Data Analysis of Social Simulations Outputs
– Focus on variables dispersion

Christophe Sibertin-Blanc, Nathalie Villa-Vialaneix

IRIT, Université de Toulouse, 31042 Toulouse, France
SAMM, EA4543, Université Paris 1, 75634 Paris, France

sibertin@ut-capitole.fr, nathalie.villa@univ-paris1.fr

Abstract. In the domain of social simulation, there are very few papers reporting on the statistical analysis of simulation results, while it is very common in empirical social sciences. The paper advocates the expansion of the statistical analysis of social simulation outputs, as a very efficient way to improve the interpretation of simulation results and so the understanding of the system that is the model's target. This is illustrated by the study of a simulation model designed to analyze a real situation related to the management of a river in South West of France. Several standard statistics methods are used to shed light on the possible outcomes of the discussion between the actors.

Keywords: Agent-based modeling, social simulation, statistical analysis.

1 Introduction

The standard way to build a social simulation model may be sketched as this: you are concerned by or interested in a phenomenon that occurs in some *system of reference* which, according to the classification of (Boero et al. 2005), can be either a particular "*empirical space-time circumscribed"* case, the application of a "*theoretical construct intended to investigate some properties that apply to a wide range of empirical phenomena*" or "*focus[es] on general social phenomena*", or stylised-fact. This phenomenon is characterized by *indexes*, which allow to measure the various features of each occurrence of the phenomenon and whose value is directly measured, given by an expert, collected in any way or resulting of a treatment of these, and The simulation model is built to produce "outputs", also issued directly or resulting from additional treatments, which values are as close as possible to the indexes when it is run in the appropriate conditions.

To validate the model and to ensure that the mechanisms it embeds are able to reproduce the phenomenon of interest, the model building process includes the use of statistics to identify the model's parameters whose initial values influence the model's surface response (sensitivity analysis) and to give to each parameter the most suitable value (calibration). The simulation model is run many times, and optimization techniques are used to calibrate the parameters in such a way that the univariate statistical properties of each output variable (i.e. mean, standard deviation, autocorrelation if the variable is distributed in space or time) are as close as possible to the properties of the corresponding index in the system of reference.

In simulation models designed for the study of systems such as the customer waiting times from a queuing system, bottleneck in mass transit system during rush hour, the throughput of a production workshop or the mean time until a machine breaks down, it is very common to perform statistical analyses for the evaluation of system performances (duration of the start-up phase, steady-state analysis, confidence intervals, …). In these cases, the model is analyzed to establish its own internal control logic, not in order to improve its mirroring of a system of reference (see (Law 2010) as an instance of many papers on this topic at the *Winter Simulation Conference).*

Many authors advocate the systematic analysis of simulation models in accordance with Axelrod (1997) and Gilbert & Troitzsch (2005). The need for engineering tools and principles to improve the practice of Multi-Agent Based Simulation and enhance the results obtained in this way is widely recognized, see for instance (Lorscheid et al. 2012; 2013). In this line, we claim that this kind of statistical analysis could be beneficial for the study of social simulation models as well. While the system of reference (SR) is most often observed only once, since experimentation in social affairs are rarely feasible, the simulation model is run many times (at least thirty times or more) and thus we can proceed to a statistical analysis of the data produced by these runs as if we had thirty exemplars of the system of reference. In fact, the statistical analysis is very common in empirical social sciences for the analysis of questionnaire surveys, data collected from archival records or dataset pick up in whatever way.

Then, the question is no longer to compare the value of each index observed in the SR with the mean value of the corresponding simulation output; it is to consider each run as an observation and to proceed to a statistical analysis of this dataset. By nature, the results of this data analysis are not directly related to any of the indexes of the SR that have been used to build the model; they bring a new kind of knowledge, beyond the matching between the SR indexes and the simulation outcomes. This knowledge is based on the mode of operating of the simulation model under various circumstances (instantiated by the series of random values of each run) and thus it bears on deep characteristics of the simulation model (Evans et al., 2013), properties which can not be identified in the course of a single observation.

Then, three cases can occur:

- the property is already identified and well known by the experts of the SR, so that the data analysis brings a new piece to the validation of the model;
- the property is in contradiction with what the experts know about the SR, so that the data analysis questions, more or less severely, the validity of the model;
- the property is not a fact known by the experts of the SR but it is consistent with their actual knowledge, so that the data analysis is likely to bring a new piece of knowledge about the SR to the extent that the relationships between the SR and its model are well-defined.

We do not believe there is a uniform way to conduct the systematic statistical analysis of results of any simulation model, because the methods likely to provide interesting findings depend on the very nature of the SR and the hypotheses that the mo-deller has in mind and would like to test. Moreover, statistics is a quickly growing discipline and new analysis techniques are continuously developed to tackle specific questions.

