would not have been possible.
I would also like to thank Anne Dray and Claude Garcia from the ETH Zurich who followed and helped me during the whole internship with teleworking sessions due to the sanitary crisis. They especially invited me to participate to the IUCN conference in Marseille, which was an exceptional and exciting moment: the culminating point to close this internship.
I also thank the UMR SENS of CIRAD for helping me to discover and master the formalism, then to learn how to implement agent-based models with Cormas.
Finally, I would like to thank my tutor, professor Hazaël Jones who followed me during the whole internship; his advice was always relevant.
The participative modeling approach seems promising to me and I would like to extend the experience by a thesis in this field.

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General introduction

In order to assist in the co-management of natural resources in the Congo Basin, a role-playing game (RpG) was developed as part of the CoForSet project led by CIRAD's Forests and Societies Unit. The designers of this game, called MineSet, wanted to create a computerized version to facilitate its use and dissemination. The following problem emerged: How to transform a role-playing game into an interactive simulation game?

This internship report is organized around various aspects that include participatory modeling and more specifically the ComMod approach, the appropriation of the MineSet game, the formalization of the conceptual model, the choice of a simulation platform, the implementation of an agent-based modeling (ABM), the design of user interfaces, the design of autonomous agents, a sensitivity analysis on the strategies of these agents, and finally a critical look at this work.

I. Participatory modeling and its use in the CoForSet project

1) Why participation?

The World Bank (1996) defines participation as "*any process that helps people influence and take some control over decisions that affect them, from the construction of public policy to the selection of appropriate technology*" (WB, 1996). Thus, many comparative studies on development projects show the benefits of participation and call into question the top-down approach (consisting of the authorities indicating the decisions to be taken locally) in the construction of projects (Mathevet et al., 2010). Participation has become widespread, to the point where it has become an essential part of development projects (Pretty, 1995).

The purpose of participation is to ensure that all stakeholders have the right to take part in a decision that affects them. It enables the *empowerment*[1] of participants through the modification of perceptions, social learning, involvement in the decision-making process and the distribution of power within a social group.

For some years now, participation has been a "buzz word" (Voinov and Bousquet, 2010). It has become almost unavoidable for development and planning in the field of organizations and environmental management. Thus, directives (especially in Europe) compel political managers to involve stakeholders in decision-making on socio-ecosystems (SES). This close interaction between decision-makers and stakeholders would force stakeholders to be more involved in the decision-making process, and even in the modeling phase of their SES.

a) The concept of participatory modeling

A socio-ecosystem integrates both an environmental and a human and social dimension. By nature, a SES is complex and can be seen as a set of four interacting components: i) a geographical area (a natural area for example) with ii) resource units (animal species, water, forests...), iii) a governance system and iv) the users who live on this space and use the resources. Often interdependent, the actions of each one have effects on the others with feedback phenomena that are difficult to

[1]Based on the idea of power, empowerment is taking control over its own life (Laborie, 2020).

understand. However, there is still no modeling of SES as a structured research field, with a methodological framework, a unified and well-defined approach (Le Page, 2017). Therefore, there are many approaches to address these complex systems. In this perspective, some modelers consider that an analytical approach based on equations would be less appropriate than an algorithmic approach based on a combination of simple mechanisms. The website http://participatorymodeling.org, specialized on the different participation methods, defines participatory modeling as follow:

Participatory modeling (PM) is an intentional learning-to-action process that engages stakeholders' implicit and explicit knowledge to create one or more formalized, shared representations of reality. In this process, participants co-define the problem and use modeling practices to facilitate the group's description, solution and decision-making actions. Participatory modeling is often used in environmental and resource management contexts. Advantages of this approach include a high level of ownership of decision making and a structure for making goals and outcomes explicit, open to evaluation and revision.

Based on an early classification developed by Arnstein (1969), Van Bruggen et al. (2019) propose a typology of participation for PM that differentiates:

- Modeling with nominal participation that includes actors to legitimize the project and disseminate results,
- Instrumental modeling that uses actors to make the process more efficient and effective,
- Representative modeling that takes into account the needs and demands of stakeholders in the decision-making process,
- Transformative modeling, which aims at reciprocal top-down and bottom-up empowerment.

In the latter, participation is a means, but also an end. The model is co-constructed through a dialogue between researchers and stakeholders. The participants maintain control over the use of the model. According to Barreteau et al. (2013), participatory modeling (PM) approaches can be classified according to the degree of stakeholders' involvement in the different stages of the modeling process. In the context of this internship and project, the degree of involvement of the stakeholders of the TRIDOM region in the Congo Basin has the objective of social learning. It is characterized by a strong and regular interaction of the participants in the process of co-construction of the model at different stages.

b) The ComMod approach

A sub-type of participatory modeling is the Companion Modeling. The objective is not to predict, but to provoke exchanges between participants, to reveal points of view, to share representations, and to explore possible futures together. Although the term "companion modeling" appeared in 1996 (Bousquet et al., 1996), which promotes the use of role-playing games (Barreteau and Bousquet, 1999), the word ComMod (for "Companion Modeling") and the approach were formalized later (Bousquet et al. 2005, Etienne, 2011).

Figure 1: photo of a workshop using an interactive computer model as part of a ComMod approach (Photo A. Perrotton)

The approach is based on the principle that no model is neutral: this is the product of our interpretation of the world. Especially in the social domain and the study of human behavior, asserting its neutrality is an open door to manipulation (Mullon 2005; Daré et al, 2010, Laborie, 2020). This is even more true since the sustainable and equitable management of renewable resources requires the involvement of different decision makers and stakeholders. In order to limit this manipulation, the purpose of the ComMod approach is to integrate the different actors into the simulation so that they put themselves in a situation and act by playing their own role or by putting themselves in the place of others in order to understand other points of view. Published in the journal "Natures Sciences Société", the founding article (ComMod, 2005) specifies that the ComMod approach has a double objective. The first is to understand the SES, i.e. to distinguish the role of actors in the processes, the production of knowledge on a development issue and the shared construction of indicators that must be relevant to all. The second objective is to help collective decision-making. This objective is facilitated by the playfulness of the approach, which helps to unblock unspoken situations, facilitate exchanges of points of view, clarify the issues at stake for the group and enrich the decision-making process. In short, the ComMod approach aims at changing the representations of the different participants. It favors the creation of a group that will be able to solve a problematic situation on its own. Rather than providing solutions to a group in the manner of top-down approaches (turnkey solutions), the approach aims to assist local stakeholders to find solutions on their own by projecting themselves over the long term. According to this posture, the model is only an intermediary object acting as a mediator between the different participants.

A ComMod approach is a rather long process which goes through several stages of which modeling is only one phase. Once the objective has been defined and a first conceptual model established, the process often includes role-playing sessions with the stakeholders (Figure 1). These sessions allow for the enrichment of knowledge to better understand the SES and thus modify and improve the underlying model. On the other hand, they encourage the establishment of a dialogue between the various stakeholders, allowing them to step back and discuss the problems encountered. The importance of these two points depends on when the workshop is conducted in the process.

Often these sessions are conducted in three parts: the briefing, the game and the debriefing. The briefing serves to welcome the participants, explain the purpose of the session and introduce the model. After a handover phase and the assignment of roles, the game takes place, often around a board. A "game master", also called a facilitator, organizes the game. Finally comes the debriefing with first a discussion of the feelings expressed by the participants and the direction taken by the simulated scenario. This is followed by a more in-depth study of the session where different issues are discussed. This last phase is important because it is at this point that the model is revised and the actors discuss the directions they wish to take collectively.

2) The CoForSet project

CoForSet is a project coordinated by CIRAD and associates several organizations in Europe and Africa. Funded by the "Fondation pour la Recherche sur la Biodiversité" (FRB) and the "Fonds Français pour l'Environnement Mondial" (see Annex 1 for all collaborators), the project builds on and continues a previous project, CoForTips. The project started in 2014 and ends in 2017.

CoForSet's study area is the Congo Basin, specifically a region called TRIDOM (for Tri-National Dja Odzala Minkebe) that straddles southeastern Cameroon, northeastern Gabon and northwestern Republic of Congo. It is a region rich in tropical rainforest with almost 97% of its surface covered (Quétier, 2015). It is also a biodiversity hot spot with the presence of many large mammals such as the elephant or the gorilla. Finally, the inhabitants of these forests, in particular the Pygmies and Bantus, use the resources of the forest for their subsistence. On the other hand, the exploitation of these forests for timber, agriculture and iron ore resources is also a great opportunity for the countries that occupy the region for their economic development. Until now inaccessible, the opening of these areas and the installation of new inhabitants threaten the balance of this system. This region is therefore a complex socio-ecosystem (SES) subject to various anthropic pressures.

The project is organized in three parts. The first is to understand the SES of the TRIDOM area. For this, it builds on the results of the previous project by focusing on mining projects and the implementation of ecological compensation mechanisms. The second component is the construction of biodiversity scenarios integrating social, economic, ecological, geophysical and governance aspects. These scenarios must include and evaluate the impact of industrial projects in sensitive habitats. The third component aims to make the results of the research sustainable in the decision-making process at the regional and national levels. To this end, the CoForSet project has developed tools for the various actors in the region (NGOs, forestry and mining companies, governments, etc.) so that they can better anticipate their actions, implement good environmental and social practices, and establish a constructive dialogue between the various actors so as not to harm anyone. To this end, the project researchers decided to use the participatory approach ComMod with the creation of a role-playing game as a product.

3) The MineSet role playing game

a) Usage context

The MineSet role-playing game is the result of discussions between the project's researchers and TRIDOM stakeholders. It aims to represent the interactions between resources and the users of these resources. Based on a conceptual model developed over a long period of time, the game transcribes the ecological processes of the region, external factors such as demographics, changes in governance, cultural changes, but also the individual strategies of the actors. MineSet was presented several times to various representatives of the area so that they could test it and participate in its adjustments (Figure 2). Stakeholders included members of the Gabonese government, NGOs, and large companies such as Total. In the first few sessions, the games resulted in the transformation of remarkable habitats, a decrease in forest cover, and an increase in conflicts with local populations, which led the players to realize the complexity of the SES. The sessions that followed led to better management of the three pillars of sustainable development (ecological, economic and social) through the implementation of collective actions by the players.

Figure 2: Photo of a MineSet workshop

MineSet is thus a role-playing game that, as one participant said, becomes "a decision support tool in the choices that must be done for an investment project”. However, the game can have other applications. At the Forest Stewardship Council (FSC) in August 2017, the role-playing game and its debriefing helped to unblock discussions that had been stalling for two years. The different members of the FSC could not find a common agreement to define regional indicators for the management of intact forest landscapes in forest concessions. At the end of three days of play, stakeholders were able to reach a common position that serves as the basis for redefining the rules for managing forest concessions.

Thus, the ComMod approach in which the MineSet game is based can be used both as a decision support tool and as a mediator to assist in dialogue and collective decision-making.

b) The interest of digitizing MineSet

Hereafter, we will refer to role-playing for the MineSet version with a physical board and to hybrid simulation for the computerized version. In reality, these two terms could be used for both situations, but for clarity sake they will be distinct.

It should be recognized that role-playing and simulation are similar. They share the same conceptual model and their main objective remains the same: to bring together actors around a socio-environmental issue in order to establish a dialogue, to better understand the interrelationships and complexity of the TRIDOM SES and to help in collective decision-making. We can compare the photos in figures 1 and 2 and notice that globally the actors are around a board whether it is physical or digital.

Nevertheless, the transition to a computerized version offers certain advantages. Five main advantages can be listed: 1) rapid calculation of resource dynamics and thus the possibility of long-term simulation; 2) calculation and display of social, economic and environmental indicators, as well as individual indicators; 3) diversity of spatial visualizations (surface, mining area, concessions, etc.) and their automatic updating; 4) recording of participants' decisions; 5) recording of games for replay during debriefing phases. In addition to these five advantages, which are valid for any computerized game, another advantage of the digitized game is that it can be easily copied and exchanged between different organizers, which is more complicated for a board game with its counters, maps, and so on (although in both cases a user manual is necessary).

c) Why an agent-based model of MineSet

If the initial objective of this internship was to computerize MineSet, it was necessary to choose which form of computer simulator was the most suitable. Keeping in mind that MineSet must above all keep its role-playing spirit, it turns out that agent-based modeling seems to be the most appropriate for this kind of exercise. O. Barreteau (2003) has highlighted the parallels between agent-based models and role-playing games: agent ↔ player, game turn ↔ time step, game board ↔ spatial grid, simulation ↔ game session. In a way, one can consider the role-playing game as a life-size agent-based model. Thus, due to these strong similarities, it is more natural to transcribe the role-playing game into an interactive agent-based model.
The original position we have taken with MineSet is to be able to free ourselves from the interactive game (also called hybrid simulation of the "Computer-Controlled simulations" types according to Crookall et al., 1986), in order to carry out strategy prospecting. Thus, a MineSet simulation can be autonomous, like a simple classical simulation of the "Computer-Dependent" type. Moreover, this option also allows participants to play MineSet even if there are missing players. In this case, the missing players are replaced by autonomous agents. This is a true hybrid simulation in the sense of Le Page et al. (2010).

II. The digitization of the MineSet role-playing game

1) Why CORMAS?

Moving from a physical role-playing game to an interactive computer simulator requires significant adaptations. For this exercise, the choice of an agent-based model platform is not without consequence. After analysis of existing tools, three platforms proved to be good candidates: CORMAS, GAMA and NETLOGO. Several discussions with the internship supervisors led us to select CORMAS. The reasons for this choice are based on both technical and circumstantial benefits.