So, in the following of this paper, we will just illustrate how statistical analysis techniques can be exploited to enhance the knowledge about social simulation models, and in this way the knowledge about the system of references under consideration. The model and the simulation outputs have been produced by a social simulation platform, SocLab[1], designed for analyzing social organizations. This platform allows the user to edit models of organizations, to study the properties of models with analytic tools, and to compute by simulation the behaviors that the members of an organization could adopt each other.

The remaining of the paper is as follows. We first present the SocLab modeling framework, the main features of the systems it allows to consider and the questions it intends to address. Section 3 presents our real-world case study related to water management in a French area and the simulation outputs. The following sections show how quite simple statistics tools allow the user to improve the interpretation of the simulations outputs. A discussion and a conclusion are finally provided in Section 7.

2 The SocLab modelling of social organizations

The SocLab framework formalizes and slightly extends the Sociology of Organized Action (SOA), introduced by (Crozier and Friedberg 1977). For space limitation we just outline the syntax and semantics of SocLab models, a comprehensive presentation of this framework and its use may be found in (Sibertin-Blanc et al. 2013a).

Roughly speaking, SOA proposes to explain why people behave as they do, especially when they do not behave as they are supposed to, regarding the organization's rules. An organization is defined as a set of *actors* and a set of relations based on the access to *resources*. Each actor has some goals, which are a mix of his own objectives and his organizational roles, and he needs some resources to reach these goals. On the other hand, each actor controls the access to some resources, and so determines to what extent those needing these resources have the means to achieve their goals. They are reciprocally dependent on each other.

Actors are assumed to be rational, that is to say their behavior is driven by their beliefs on the best way to achieve their goals. So, each actor cooperates with others in the management of resources under its control to get from them access to the resources it needs itself. We call the process, by which they mutually adjust their behaviors with respect to others, the *social actor game*. The well-known regulation phenomenon results from this process: the adjustments drive actors to exhibit quite steady behaviors as if they obey to external rules. So, SocLab proposes to shed light to regulations of organizations, how and why they occur, with what shape.

Figure 1 shows the SocLab metamodel of the structure of organizations. Accordingly, the model of an organization includes:

- the list of the *actors*;

[1] http://soclabproject.wordpress.com

- the list of the *resources*: each resource is controlled (or managed) by one actor[2]. This actor behaves in a more or less cooperative way and the *state* of a resource measures (on a scale of -10 to 10) how much he tends (or not) to cooperate with others by favoring (or hindering) the access to the resource;
- the *stake* of every actor on every resource: this quantity measures the importance of the resource for the actor. The more a resource is needed to achieve an actor's important goal, the higher the corresponding stake (on a scale of zero to ten; the sum of the stakes for every actor sums to ten);
- the *effect function* of every resource on every actor having a not null stake on this resource: this function quantifies how well the actor can use the resource to reach his goals, depending on the state of the resource;
- the *solidarities* of every actor towards each of the others.

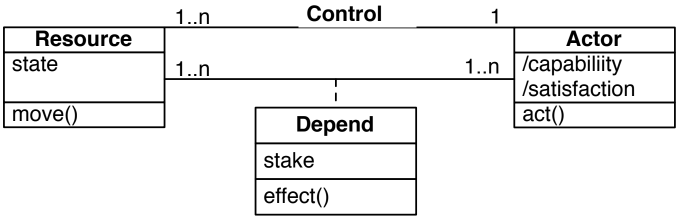

Fig. 1. The SocLab metamodel of organizations as a UML Class diagram

A *configuration* (or state) of the organization is defined as the vector of the resource states. Thus, a configuration is characterized by the level of cooperation of each actor with regard to others. In any configuration of an organization, every actor gets from others some capacity to access the resources needed to achieve his objectives. This *capability* of an actor *a* when the organization is in a configuration $s = (s_r)_{r \in R}$ is calculated as the sum on the resources of the values of effect functions weighted by the actor's stakes:

$$capability(a, s) = \sum_{r \in R} stake(a, r) * effect_r(a, s_r) \qquad \textbf{(1)}$$

This raw capability is weighted by the solidarities between actors, so that the important output we will consider is the *satisfaction* of actors, where:

$$satisfaction(a, s) = \sum_{b \in A} solidarity(a, b) * \sum_{r \in R} stake(b, r) * effect_r(b, s_r) \qquad \textbf{(2)}$$

To compute the configurations that are likely to be issued by the regulation process within an organization, the SocLab platform includes a simulation engine which implements the social game and so computes which behavior each actor is likely to adopt (El Gemayel et al. 2011; Sibertin-Blanc et al. 2013b). To this end, a multi-agent implementation of the model of an organization provides the actors with rationality for playing the social actor game. Social actor agents try, as a meta-goal, to get a high level of satisfaction, i.e., to have the means needed to achieve their concrete goals. However, according to the *bounded rationality* assumption (Simon 1955) they just look for a "satisficing" level of satisfaction, not an illusory optimal one. So, within a

[2] SocLab allows resources to be controlled by several actors but, from the social point of view, each one governs his own behavior.

trial-error reinforcement learning process, each actor maintains a dynamic *level of aspiration*, and a simulation terminates when a stationary state is reached because every actor has a satisfaction that is over his level of aspiration. A state is stationary if actors manage the resources they control in such a way that every one accepts his level of satisfaction and the ones of others: the organization can work in this way, a regulated configuration has been found. The length of a simulation, *i.e.* the number of steps necessary to reach a stationary state, indicates how it is difficult for the actors to jointly find how to cooperate.

3 The management of the Touch river

The simulation model to which we will apply statistical methods concerns the management of a river called Touch. A detailed presentation of the case is given in (Sibertin-Blanc et al. 2013a; 2013c) including the empirical and theoretical dimensions of the system of reference, a detailed presentation of the SocLab model.

Touch is a tributary of the Garonne in which it flows downstream of Toulouse, an agglomeration of one million inhabitants in the South West of France. Its catchment area covers 60 municipalities and its course crosses 29 municipalities. Three fourth of these municipalities stand upstream and are mainly agricultural villages or small towns. Other municipalities, located downstream, form a dense urban area of the Toulouse agglomeration. Downstream municipalities have had to deal with several episodes of flooding during the past decades. They consider that upstream municipalities do not cooperate enough and they have tried to protect themselves by building dikes that, even if expensive, are not sufficient to eliminate the flooding risk. On the contrary, upstream municipalities, strongly influenced by farmers, consider that they have done their best for preventing flooding by letting some land lying uncultivated, in order to absorb the excess of water in case of flooding.

Since 1995, the French water policy requires the elaboration of a flood risk prevention plan (FRPP) of each river, and this obligation was reinforced by the European Water Framework Directive (WFD 2000/60/EC), transposed into the French law as the Law on Water and Aquatic Ecosystems (LEMA, Law of 30 December 2006). On the occasion of the establishment of the PRPP of the Touch, B. Baldet (2012) studied the difficulties to reach an agreement that combines the views of all the field stakeholders and administrative authorities. He analyzed the field observations to the light of several sociological theories. The SocLab model, whose simulation results are analyzed in this paper, describes the system of organized action devoted to the elaboration of the Touch's FRPP and has been designed in order to formally confirm (or infirm) the empirical findings.

The simulation model includes 10 actors which are involved in the management of the river and somehow depend on the FRPP:

- *actor 1*: *Departmental Territory Direction (DDT)* acts as the State representative and will instruct the new FRPP; it controls the *Validation* resource.
- *actor 2*: *National Office for Water and Aquatic Ecosystem (ONEMA)* is the reference agency for the monitoring of water and aquatic environment; it controls the *Expertise* resource.

- *actor 3*: *Adour-Garonne Water Agency (AEAG)* is the operational authority in charge of strategic plans at the basin level. Accounting for the requirements of the various water uses and of the protection of aquatic ecosystems, it defines, supervises and funds the water policy; it controls the *Funding* resource.
- *actor 4*: a *citizen organization* of riparian farmers in the upstream area. They own floodplain land and, as they are riparian, they have the right to use the river and must maintain the banks; it controls the *Lobbying* resource.
- *actor 5*: the *group of 25 upstream municipalities* that have 21,000 inhabitants; it controls the *Control of flow* resource.
- *actor 6*: the *group of downstream municipalities* (75,000 inhabitants) that are incriminated at each occurrence of a natural catastrophe. Due to flooding threats, they must prohibit any building on a portion of their territory; it controls the *Self funding* resource.
- *actor 7*: the *inter-communal association for water civil engineering (SIAH)*, in charge of the management of Touch. It includes representatives of the 29 riparian municipalities and has to maintain the river bed and banks and funded by the actor 3, see http://www.siah-du-touch.org. It is represented by its active manager who favours the cooperation among municipalities while worrying about the Good Ecological Status of the river; it controls the *River management* resource.
- *actors 8* and *9*: political authorities, the *regional* and *departmental councils*, respectively. They can bring additional financial support to civil engineering measures; it controls the *Additional funding* resources.
- *actor 10*: an *engineering consulting firm*, specialized in water, energy and environment, in charge of technical studies. it controls the *Studies* resource.

The actors which are the most engaged in the negotiation are actors 6, 4 and 5 from the population point of view, and actors 7, 3 and 9 from the institutional point of view. All these actors are strongly concerned by both the elaboration and the further implementation of the FRPP. Actors 1, 2, 8 and 10 are less concerned. In this model, each actor controls a single resource that summarizes its means to influence the discussion. We do not introduce them for space limitation neither the stakes, effect functions and solidarities, see (Sibertin-Blanc et al. 2013c) for details.