CORMAS (for "Common-pool Resources and Multi-Agent Systems") is an agent-based modeling and simulation platform dedicated to renewable resource management (Bousquet et al., 1998, Bommel et al., 2015). As a free and open-source software, CORMAS is used by an international community of researchers willing to study the relationships between societies and their environment. As explained in Le Page et al. (2012), CORMAS occupies an original and dynamic place among existing platforms: interactive simulation. Its developments have fostered the strengthening of the ComMod community interested in collective model design and participatory simulation.

A first difference between the selected platforms concerns the way of coding. On the one hand, GAMA and NETLOGO (both based on Java) use a classical scripting language. On the other hand, CORMAS uses Smalltalk, a "pure" and dynamic object-oriented language with a simple syntax (subject-verb-complement form). Even if at first sight it can discourage some people who already have some knowledge of classical programming, Smalltalk seems more intuitive and accessible for beginners in computer science.

But one of the big advantages of Smalltalk is its flexibility once the simulation is launched. Indeed, it is possible to modify the behavior of an object without having to restart the simulation ("edit and continue" method as opposed to "edit, compile and run"). This aspect is very close to the role-playing game and is much more complex to achieve with GAMA or NETLOGO. This flexibility also makes it possible to check the consistency of a code and to modify it on the fly, which is a big advantage when developing a prototype.

Moreover, CORMAS offers tools that allow us to interact directly with a simulation by adding new elements (such as a token), by destroying or moving an object, or by asking it to perform an action (by sending a message). These possibilities are the basis of the MineSet role-playing game (non-computer version) and would have been much more complex to realize on the two other platforms which are not designed for such interactions.

We chose CORMAS because MineSet's objectives fit exactly into its domain. GAMA and NETLOGO offer other undeniable advantages, such as better connectivity with GIS or 3D management for the former, and simplicity and efficiency for the latter, which offers many modules and has the largest user community.

This work is not my first experience with agent-based modeling. During an internship in Australia, I was led to use GAMA which showed its efficiency to simulate water flows on a large territory. Although this experience was very positive and it is time-consuming to learn a new language, the advantages offered by CORMAS convinced us to use this platform.

In addition to the technical aspects, the choice of CORMAS was also based on more circumstantial considerations. Anne Dray, one of my supervisors, already knows and uses CORMAS. Moreover, being located at CIRAD, it was easier for me to get help from the members of the SENS research unit who develop and manage CORMAS. The learning of this platform was thus facilitated and the communication with my supervisors was simpler.

2) The MineSet rules

The first part of my work was to conceptualize the current rules of the MineSet game using the UML formalism (for Unified Modeling Language, OMG), a graphical object modeling language. The modeling of the game is based on the reports presenting MineSet at the time of its conceptualization, but also on the exchanges with my internship supervisors because the rules were not all well described. The diagrams below represent a description in UML of the structure of the board game and of part of its rules.

It is from these diagrams, which are more formal, that we can code the computerized game, hence the importance of their realization. Moreover, they facilitated the establishment of a dialogue between my supervisors and me because some of them were not familiar with agent-based modeling in Cormas.

The UML formalism offers several types of diagrams that constitute particular "views" of a model. Thus, class diagrams present the general structure of a model, while sequence, activity or state-transition diagrams reveal its dynamic aspects.

a) General structure of the model

The class diagram in Figure 3 provides an overview of the elements that compose the model, as well as their relationship to each other.

The game model is structured in 3 packages. The first one corresponds to the board and the space (in green). It is composed of 100 hexagonal cells with different roles. Each cell is covered by a land use which can be either urban or forest (depending on its quantity of wood, each forest takes a distinct state). The set of forest cells corresponds to the rural landscape. Some cells are grouped together to form a mining or forestry concession. In addition, each player has his own individual board where he places his tokens and money.

The second package (yellow) is composed of all the tokens. There are the Population, Truck and Road, Resource, Mine, etc. Each resource token is initially placed on a cell, then when it is harvested by a truck, it is placed on the player's individual board.

Finally, the third package (blue) contains the "non-Players" and the players agents who take on the role of companies (up to 9 players in total). After acquiring their concession, these players (who specialize in either logging or mining companies) use their means of production to harvest, build, trade, etc. The non-player agents are the markets, NGOs, ministries and others that are managed by the organizer of a game session.

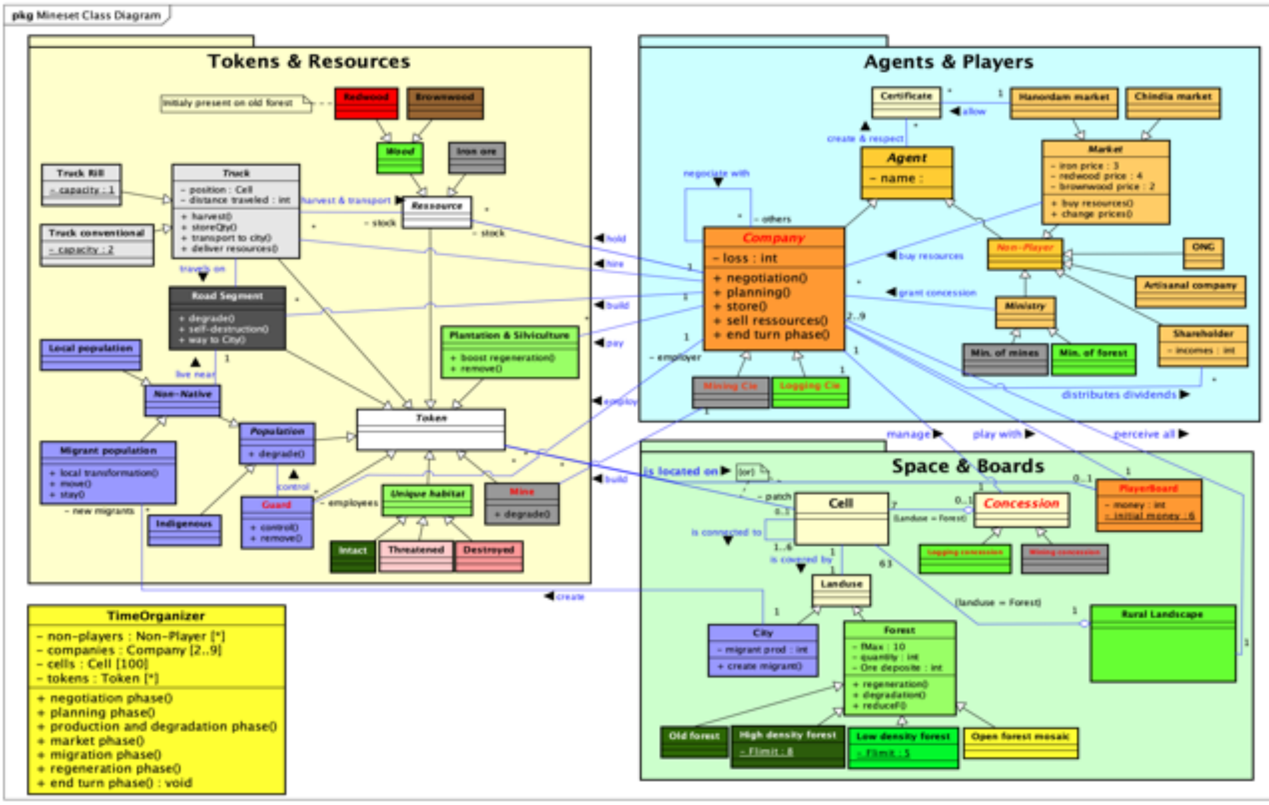

Figure 3: Class diagram of the MineSet roleplay

We therefore understand the three packages that this game explores: the social dimension (with companies, NGOs and other non-players, but also populations and guards), the environmental dimension (with the more or less degraded forest cover and the wood resources they provide, as well as the “unique habitats” for rare species), and the economic dimension, which can be guessed here with the prices of the resources determined by the markets and the establishment of mines to extract the minerals.

This class diagram provides a broad overview of the role-playing game structure and the underlying model with the companies representing the players as the main class. Their actions have impacts on all 3 dimensions of the game. For example, setting up a truck allows players to harvest resources and get rich, but this is done at the expense of the environment which is degraded.

In addition to the 3 packages, a particular entity is presented: the *TimeOrganizer* which corresponds to the game master in charge of organizing the progress of a simulation. It does not dictate to the entities the actions to be carried out but only specifies the phases of each game turn.

Even if this diagram is quite explicit, it is often useful to supplement it with a more detailed textual description. It is important to emphasize that this diagram, which, all in all, is not very complicated to understand, nevertheless required a lot of work for its elaboration with many interviews with the game designers in order to make it both complete and as concise as possible.

In its structure, the computerized version is very similar to the board game: the subjacent models are similar. The main difference lies in the Company agents (Figure 4).

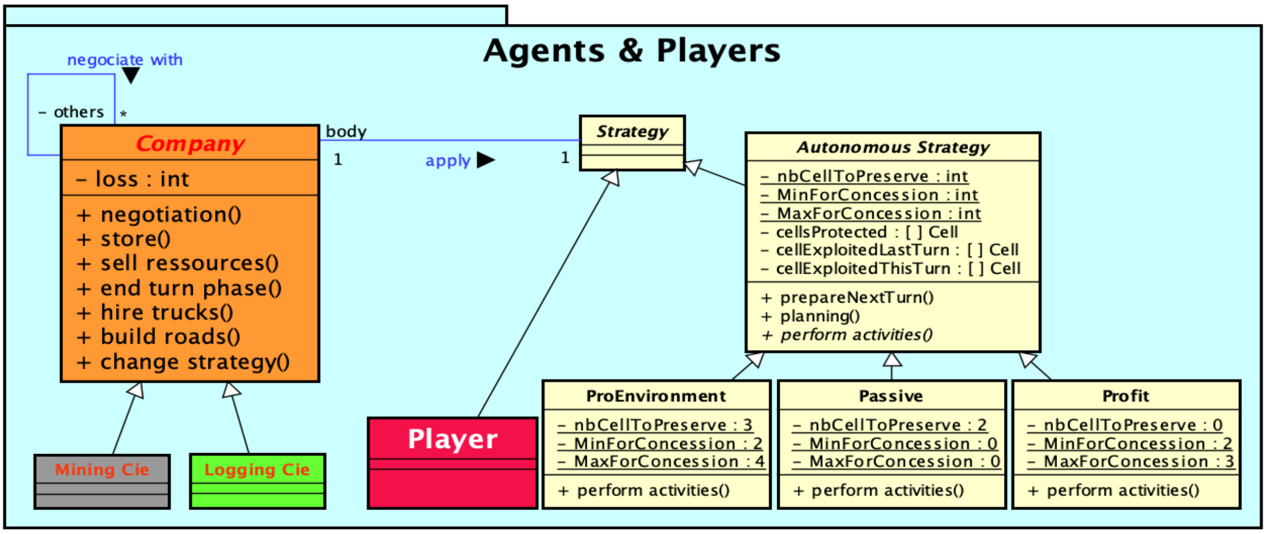

Figure 4: Class diagram of agent-avatars

The computerized game must be able to be used with a variable number of participants. The players assume the role of a forestry or mining company. In order to enhance the flexibility of the computer game, a new class has been added: *Strategy*. Thus, the company agent is artificially separated from its decision system. This artifice, called the "Actor-Role pattern" by Coad et al (1995), reifies the notion of role2. The addition of this class gives any agent the ability to change strategy during the game and to be played by a real person or to become autonomous at any time (by using the *changeStrategy* method). The Strategy class specializes in 4 subclasses: the *Player* which becomes the avatar of the real player of the board game and three other autonomous classes: *Profit*, *Passive* and *ProEnvironment* which are entirely managed by the computer. These strategies differ in the way they organize actions (the perform_activities method is different for each type of strategy[3]), but also regarding the spatial cells that the agent decides to preserve.

Finally, it should be noted that in the digital version, the timeOrganizer, which is the conductor of the game, takes care of the order in which the actions are performed. For the computer version, the orchestration is no longer managed by a person (the facilitator), but by this entity (also called Scheduler in the ABM world).

b) Sequence of a game turn

The UML sequence diagram in Figure 6 helps to better understand the organization of a game turn. Indeed, in agent-based modeling, the simulated time is often managed by a step-by-step system. For

[2]The endpoint of an association between classes in UML is a role that specifies how an entity is perceived by others. For example, for the association "hold" between the classes Company and Resource, the instances of Resource can play the role of stock with regard to Company. However, object-oriented languages are dedicated to the treatment of objects that do not change their type over time. But when we are interested in the representation of humans or animals that can evolve, transform and change their behavior during their life, it is useful to aggregate the concept of agent into a set of closely related classes. P. Coad's Actor-Role pattern reifies this notion of role in order to associate a specific behavior to the agent playing this role, but also to allow it to change its role (and thus its behavior) over time. The class diagram of figure 4 shows an example of this pattern where the role is replaced by the strategy which is not a simple label but which implies a specific behavior of the company which can modify its attitude over time according to its local environment. Moreover, the use of this pattern encourages polymorphism which facilitates the management of the code and the future evolutions of the model.

[3]This principle is called "polymorphism" in object modeling.

MineSet, a step is equivalent to 10 years. As a game should last approximately 50 years, five rounds of play are usually performed.

Since the dynamics of the game must follow a certain logic, it is important to organize the different phases and activities of a game turn. For the purpose of readability, it should be noted that the step in Figure 5 does not represent all possible actions, but only one simple scenario among others.