The analysis of the debates, notably within the SIAH, shows three main options for the Touch management, each one supported by committed actors:

(O1): protecting the downstream towns against floods, and defending the interests of these municipalities (supported by actor 6);

(O2): protecting the daily life of upstream villages, and especially supporting agricultural activities (supported by actors 4 and 5);

(O3): ensuring a good ecological state of the aquatic environment (supported by actors 2 and 3).

Upstream and downstream municipalities are interdependent, though their respective interests are different or even conflicting. So the elaboration of the FRPP includes a fourth option which is probably the main issue of the discussions:

(O4): finding a solution which is a compromise acceptable to the population and its representatives (sought by actors 7, 3, 1, 8 and 9 by order of influence, according to their respective status). This issue is essential because, whatever the chosen solution for the Touch management, it will not be effectively implemented if it is not agreed by the operational actors.

The SocLab platform provides tools for the analytical investigation of (the model of) organizations. For instance, it computes indexes about structural or state-dependent properties of an organization and allows to interactively explore the space of the configurations by computing, e.g., the configurations which optimize or minimize the satisfaction of a given actor or the Nash equilibria. These analytical results shape the context where the regulation process takes place. They contribute to the interpretation of simulation results (Sibertin-Blanc et al. 2013b) by placing what happens in the range of what could happen.

The dataset we examine contains the outputs of 100 simulation experiments with the same initial values: the resources are put in the neutral state (i.e. the 0 value, and runs with different values give same results). Thus, experiments vary just by the seed of the random numbers generator. The output variables are the number of steps to reach convergence (a stationary configuration), the state of the 10 resources and the satisfaction of the actors at the end of the simulation. The higher the state of a relation, the more cooperative the controlling actor is. The level of cooperation of a resource is evaluated as the total satisfaction it provides, accounting for the fact that most relations are conflictive: most states provide a positive satisfaction to some of the (dependent) actors and a negative satisfaction to others.

The satisfaction of each actor, *i.e.* its capability to reach its goals, is determined according to Equation (2) by its solidarities, the state of the resources he depends on, its stakes and the effect functions of the resources it depends on. A quick sensitivity analysis of these parameters (without checking interactions) shows that the model's response is not sensible to a variation of 15% of there values. Each actors put 3 or 4 stake points on the relation it controls so that its satisfaction depends about one third on its own behavior. The range of values of actors' satisfactions are quite dispersed, from 90 (actor 2) to 195 (actor 6). The lower bounds (the worst configuration for each of them) are on a scale of –25 (actor 2) to –85 (actor 6) and the upper bounds (the best configuration) on a scale of 60 (actor 8) to 110 (actor 6). The dataset may be found in (Villa-Vialaneix *et al.* 2014) together with some other results[4].

4 Univariate Statistical Analysis

A quick overview of the variables distributions is provided in Figure 2. The number of steps is strongly skewed with a small number of simulations having a very large number of steps; so, the mean or median are not a good summary of the distribution. Most resource states (except for “Self funding”, “River management” and “Additional funding”) also have a skewed distribution, with several outliers having small values. The scattering of the state variables is very varied: some variables have a very small dispersion, like “Validation” (which is frequently equal to 10, its maximum possible value) or “Additional funding 2” which is almost always equal to 6 (also its upper

[4] See also http://www.nathalievilla.org/soclab.html.

bound value). For these resources, as well as for “Lobbying”, “Control of flow” and “River management” (but to a lesser extent), the organization's constraints are such that the management of these resources seem almost fixed in advance. On the contrary, “Expertise”, or even “Self funding” and “Additional funding” are resources that have a larger dispersion (for “Expertise” the values spread on the whole range from – 8 to 8): the actors which control these resources are less constrained by the organization and a deeper analysis is necessary to decide whether they hesitate between quite equivalent attitudes or whether they have enough power to strategically adapt their behavior to the context.