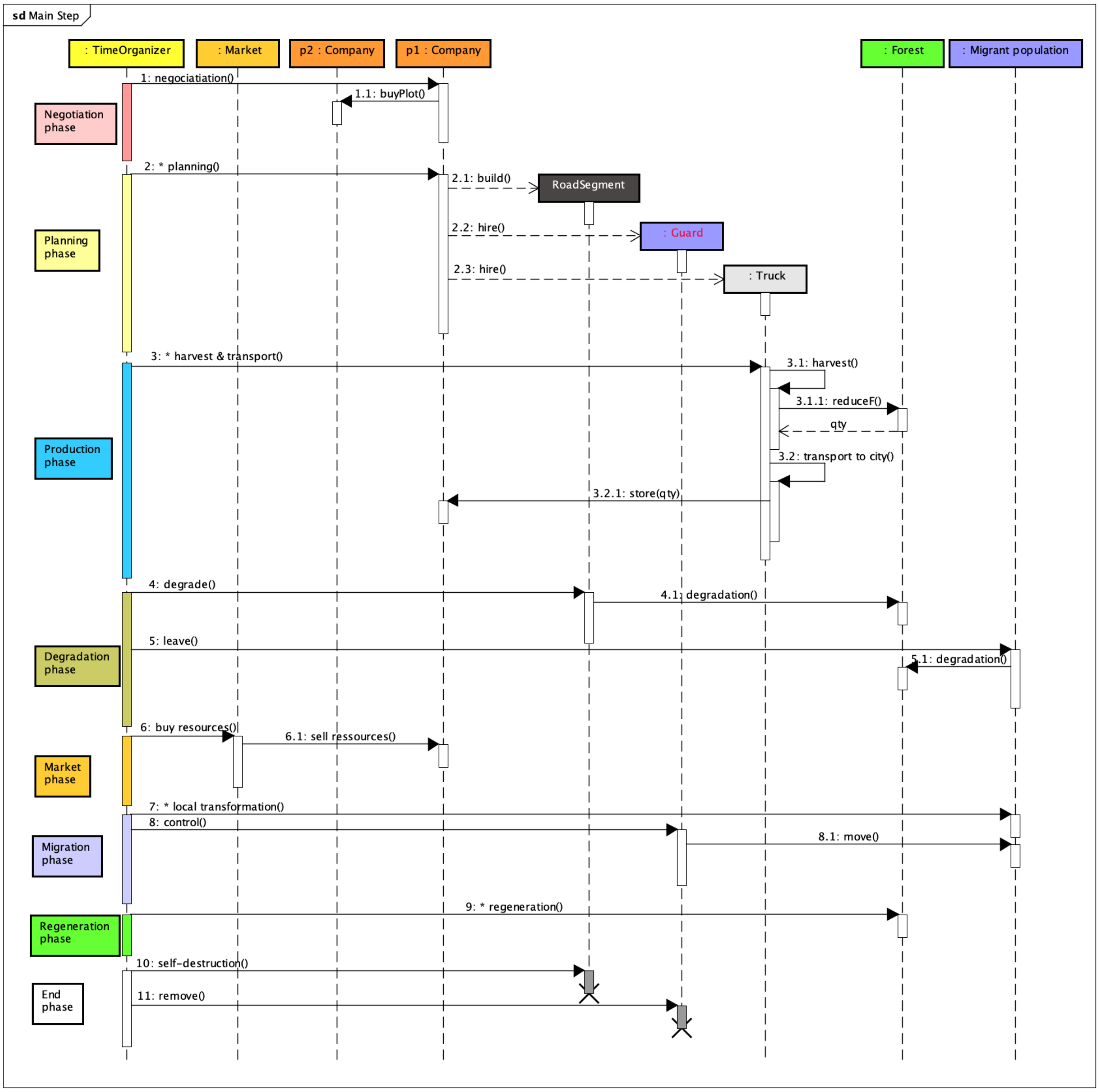

Figure 5: UML sequence diagram of a MineSet game round

As explained before, the timeOrganizer directs the order in which the actions are arranged. The first phase corresponds to a phase of discussions and exchanges between the players. This is the essential phase of the game where the players negotiate and coordinate. For the digital version, it corresponds to the break between two rounds. This phase is followed by the application of decisions which are concretized by the distribution of the various tokens by the players. All the following phases are automated. Thus, the trucks collect the local resources and bring them back to the companies (economic and ecological aspect). Then a market sale phase is executed, in which the companies sell their resources and earn money (economic aspect). Next, a migration phase occurs during which people move and settle on the landscape (social aspect). During the regeneration phase, new resources are created (ecological regeneration). Finally, the end-of-turn phase enables final adjustments and prepares the next turn.

c) Activity diagrams

The last kind of UML diagrams we used are activity diagrams. They are generally made to represent the behavior of an entity by the succession of actions and by decision points (diamonds and conditional guards). These diagrams make it possible to visualize behavioral patterns and to identify the moments when a decision may cause the entity to move towards one path or another. The following section presents these diagrams describing the behaviors of the three strategies.

These diagrams can also be more detailed in order to be closer to the computer code. This is the case of the diagram below which presents the general activity of a truck (Figure 6).

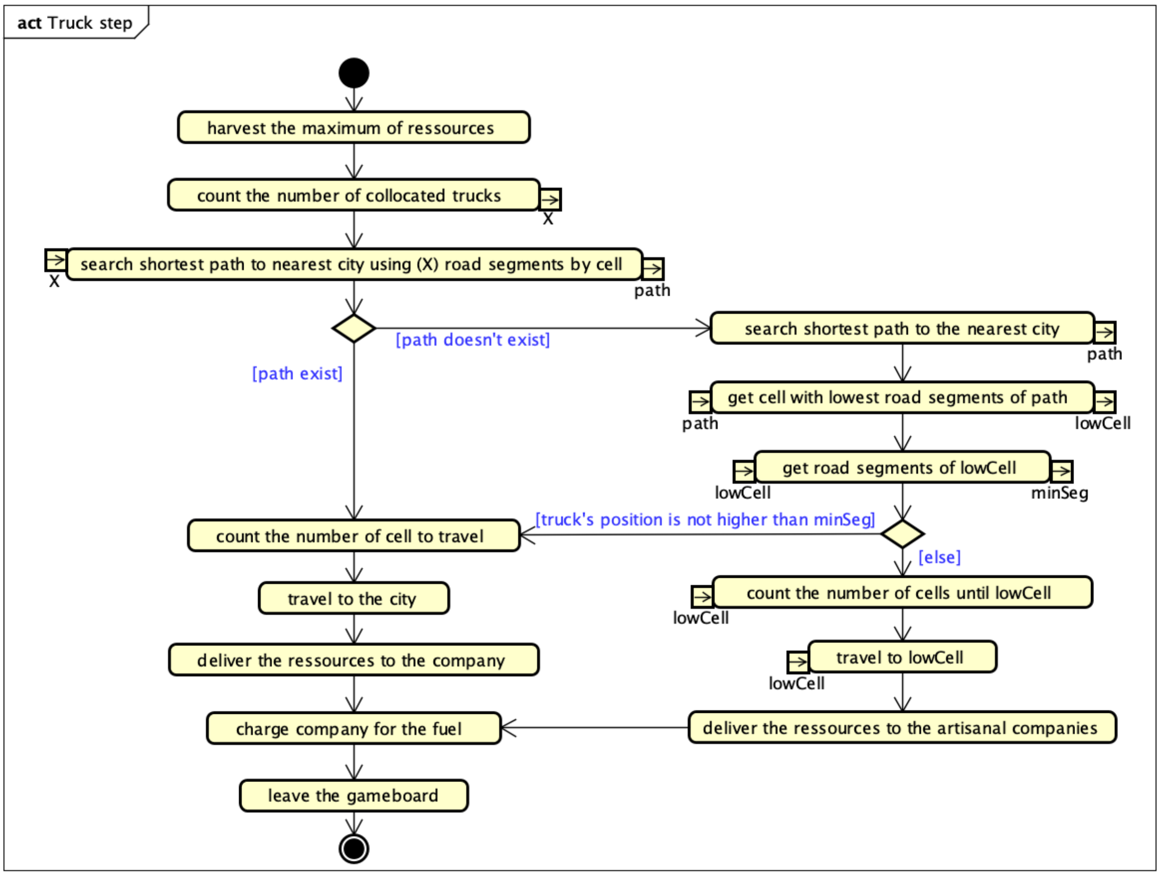

Figure 6: MineSet truck activity diagram

The objective of this diagram is to explain and formalize the movement of the trucks that are responsible for bringing the resources to the company. To do this, they must go to the nearest town. The difficulty is that there must be enough roads for them to get to their destination. Two situations arise: one where everything goes well and the trucks arrive in town to deliver their products to the company that employs them, or where trucks get stuck on the road and lose their loads (which are then picked up by a local craftsman). Both of these situations are explicitly shown in this diagram.

3) Implementation of the digitized game

From these different diagrams, it was easier to translate them into computer code X. This implementation was done on the Cormas platform by coding the classes and methods in Smalltalk (VisualWorks). To learn this object-oriented language, I used the teaching material proposed on the Cormas website as well as the Smalltalk books freely available on the website of S. Ducasse (http://stephane.ducasse.free.fr/FreeBooks.html).

This section gives a visual overview of the digitized MineSet game with the graphic tools that were used. It also presents the three autonomous strategies.

a) Presentation of the digital MineSet

The most important graphical interface of MineSet presents the game board (spatial grid) with the tokens located on it. Figure 7 shows this visual at the beginning of step 1.

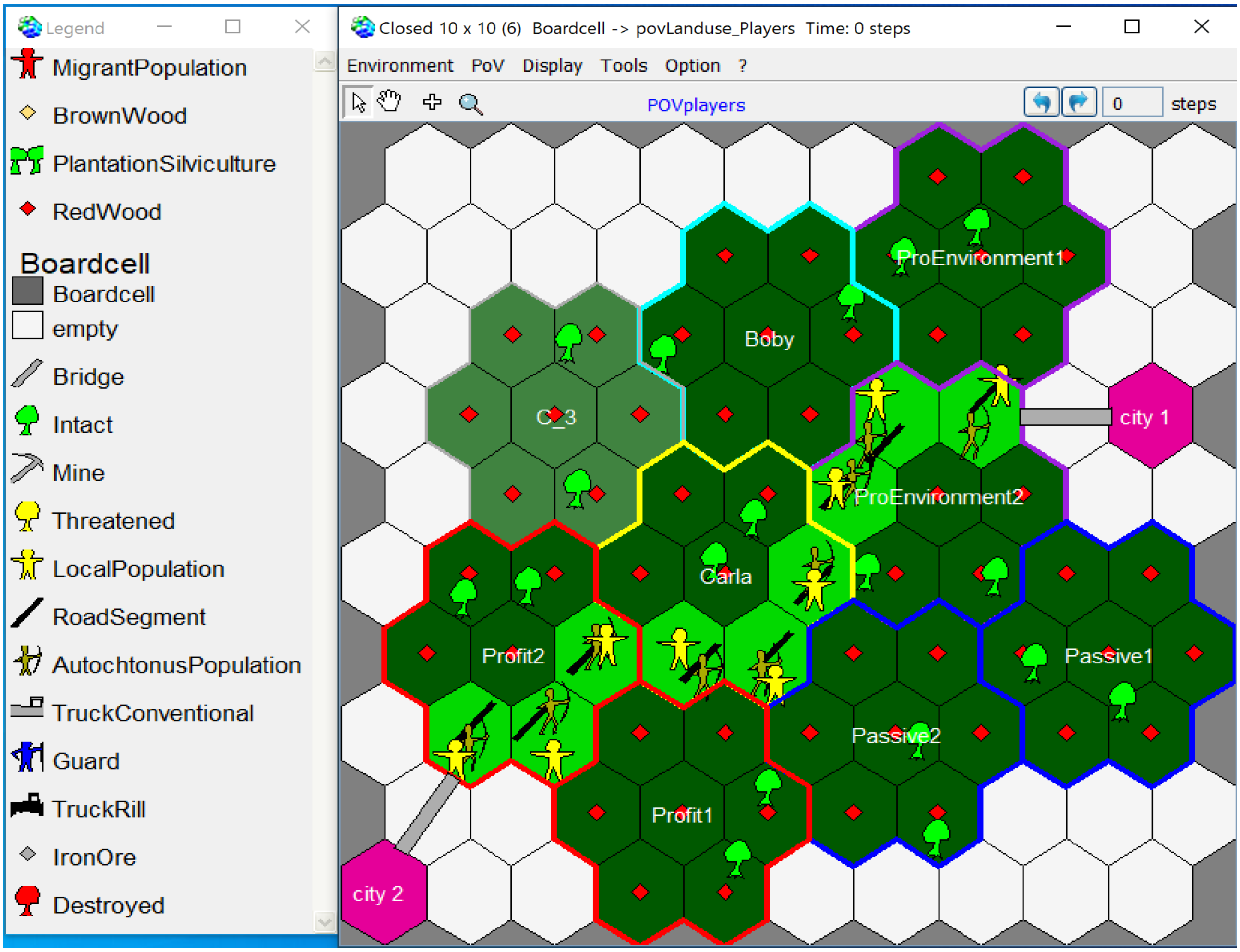

Figure 7: MineSet's numerical board in Cormas. In this example, 2 concessions belong to players, 6 belong to autonomous agents and one (C_3) is not affected.

This spatial grid is very similar to the physical game board as shown in the first section (see Figure 2). The game squares are instances of cells ("Cell" in the class diagram, Figure 3). The white squares are out-of-game; the pink ones are the cities; the others form the rural landscape. For these, the shade of green reflects the amount of forest in each cell. There are also groups of seven cells in clusters that form forest concessions recognizable by their thick outlines. Each concession displays the name of the player with whom it is linked. The color of the border is the same as the color assigned to the player when the game is initiated (Appendix 2). Concessions that are not occupied by players or agents have a duller color (e.g., C_3). Finally, this grid also shows the initial configuration of the map where a road from one city to another is drawn. It is represented by black sticks that symbolize road segments. All the way along, this road is occupied by local and indigenous populations. This interface presents all the data of the tokens on the board (owner of a truck, quantity of forest on a square, etc).

The manipulation of the tokens by the players is done by tools. Thus, a click on the "+" button at the top right of the grid allows the player to add tokens that the player places with the mouse on the board. It is also possible to exchange concession areas with other players. Figure 8 shows two tools: the first one to add new tokens to the grid and the second one to manipulate the entities by sending them messages.

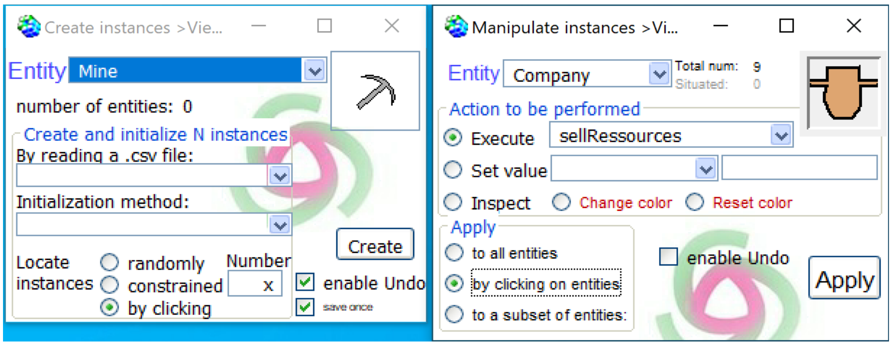

Figure 8: Two tools to create and manipulate counters

In order to follow the evolution of certain numerical indicators, probes' interfaces can be displayed at any time and it is possible to select the desired indicators (Figure 9).

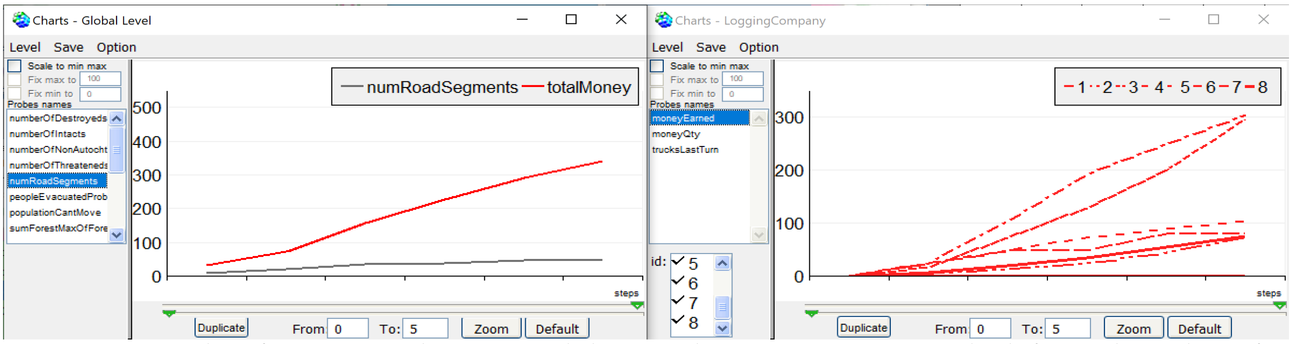

Figure 9: Graphs of MineSet indicators and their evolution over time. On the left, total number of roads and money supply; on the right, money per agent.

It is through this view that all the indicators of interest can be followed. CORMAS offers the possibility to show the global variables (such as total quantity of wood, monetary mass...) but also the indicators of each instance.

b) The different strategies

In order to be able to play MineSet even without nine players, this digital version proposes to replace the missing participants by autonomous agents. In order to simulate their behaviors, we have defined three strategies aiming at transcribing player archetypes. However, it should be noted that these strategies remain automata with stereotyped behaviors offering little flexibility. The following sections present the functioning of these strategies. They will be followed by the analysis of the results in chapter IV.

1. The "Profit" strategy

The activity diagram in Figure 10 describes the behavior of an autonomous agent managing his dealership by trying to maximize its profits.

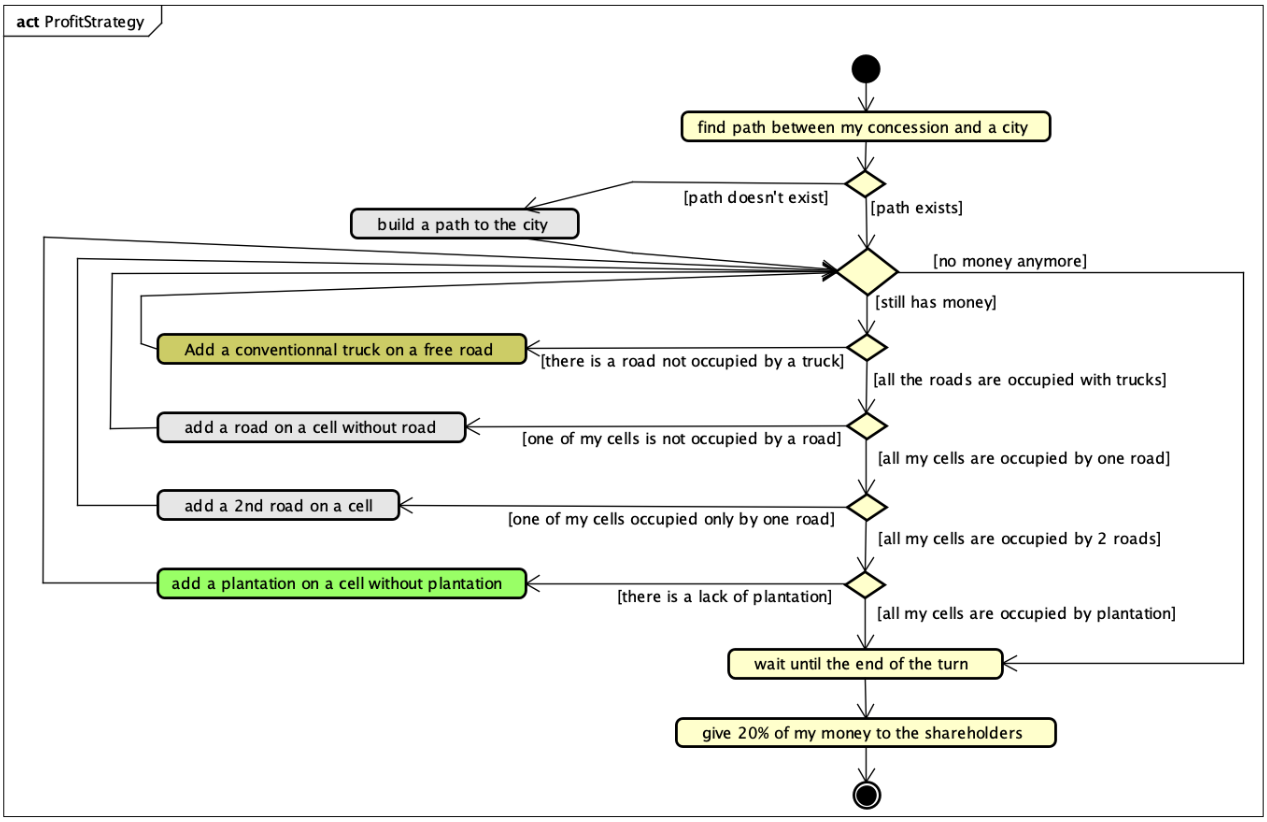

Figure 10: Activity diagram of the "Profit" strategy (colored activities correspond to concrete actions on the game)

This strategy aims to set up as many trucks as possible in order to harvest as many resources as possible. Focused only on its own profit, it has no consideration for environmental aspects. It is a short- and medium-term strategy with, at best, the establishment of plantations to produce a maximum of wood. It is also a strategy that invests heavily at the beginning of the game to acquire a concession that is easily accessible from a city and that borrow to make large investments quickly.

2. The "ProEnvironment" strategy

The activity diagram in Figure 11 describes the behavior of an autonomous agent that manages its concession while trying to protect the forest as much as possible.

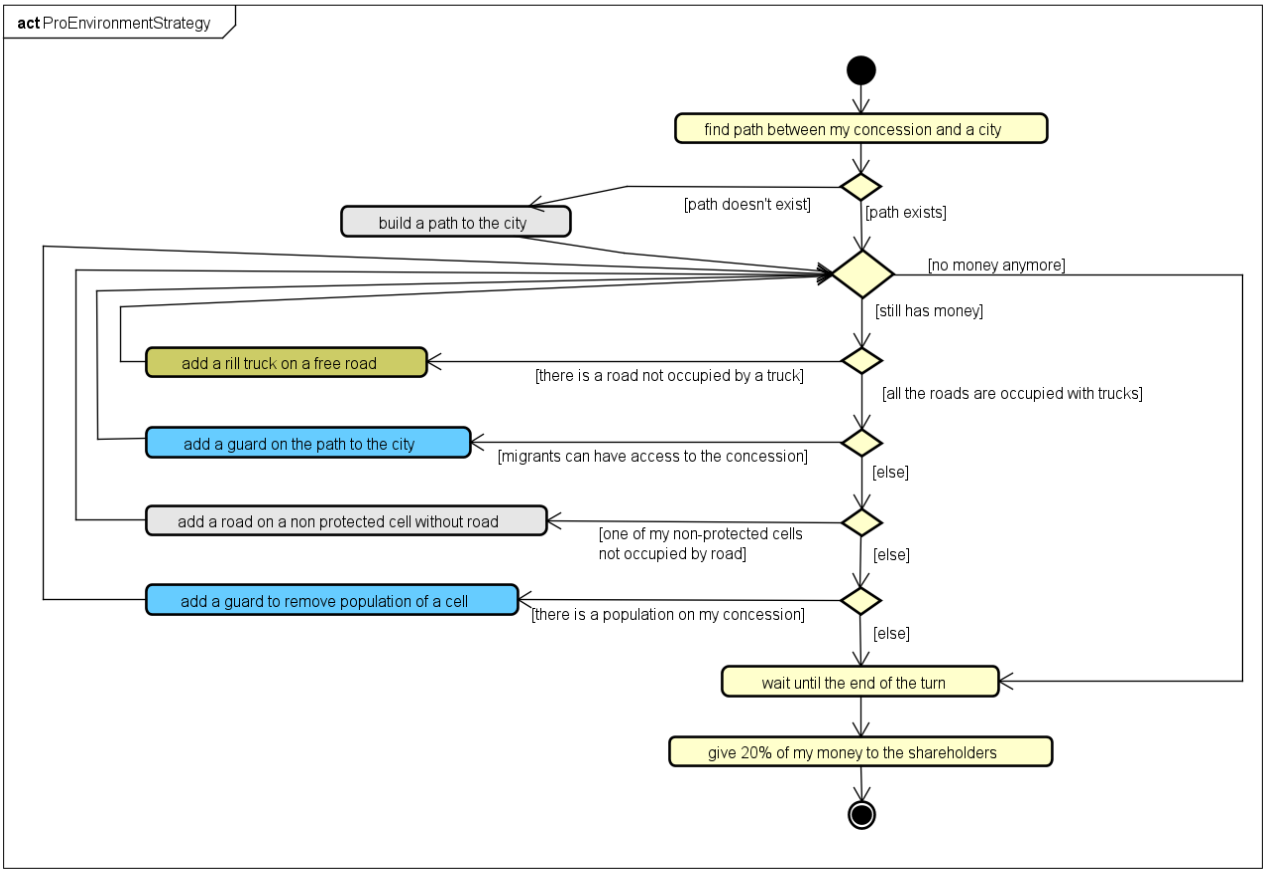

Figure 11: Activity diagram of the "ProEnvironment" strategy

Unlike the previous strategy, this strategy prioritizes the environment above all. For this reason, it will not exploit some of the cells of its concession (nbCellsToPreserve = 3, see Figure 4). In addition, it prevents populations from settling in its concession and potentially degrading the forest. Secondly, this strategy foresees to take only a limited amount of wood that will regenerate during the turn. The company thus carries out rather small extractions. Finally, the company takes the risk of investing to gain access to a central concession in order to protect the environment as much as possible from other actors.

3. The "Passive" strategy

The activity diagram in Figure 12 describes the behavior of an autonomous agent that manages its concession by minimizing the number of actions.