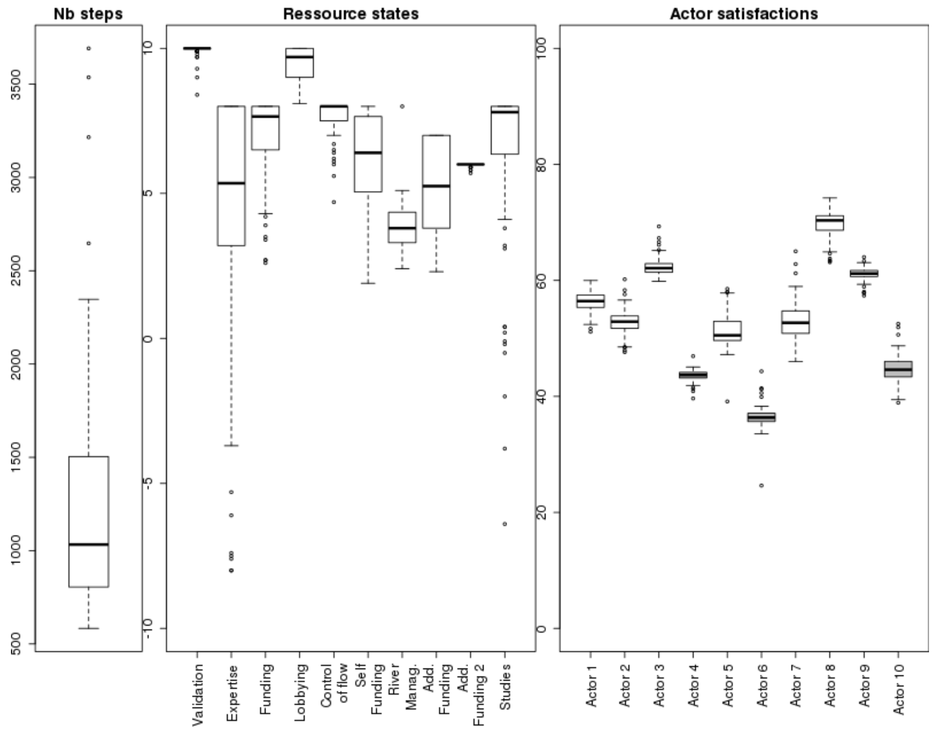

Figure 2. Boxplots for the number of steps before the simulations converge (left), the resource states (middle) and the actor satisfactions (right, grey boxplots indicate a median satisfaction below 50).

The satisfactions of most actors are approximately symmetric, but with a small variability regarding their range. Actors 3, 8 and 9 are the most satisfied in almost all simulations (actor 8 appears the most satisfied, but it is less committed in the game), while actors 4, 6 and 10 are frequently little satisfied. As actor 6 has a low satisfaction, the option **(O1)** will probably not prevail. The same holds for actors 4 and 5 and the option **(O2)**, but to a lesser extent. As the satisfaction of actors 2 and 3 is slightly better, the option **(O3)** seems to be the most likely. As the satisfaction of actor 7 is medium, it seems that a compromise that would be acceptable by most actors is possible **(O4)**, and this is compliant with the fact that none of the options **(O1)**, **(O2)** or **(O3)** strongly prevails upon the others.

The dispersion of the actors' satisfactions shows that the position of actors 4, 9, 6 and 3 are well settled, while the positions of actors 5 and 7 are more precarious. Considering their respective range of values, the actor satisfactions are globally more steady (with smaller dispersions) than the resource states: the variation coefficients of actor satisfactions have a range of 0.02 to 0.06, whereas those of resource states have a range of 0.06 to 0.98 (except for “Additional Funding 2”). This fact might be interpreted as a form of fairness among actors ensured by a complex system effect: actors arrive to compensate a decrease of accessibility to a needed resource by a better access to other ones.

5 Correlation analysis

Figure 3 shows a graphical representation of the correlation coefficients between all pairs of variables. The number of steps has a slight negative influence on all actors (and resources), except for upstream actors 4 and 5. This is a general and meaningful property of the simulation algorithm: long simulations indicate that actors struggle to find a configuration that provides each of them with an acceptable level of satisfaction, and this difficulty to cooperate entails lower levels of satisfaction. Here, Actors 4

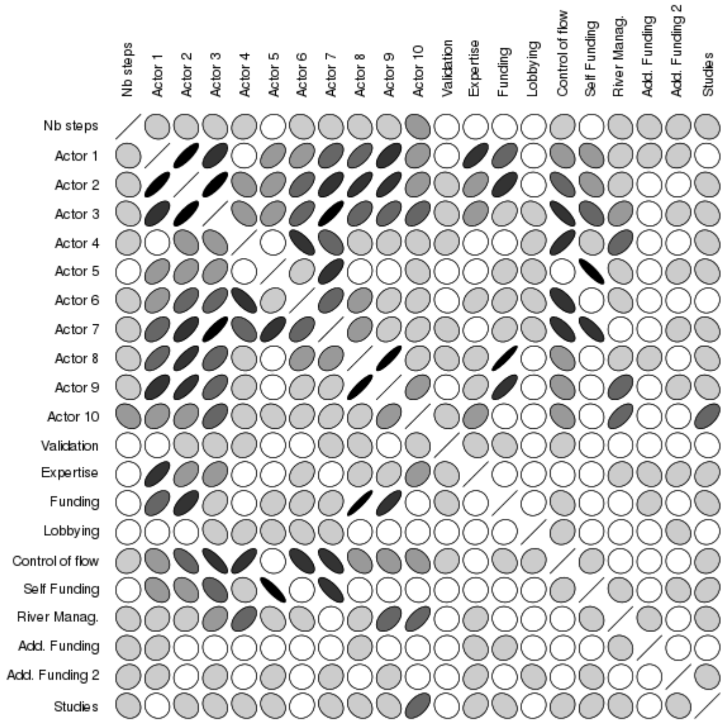

Figure 3. Graphical representation of the correlation coefficients between pairs of variables: the thinner the ellipse, the larger the absolute value of the correlation coefficient (see MURDOCH and CHOW, 1996, implemented in the R package ellipse). The grey level matches the absolute value of the correlation coefficient (darker colors are used for larger values).

and 5 are the beneficiaries of delay in convergence, and their conflict with the remaining of the organization is confirmed by further analysis.