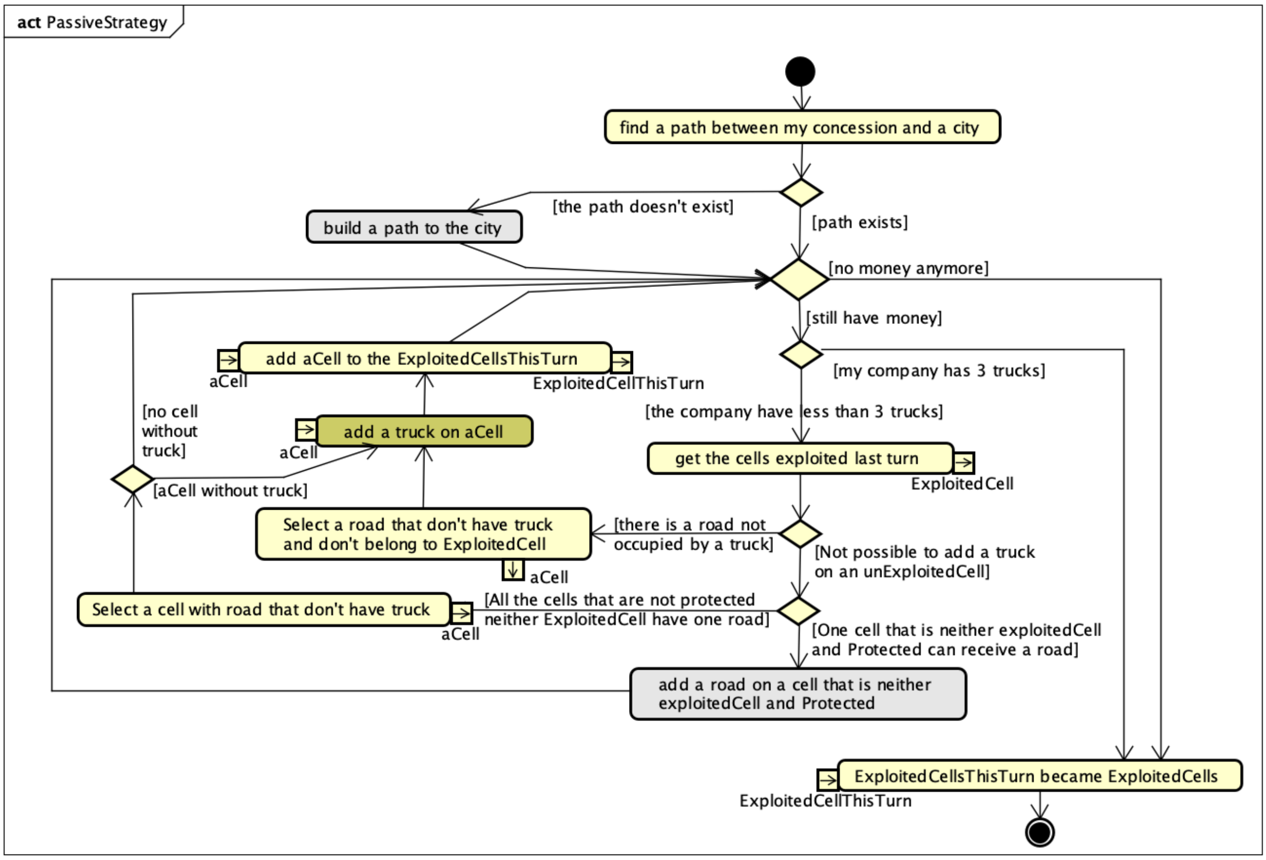

Figure 12: Activity diagram of the "Passive" strategy

Unlike the other two, this strategy aims to reduce its risks and invests as little as possible. It is also a hybrid strategy between environmental protection and personal profit. To do this, it rotates the use of the cells in its concession. To protect the environment, a small part of its concession is not exploited. On the other hand, it does not prevent the population from settling on its concession.

III. Analysis of the autonomous strategies

1) Analysis of each strategy individually

In this chapter, each kind of strategy is analyzed individually. In each case, there are two situations: a single company having access to the whole space without worrying about competition (the "solo" analysis), and nine companies occupying the whole territory with competition for the choice of concession and access to the loan (the "nine" analysis). In each situation, we analyze the three pillars of sustainable development through the game, namely economic (money), social (population size) and environmental (quantity of wood). Finally, all these companies being forestry companies, we also analyze the influence of the price of brown wood in the success or not of the strategy.

a) « Profit » strategy

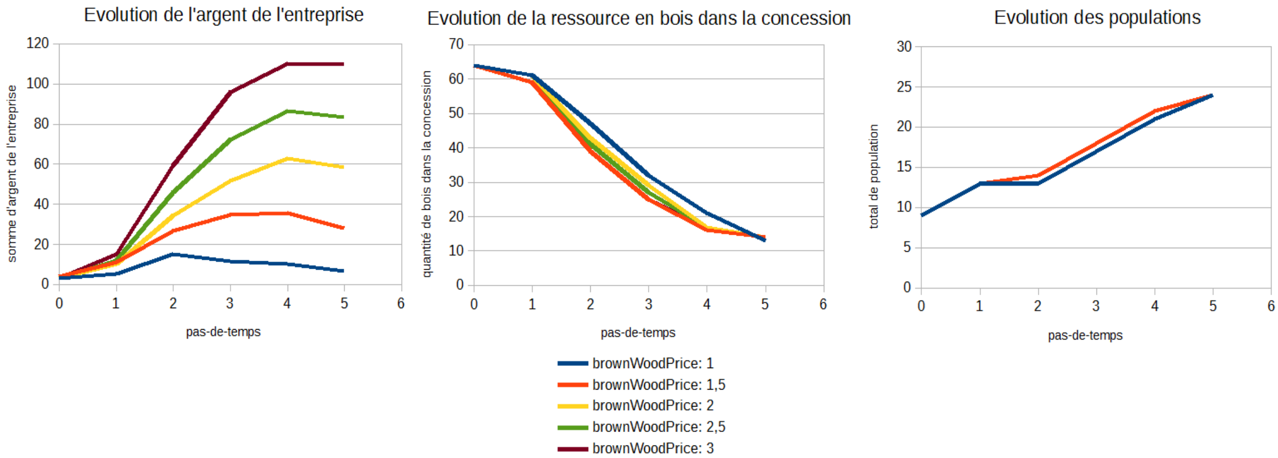

Figure 13: Graphs of the Profit strategy with 1 agent

Figure 13 shows that the Profit strategy tries to maximize money gains over the short and medium term. We note a gain of money over the first 30-40 years (as a reminder, a time step is equivalent to 10 years). However, after a while, we notice a stagnation or even a drop in the money income. This can be explained by the second graph where we see that the available resources drop drastically. Indeed, at the end of the simulation, the quantity of available wood is exhausted and the forest does not have time to regenerate (at each turn the quantity of wood is regenerated until 14 units, but this limit is reached and exceeded). Finally, from a social point of view, the migrant populations can settle in the territory, although with only one company, the space is small (only 7 cells), which limits their settlement.

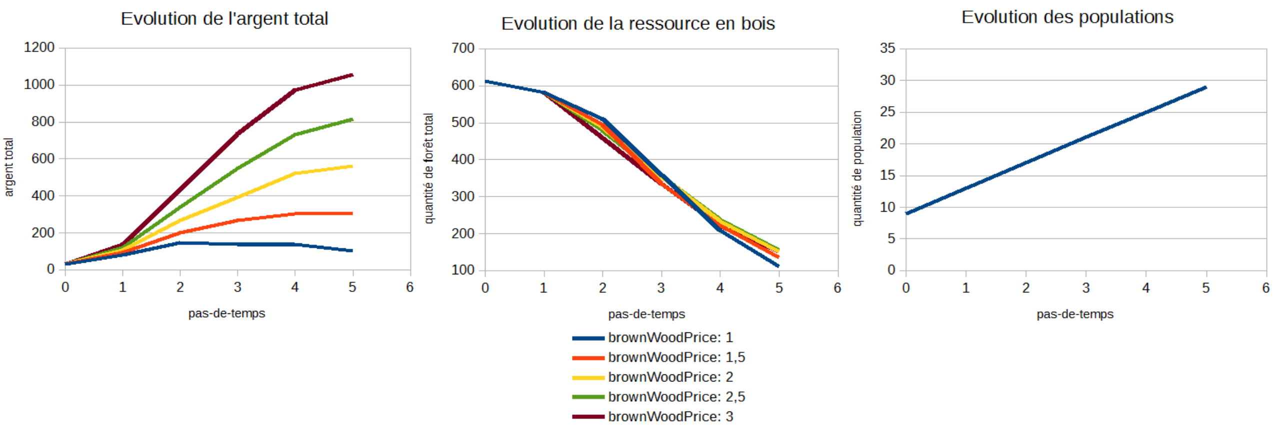

Figure 14: Graphs of the Profit strategy with 9 agents

These trends are also found when the number of companies is higher (analysis "nine", figure 14). The following graphs have the same structure as the three previous ones. However, two interesting elements can be noted. First, all the migrant populations manage to settle in the territory, which is much larger. The second is the influence of the price of wood. We notice that when the price of wood is very low, the quantity of wood still available is even lower. This is due to the fact that some companies may not have the funds to try to replant trees.

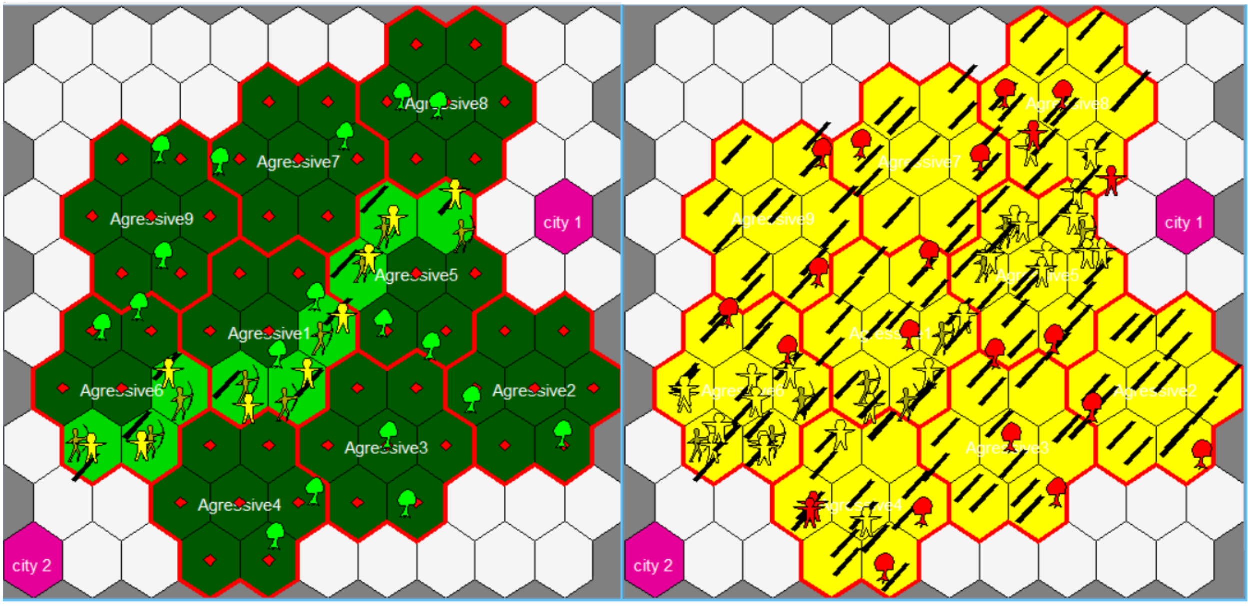

Figure 15: Evolution of the game board with 9 Profit agents; timesteps 1 and 5

We can therefore conclude that "Profit" is a strategy that maximizes its profit in the short and medium time. Populations can settle on the territory but there is no consideration for the environment. This is very visible when we look at the board (Figure 15) where we can see that all unique habitats are destroyed. Moreover, this strategy is globally little impacted by market prices, as the money curves have more or less the same shapes (even with a price of 1 unit per brown wood, the companies get richer).

b) « ProEnvironment » Strategy

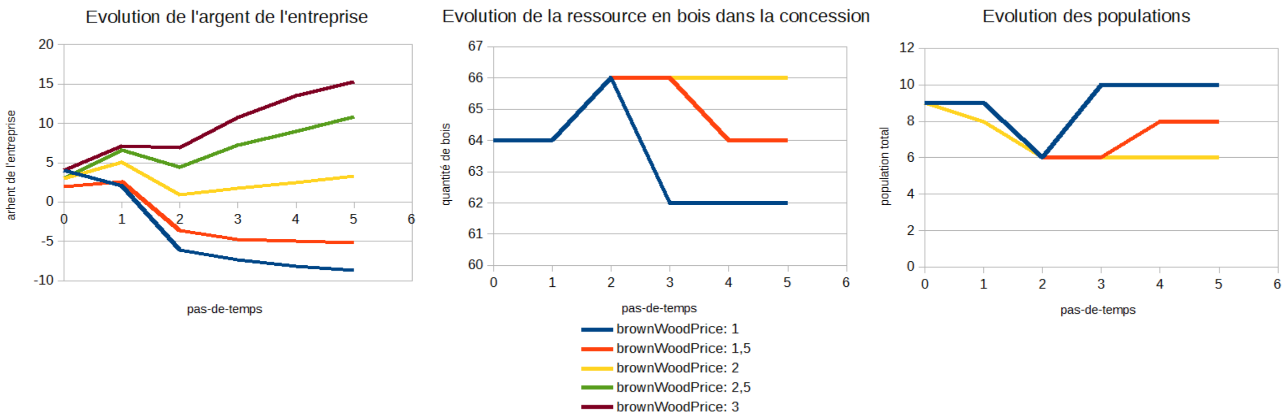

Figure 16: Graphs of the ProEnvironment strategy with 1 agent

For the ProEnvironment strategy, we notice that the graphs in Figure 16 are quite different from those of the Profit strategy. First of all, the market prices have a greater impact on the evolution of the curves. In the case where they are low, the company even becomes unprofitable. It is important to remember that in the "solo" situation, the company is not in competition with other companies. We obtain two situations: bankruptcy and survival. The quantity of trees indicator is lower in the bankruptcy situation. The same is true for the population indicator, because the company ProEnvironnement aims to prevent the installation of populations on the territory (because they degrade the environment). However, when the prices are low, the company cannot prevent their installation.

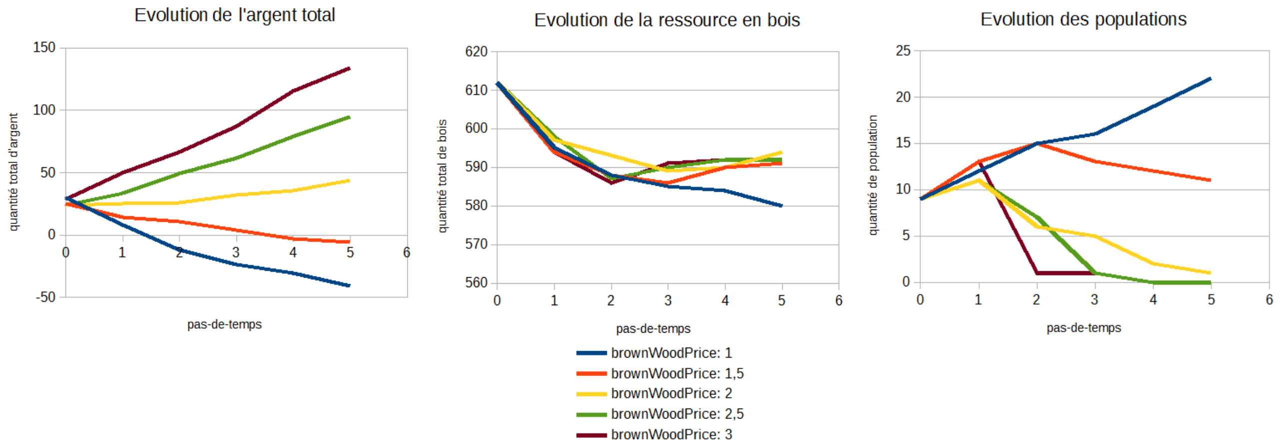

Figure 17: Graphs of the ProEnvironment strategy with 9 agents

With nine enterprises in the territory (Figure 17), these indicators remain similar. When the companies have enough money (price of wood higher than 2), it is noted that they remain profitable in the long term and that the populations are even evicted. As for the total amount of forest, the decrease is explained by the creation of small roads to reach the concessions. This decrease is rather small (20 out of a total of 610, as can be seen on the board at time step 5, Figure 18). Finally, what the graphs do not show, but is visible on the board when the price of wood is 2 or less, is that competition for concessions and access to loans is causing some companies to fall (the 2 concessions at the bottom of the map in Figure 18).

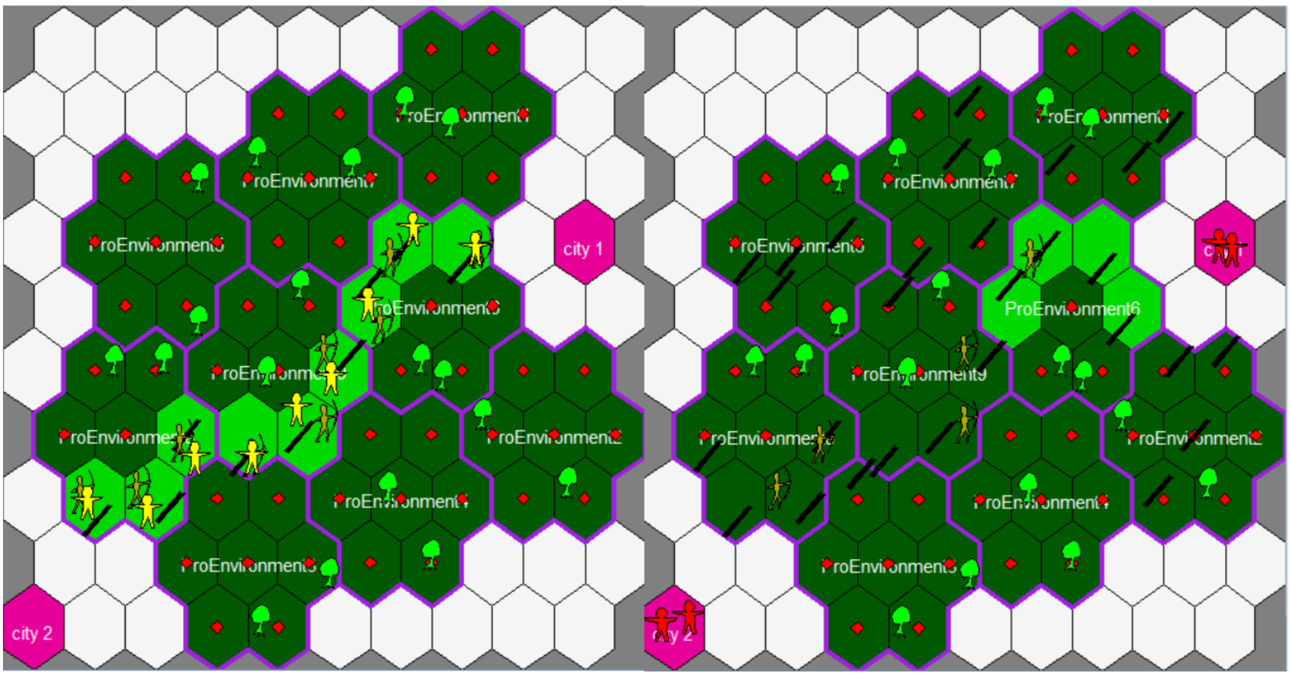

Figure 18: Evolution of the game board with 9 ProEnvironment agents; timesteps 1 and 5

This strategy emphasizes the environment, as its name suggests, but at the expense of the population and even the economy. It is, however, sensitive to falling prices for timber, and some competition may arise between companies, especially for the most attractive concessions.

c) « Passive » strategy

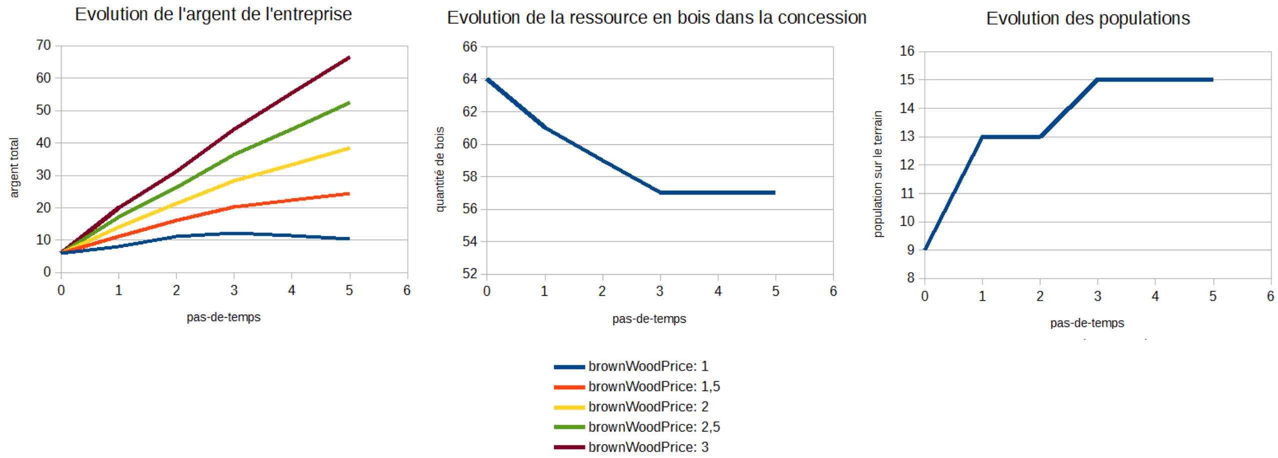

Figure 19: Graphs of the Passive strategy with 1 agent

For the Passive strategy, the graphs in Figure 19 show great stability despite changes in the price of wood. It gains money regardless of the situation (except for the case where the price of wood is 1 unit, where it stagnates). Then, there is a slight decrease in wood that quickly stabilizes. The same is true for the population that enters the territory up to a certain level.

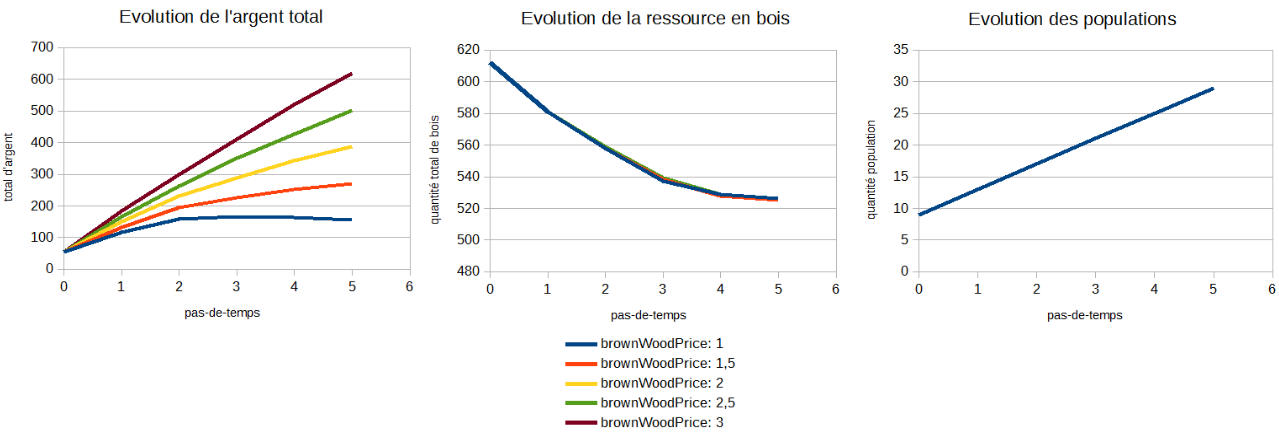

Figure 20: Charts of the Passive strategy with 9 agents

Compared to the situation with one agent, the " nine " analysis (Figure 20) shows very similar curves. However, there is a difference in the quantity of wood, which reaches equilibrium later but remains high. The greatest difference is in the populations that settle on the territory without discontinuity. The last interesting point to note is the spatial configuration (Figure 21): the board is made up of islands of vegetation with forests in good condition.

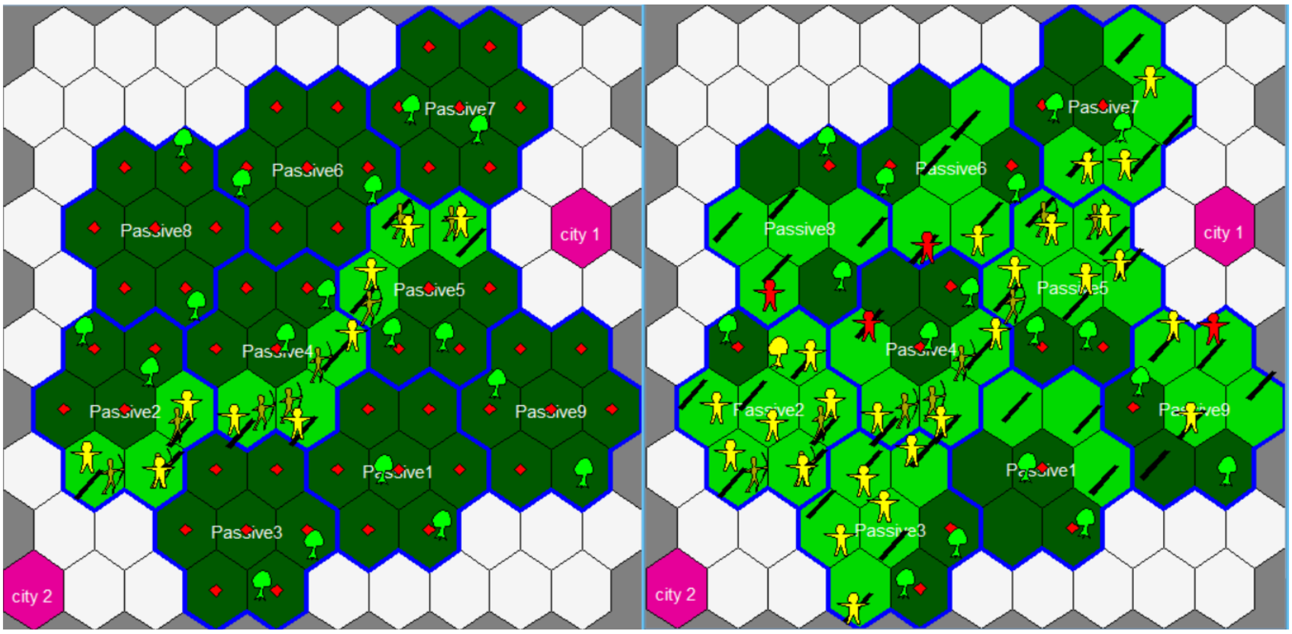

Figure 21: Evolution of the game board with 9 agents Passive; timesteps 1 and 5

This strategy, which invests little and sets up harvest rotations, seems to be a profitable strategy in the short to long time. The quantity of forest is not much lower than the ProEnvironment strategy. Finally, from a social point of view, the installation of new populations is done on the untouched squares, thus without worrying about local conflicts or refusal of access to the territory.