The correlations between the actors' satisfactions show two groups of strongly related actors: actors 1, 2, 3 and 7; actors 8 and 9. Actors 1, 2 and 3 are organizations that represent the State and carry out public policies. The positive correlation between their satisfactions means that their main interests are consistent and that these three domains of the State policy strengthen one another. Moreover, actor 7, instituted by actor 1 and funded by actor 3, is shown to be in accordance with the State services. Actors 8 and 9 are political institutions and it is not surprising that they have similar interests on topics such as the river management. Moreover, the correlation between the two groups is positive: there is no conflict between the State and the local authorities.

As for actors 4, 5 and 6, the most concerned with the river functioning, they have to be regarded in conjunction with actor 7, which is the place where they can build a compromise together. Actor 5 seems careful; surprisingly, it does not support the farmer association nor is it in conflict with downstream municipalities. The case of actor 4 requires a specific attention: it is in conflict with actors 6 and 7, and also with most of the other actors. However we will see that it is not powerful enough to prevent a decision to be made (this is because the effect functions of the relation it controls have a small amplitude). The satisfaction of actor 7 is positively correlated with those of actors 5 and 6, and also actors 2 and 3: these actors support the options **(O1)**, **(O2)** or **(O3)**. This fact confirms the possibility of a compromise **(O4)**, which has already been pointed out in the analysis of the actor satisfactions.

Regarding the correlation between actors and resources, let us recall that, through the effect of solidarities (see Equation (2)), each actor depends more or less on most resources. Some actor satisfactions are strongly correlated with resource states: "Expertise" conditions the satisfaction of Actor 1, in accordance with its strong concern with ecological issues that are the main criteria for the state of this resource. The satisfaction of Actors 8 and 9 is strongly correlated with "Funding" because a higher financial engagement from Actor 3 means a lesser need for their financial effort; moreover, Actor 3 bases its commitment on ecological issues and so its concerns meet those of Actors 8 and 9. "Control of flow" is the most influential resource on actors, in value and in proportion regarding its small dispersion (see figure 1): it is positively correlated with the satisfaction of Actor 4 and strongly negatively correlated with the satisfaction of all other actors, except Actor 5: a low level of this resource means a stronger control on river and thus a higher decision power for Actors 2, 3, 6 and 7. "Self funding" is strongly negatively correlated with the satisfactions of Actors 5 and 7: a high level for this resource means a higher decision power for Actor 6 which reduces the decision power of actors 5 and 7. Finally, "Lobbying" is not very influential on the actors' satisfaction and thus, while actor 4 is in conflict with others, it does not have the means to make its point of view to prevail. These results show that, despite its very structure, the behavior of the model is strongly non-linear: the satisfaction of most actors is lowly correlated to the resource it controls and, as expected, actors compensate losses due to their concessions by a better access to others' resources.

There is no remarkable correlation between any pair of relations. Despite the significant correlations between their satisfactions, the actors' behaviors are independent of one another. There is no coordination or coalition within a subgroup of actors, no actor seems to influence the behavior of another one; in other words, each actor is autonomous with regard to others. A Principal Component Analysis of the resources' states confirms this fact since the first two components explain just 29.7 percent of the variance: no relation plays a preponderant role.

Regarding actors, the first two components of the Principal Component Analysis explain 69 percent of the variance and confirm the analysis of pairwise correlations between actors' satisfactions (see Figure 4). Actors 10, and 5 to a lesser extend, are not very influential; actor 4 is in conflict with all others, especially 5, 6 and 7; actors 8 and 9 go closely together; actors 1, 2 and 3 also go together. Finally, the position of actor 7 is very noticeable, since it is the key actor for the option (**O4**): being very close to actors 5 and 6 and not so far from actor 3, it seems to have the means to promote this option.

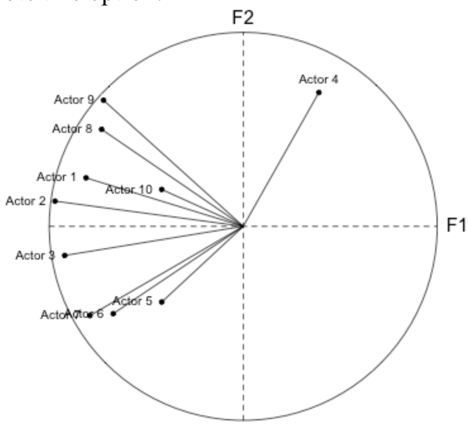

Fig. 4. The position of each actor shows its relative contribution to the variance of actors' satisfactions. Actor 4 is in clear opposition with all others, mainly Actors 7, 3, 6 and 5.