2) Analysis of the gathered strategies

For this analysis, the three strategies are merged, with two different situations: one with a different strategy for a total of 3 companies ("1P1P1P"), and the other with three strategies of each type for a total of 9 companies. In each case, we compare the results between strategy types. They are analyzed first from an economic point of view, then from an environmental point of view and finally from a societal point of view. Each time, 50 repetitions are performed to eliminate random aspects. The following graphs correspond to the average of these repetitions.

a) Analysis with 3 companies: 1 Profit, 1 ProEnvironment, 1 Passive

From the economic point of view (Figure 22), we notice that the curves have the same shapes as for the individual analyses. Same observation for the environmental indicator (Figure 23). However, we note that the overall behavior of the quantity of the wood resource is more similar to that of the Profit strategy. Even the ProEnvironment strategy cannot counteract the decrease in wood resources, regardless of the price of brown wood.

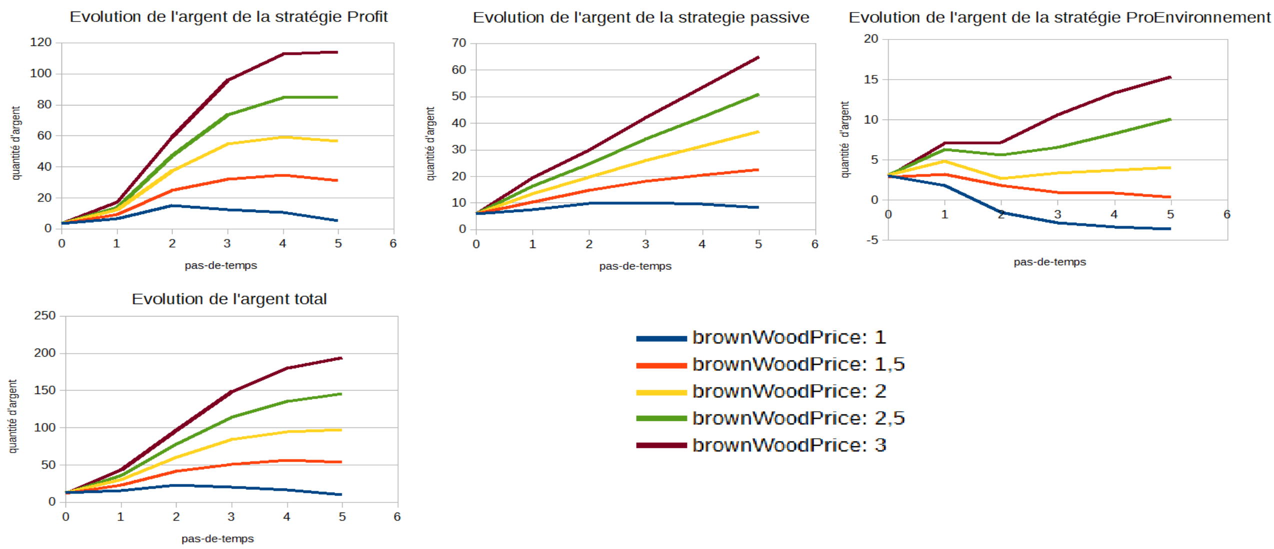

Figure 22: Graphs of the economic pillar; case 1P1P1P; The bottom graph represents the sum of the three strategies

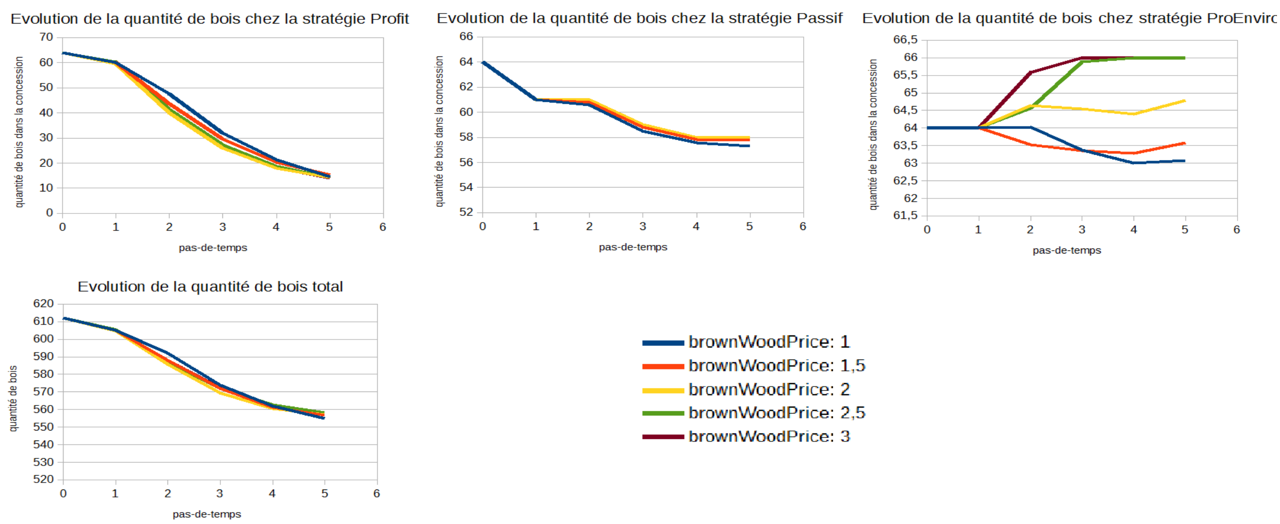

Figure 23: Graphs of the environment pillar; case 1P1P1P; The bottom graph represents the sum of the three strategies

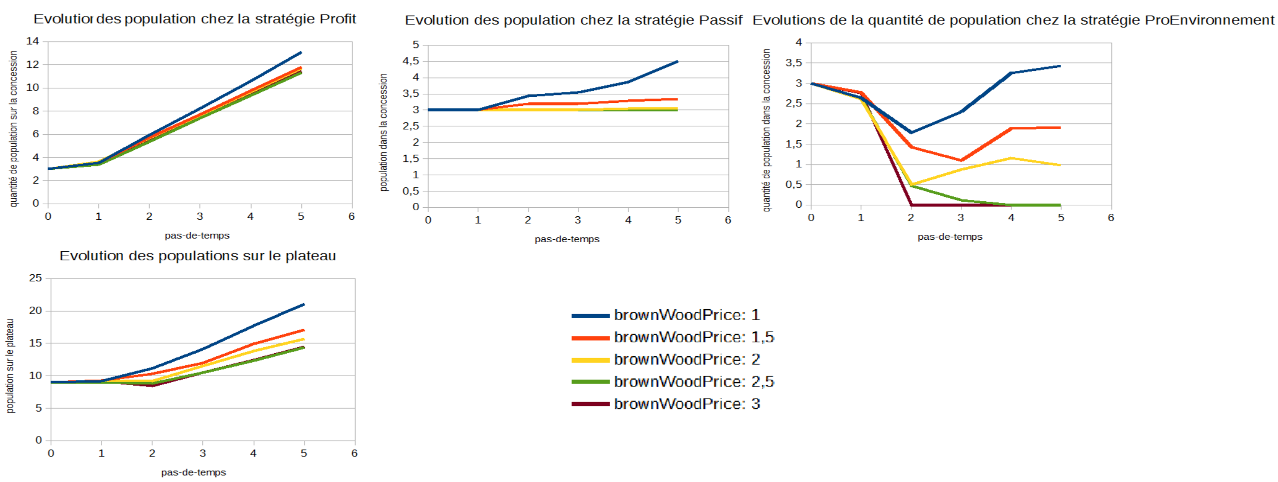

Figure 24: Graphs of the social pillar; case 1P1P1P; The bottom graph represents the sum of the three strategies

A new phenomenon emerges when studying the social aspect (Figure 24). Although the graphs of the Passive and ProEnvironment strategies are similar, the curves of the Passive strategy stagnate. This phenomenon can be explained by the fact that on one side of the concession, the migrants move directly into the concession of the Profit agent and on the other side of the concession, the entry is blocked by the guards of the ProEnvironment strategy (Figure 25). We can see that when the price of wood is 1 unit and the ProEnvironment strategy fails, migrants settle in the territory. But the populations do not settle immediately on the territory. This is explained by the fact that, at the beginning, all the concessions are located on the main road; thus, the agents do not immediately open access for the first migrant populations.

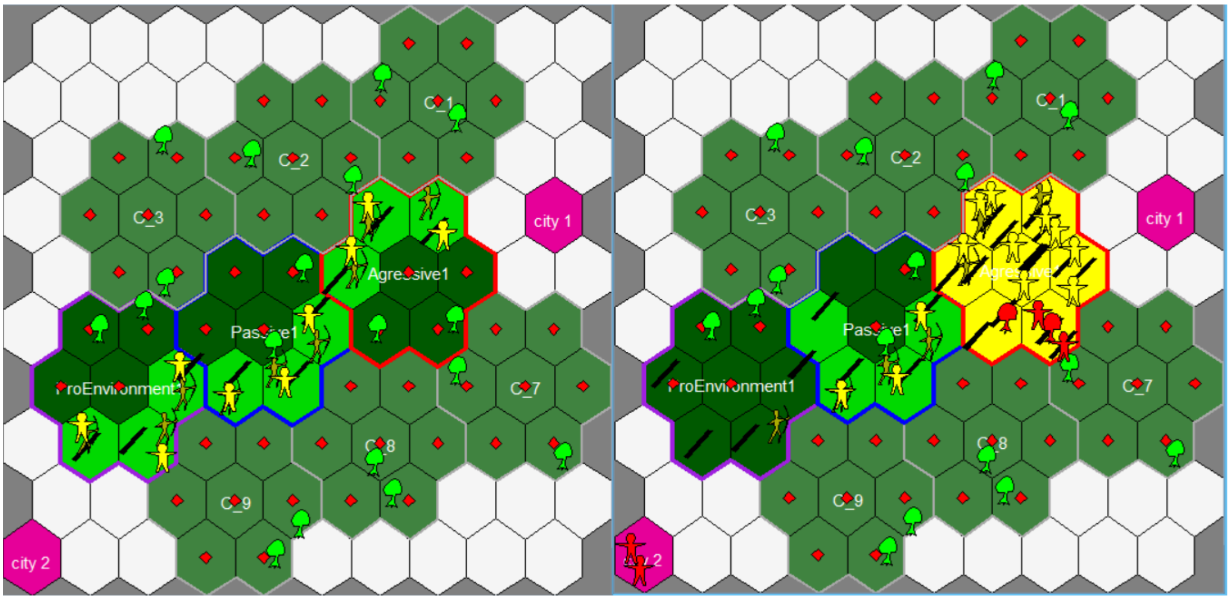

Figure 25: Evolution of the game board with 1P1P1P; timesteps 1 and 5

b) Combined "3P3P" analysis

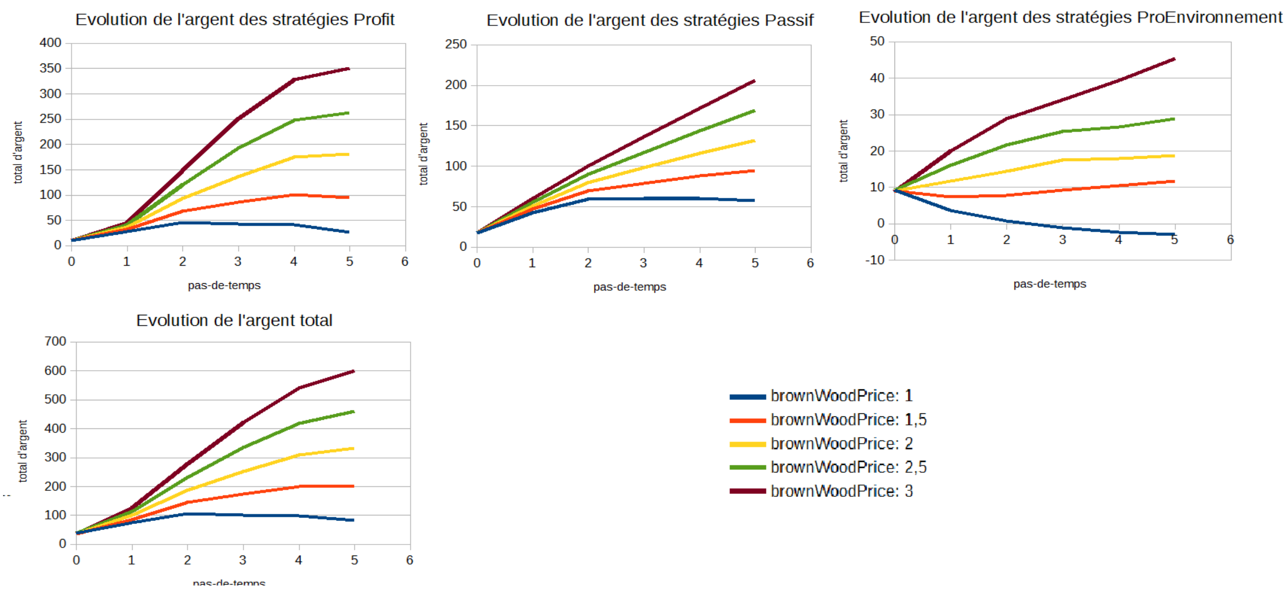

Figure 26: Graphs of the economic pillar; 3P3P3P case; The bottom graph represents the sum of the three strategies

From an economic point of view (Figure 26), even if they are very similar to those of the "1P1P1P" analysis, we notice that the curves of the ProEnvironment strategies are slightly higher. This is especially visible in the case where the price of wood is 1.5. One of the hypotheses is that the ProEnvironment strategies do not have enough money to invest other than trucks to harvest. This is confirmed by the population curves (Figure 29), where we can see that the populations are high while the strategy wants to reduce them: it does not have enough money to hire guards.