6 The modes of simulations outputs

According to SOA, simulations may include runs whose outputs are quite far from the actual observations of the system of reference: they correspond to “potentialities”, possible ways of operating of the organization, to configurations which do not actually occur but might be observed in the future. Indeed, the regulated behavior exhibited by a social system is the result of past events, situated opportunities or constraints, random choices made at bifurcation points or whatever contingent circumstance while, to the extent of its resources for adaptability and latent variety (Ashby 1962), it could operate in another way under other circumstances. A tight matching between simulation outputs and the indexes of the organization is interpreted as a structural property of the organization: a strong regulation which prevents actors to depart from normative behaviors. Thus, regarding organizations which are not strongly regulated, SocLab simulations should exhibit runs which correspond to different possible futures. Regarding our case study, it is of first importance to know whether runs are uniformly distributed or whether there are modes in correspondence with the possible options (**O1**) to (**O4**). In the latter case, their respective frequencies may serve as a forecast of the possible issues in the debate.

To study this point, we use the *hierarchical clustering* method which seeks to build a hierarchy of clusters containing similar simulations. Pairwise distance between simulations are computed using the Euclidean distance from the vectors of scaled variables (i.e., variables are centered and reduced to unit variance) containing all satisfactions, all resources and the number of steps (so that observations in the same cluster are alike for all these values) and a bottom up approach is used to aggregate the observation into clusters in a greedy way. A linkage criterion specifies the dissimilarity between clusters: we used the Ward's method which minimizes the total within-cluster variance at each step of the hierarchy. The number of clusters is chosen classically by cutting the hierarchical tree at the smallest height that corresponds to a large increase in within-cluster variance.

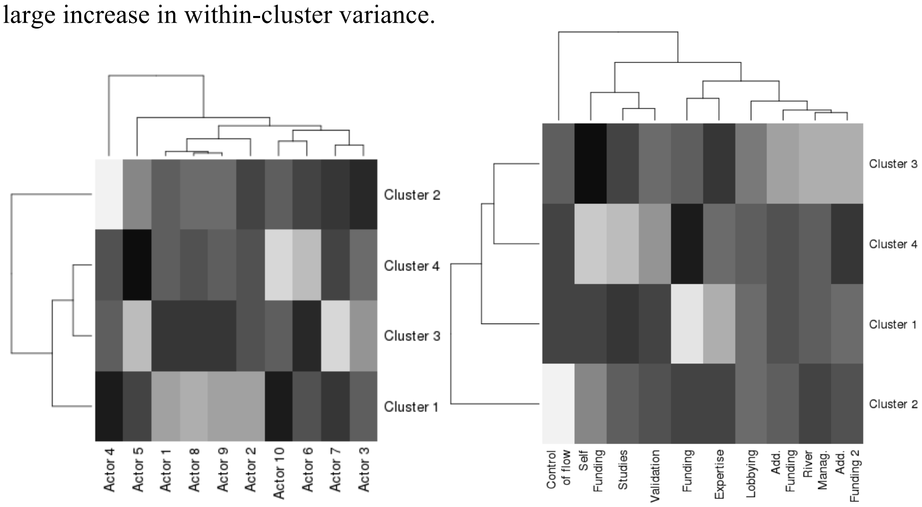

Fig. 5: Mean scaled states of actors (left) and resources (right) in the 4 clusters.

The plots shown in figure 5 read as follows. For each actor or resource and each cluster, the color indicates the mean value of the scaled variable for this class (darker colors correspond to higher values). For instance, the level of the "River Management" resource decreases from cluster 2 to cluster 3. Using the same method as for the constitution of the 4 clusters, the resources are compared regarding their values for the clusters, resulting in the dendrogram at the top of the panel. According to this super-classification, the "Studies" and "Validation" resources are very close; the same holds for the "River Management" and "Add. Funding 2" resources, which are also close to "Add. Funding 1". The smallest the length of the dendrogram path between two resources, the most similar values these resources have among the four clusters. Similarly, the dendrogram at the left side of the panel shows the similarity between the clusters regarding the values of all the observations. This display of the clustering should be completed by boxplots gathered either by clusters or by model elements.

From these figures, the following conclusion can be made:

Cluster 2 corresponds to reaching the best compromise in the process of elaborating the new public policy of Touch (**O4**). Unfortunately, it is not the most likely outcome, since the cluster includes only 7% of simulations, but it is a possible outcome.