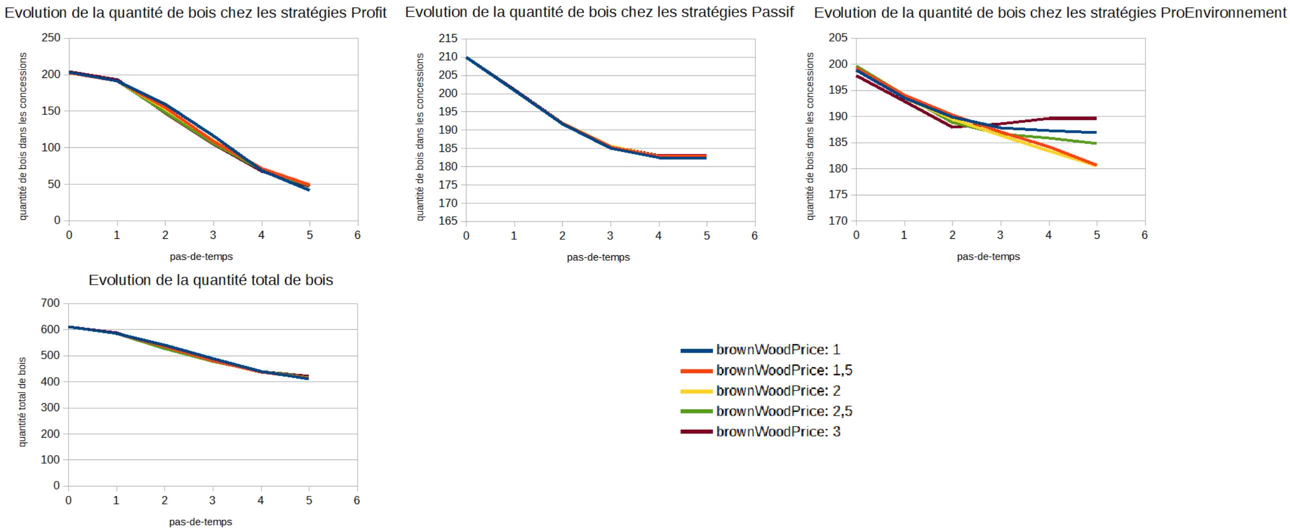

Figure 27: Graphs of the environment pillar; 3P3P3P case; The bottom graph represents the sum of the three strategies

Concerning the "environment" pillar (Figure 27), we also find the same kind of curves as in the "1P1P1P" version. Here again, it is the ProEnvironment strategy that changes. When there are 9 ProEnvironment strategies, the wood resources eventually increase or stagnate (except when the price of wood is 1). But here, except when the price of wood is very high, the quantities of forest are rather decreasing. They are even lower than in the case where the price of wood is 1. This is explained by the fact that the ProEnvironment companies survive by harvesting wood but do not manage to put in place protection measures. In addition, as this strategy invests heavily to take possession of concessions at the entrances to the territory, it is impacted by the Profit strategy, which expands roads to sell its resources in large quantities. This is most obvious when looking at the board (Figure 29).

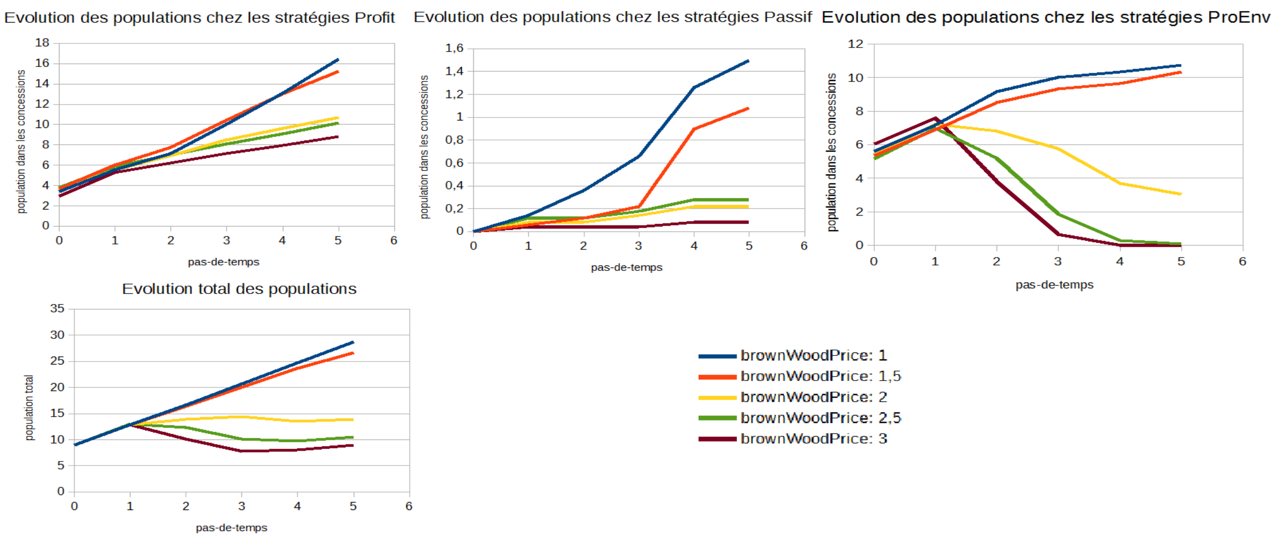

Figure 28: Graphs of the social pillar; 3P3P3P case; The bottom graph represents the sum of the three strategies

Finally, it is especially at the level of the populations (Figure 28) that we see the most changes. Indeed, when the ProEnvironment agents are in a difficult financial situation, the migrants can enter the board. The blue and orange curves show maximum growth (the curves for total populations indicate that all the populations have settled on the plateau). On the other hand, if the price of wood is higher (especially for a price higher than 2), we notice that fewer populations settle on the map. This is due to the fact that the ProEnvironment strategies have the means to control the entry to the territory. This can be seen in Figure 29.

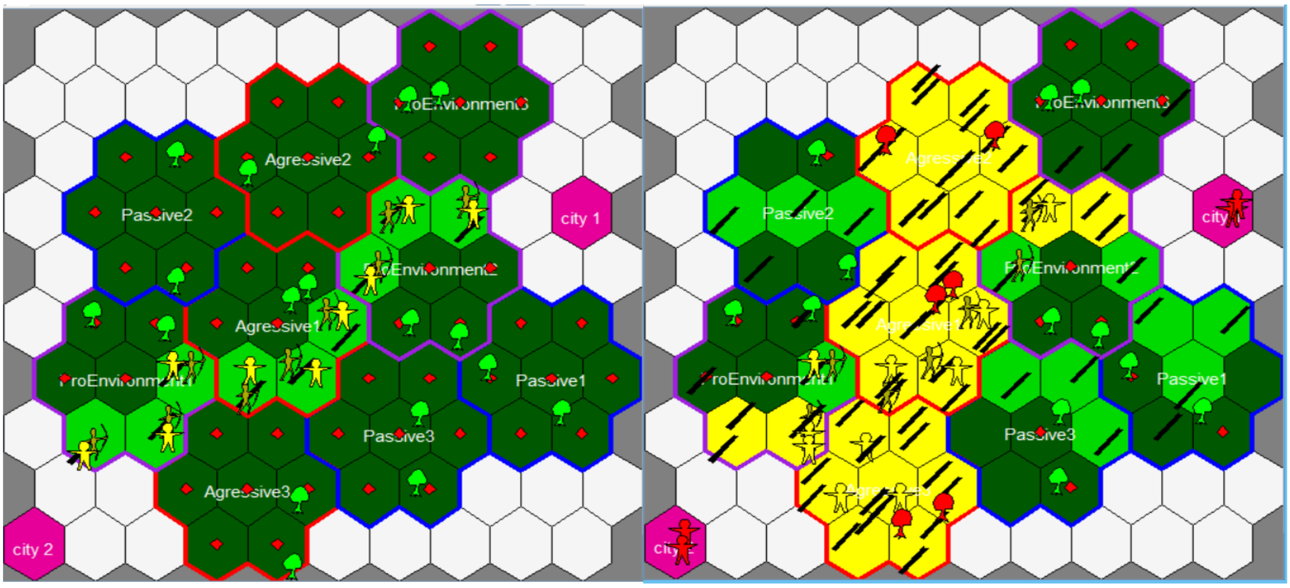

Figure 29: Evolution of the game board with 3P3P3P; timesteps 1 and 5

3) Conclusion about the strategies

The three strategies we have conceived are obviously caricatures. Although they are centered on their own concession, there is still some influence of one on the other. First, the ProEnvironment strategy reduces population settlement across the map. This even affects the strategies that want to welcome new people (Passive and Profit). On the other hand, we notice a negative influence of the Profit strategy on the ProEnvironment strategy especially when the board is completely occupied by agents ("3P3P3P"). The ProEnvironment strategy is indeed sensitive to its environment, even if this variation can also come from the price of wood. This can be seen as the need for this kind of company to obtain specific funding to help them in the preservation of the environment.

However, it is important to remember that these analyses are only exploratory. Indeed, the ComMod approach implemented in this project does not seek prediction, but on the contrary to encourage dialogue between the various actors in this territory. This is one of the reasons why we do not conduct an in-depth statistical study, despite the number of repetitions (50 per type of simulation).

Finally, one should not jump to conclusions and rank the strategies from best to worst. Indeed, we must learn from the results of the approaches while remaining as neutral as possible. It is above all the local actors who must be able to choose their decisions. Indeed, a Eurocentric participatory approach can be considered as manipulation to "modernize" these populations. Modeling allows to push a behavior to the extreme and to see its long-term consequences.

IV. Discussion

1) Possible evolutions and limits of the model

a) Evolutions

Due to lack of time but also lack of skills, some functionalities are not present, such as the implementation of more intelligent behaviors like for example prospective and adaptive strategies that would project themselves over several rounds to make their decisions.

Generating random events would also be interesting. Indeed, up to now the role of the game master remains important: he facilitates the dialogue and can decide at any time events that can stimulate the players. Implementing this kind of actions directly in the computer simulation would allow a better fluidity and a better gameplay. This would reduce the need for a game master behind his computer and make him more available to the players.

Finally, another possible evolution would be to make the current player interface more intuitive and personalized. We can even imagine that it would be available on a smartphone. Players could then permanently discuss with each other and make their decisions without going through the host. In addition to the comfort of having a specialized and mobile interface, this would authorize remote sessions, even in times of health restrictions!

MineSet was designed to establish a dialogue between forestry company managers and other local actors. However, it would be possible to adapt the role-playing game for different situations, in a similar context, but with different actors than those originally intended.

b) limits of the model and the approach

First of all, whether it is physical or computer-based, the game presents a very stylized region, far from reality. The objective behind this is to distance the participants from their reality on the ground and thus limit the conflicts between them. The other dangers of trying to reach more realism are: the possibility of losing the fun side of the game, the cost and development time that it requires, and the intimidating side that a "high-tech" tool can cause. On this last point, participatory modeling seeks cooperation, and a computer model that is too refined will rarely be criticized by the players. It is important to understand that the purpose of having a stylized empirical model is that it is always criticizable and improvable, in other words that it remains a KILT (for Keep It a Leaning Tool) model according to Le Page (2017). Even if it loses accuracy, the game must retain its attractiveness, which is not easy to find. It is the designers' decision to find this boundary, and the workshops and participant feedback help to find it.

Other limitations are related to the ComMod approach. Even if these methods are developing in Europe, there are still cultural barriers to understanding and getting involved in the process. The CoForSet project illustrates this: some project members did not manage to get involved in the co-design process and several local partners were slow to take ownership of the approach. A computerized version of MineSet could facilitate this ownership through rapid dissemination. But this will require the development of a didactic user manual.

2) General conclusion

This internship had to answer the problematic: How to transform a board game into an interactive simulator? The internship resulted in the design and implementation of the MineSet computer role-playing game, which serves as a proof of concept. Yet this report also reveals the complexity of creating such a tool. Personally, this internship opened me the door to participatory modeling, which I believe to be a promising approach to renewable resource management. It allowed me to take my first steps by discovering the ComMod approach, while developing my skills in UML conceptual modeling and its implementation on the form of an ABM with Cormas. This progression shows everything that had to be put in place to obtain an operational interactive simulator. Of course, there are still improvements to be made (individualized interfaces, adaptive autonomous agent strategies, user guide, ...). However, thanks to the simplicity of the game rules and the efficiency of the digital version, MineSet will be able to be used by the Congo Basin actors but also on future projects dealing with similar issues.

My biggest regret for this internship is that it has not been possible to apply the game in real conditions, neither with other students to test it, nor with the actors it targets. This frustration is linked to the sanitary conditions but also to the time it took me to appropriate the various skills that this process requires. However, as recommended by the ComMod approach, it is also during these sessions that the game can be refined. Afterwards, I hope to mobilize these skills and continue to apply them in the field of participatory modeling.

Nevertheless, this game has been used in a session with 40 participants during the IUCN conference (World Conservation Congress in Marseille, September 2021). The ABM- RPG combination proved to be particularly efficient: it stimulated exchanges (between the participants and with the facilitators), while making the game more dynamic (short delay between turns, quick update of the landscape, complex calculation of environmental dynamics in response to the players' actions, etc.). The recording via the ABM of the participants' actions and their impacts on the simulated system was used during the debriefing phase to analyze the evolution of the indicators and of the board, which helped to better understand the issues of the socio- ecosystem and to imagine collective solutions. I realized how effective these sessions were and how such a combination can motivate the participants.

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Appendices

Appendix 1: CoForSet Project Collaborator

Appendix 2: Game initialization interface