Cluster 1 (containing 20 simulations) contains simulations that are almost the opposite of cluster 2: in this cluster, all actors have a lower satisfaction than in other cases, except for actor 4 (and 10, which is marginal). In these simulations, the state of "Control of flow" is high and the state of "Funding" and "Expertise" is low. These simulations correspond to the success of option **(O2)** over the other options: actors 4 and 5 succeed in making their interest prevails over other actors' interests.

Clusters 3 and 4 (respectively, 42 and 31 simulations) are clusters with mostly average values, where most actor satisfactions and resource states take an intermediate value between those of clusters 1 and 2. These clusters gather 75% of the simulations and thus correspond to the most likely outcome of the negotiation process.

Cluster 3 is characterized by a stable low satisfaction for actors 5 and 7 and by a high state for "Self funding". These simulations are rather in favor of option **(O1)**. In cluster 4, actors 4 and 5 are more satisfied than in the other clusters and the state of "Self funding" and "Studies" is low. These simulations are rather in favor of option **(O2)**.

7 Conclusion and discussion

The paper has given some examples of the benefice of the statistical analysis of simulation outputs distributions to reveal causality patterns and improve the understanding of the system of reference operating mode. When a simulation model is an abstraction of a phenomenon modeled as a "stylized fact", the purpose is to propose a mechanism, as simple as possible, able to generate the phenomenon as an emergence from the interactions between the system's components. In this case, the study of the simulation outputs aims mainly to verify whether outputs are steadily focused with a small standard deviation, since their dispersion means that the proposed mechanism is not a good explanation for the phenomenon.

When the simulation model refers to a concrete system as the case considered in this paper, a "good fit" between the system of reference indexes and the simulations outputs must also be checked first to confirm the relevance of the model. But further data analyses of simulation outputs bring deeper knowledge about structural or behavioral properties of the model. These model's properties may then be interpreted in terms of properties of the system of reference to the extent the matching between the elements of the model and the system of reference is well defined. The nature of the properties of interest depends on the question that motivates the elaboration of the model. However, the model of a concrete system presumably includes a wider variety of agents, instances of different types, and so a larger number of properties to be investigated.

8 REFERENCES

Ashby, W.R. (1962) Principles of Self-Organizing Systems. In *Principles of Self-Organization,* H. von Foerster, G.W. Jr. Zopf (Eds.), Pergamon Press, Londres, p. 255-27, 1962, available at http://csis.pace.edu/~marchese/CS396x/Computing/Ashby.pdf.

Axelrod, R. (1997). Advancing the Art of Simulation in the Social Sciences. In R. Conte, R. Hegselmann and P. Terna (Eds), *Simulating Social Phenomena* (pp. 21-40). Lecture Notes in Economics and Mathematical System. Springler-Verlag.

Baldet, B. (2012). *Gérer la rivière ou la crue ? Le gouvernement du risque d'inondation entre enjeux localisés et approche instrumentée. Le cas de la vallée du Touch en Haute-Garonne*. PhD Thesis (Sociology), Université de Toulouse, June, 26th, 2012.

Boero, R. and Squazzoni, F. (2005). Does empirical embeddedness matter? Methodological issues on agent-based models for analytical social science. *Journal of Artificial Societies and Social Simulation* 8(4)6 http://jasss.soc.surrey.ac.uk/8/4/6.html.

Crozier, M. and Friedberg, E. (1980). *Actors and Systems. The Politics of Collective Action*. The University of Chicago Press, Chicago, USA.

Evans, A., Heppenstall, A. and Birkin, M. (2013) Understanding Simulation Results, chap. 9 In *Simulating Social Complexity, Understanding Complex Systems,* B. Edmonds and R. Meyer (eds.), Springer-Verlag Berlin Heidelberg 2013.

Gilbert N, Troitzsch K (2005) *Simulation for the social scientist*. Open University Press, Maidenhead.

Law, A. M. (2010) Statistical analysis of simulation output data: the practical state of the art. *Proceedings of the 2010 Winter Simulation Conference* B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, (Eds.) ISSN 08917736, IEEE.

Lorscheid, I., Bernd-Oliver H. and Meyer, M. (2012) Opening the 'black box' of simulations: increased transparency and effective communication through the systematic design of experiments. *Computational and Mathematical Organization Theory*. 18(1):22-62.

Lorscheid, I., Meyer M. and Hocke, S. (2013) Simulation Model and Data Analysis: Where are we and where should we go? *ESSA Conference*, Warsaw 10-16. Sep 2013

Murdoch, D.J. and Chow, E.D. (1996). A graphical display of large correlation matrices. *The American Statistician* 50: 178-180.

Sibertin-Blanc, C. Roggero, P., Adreit, F., Baldet, B., Chapron, P., El Gemayel, J. Mailliard, M. and Sandri, S. (2013a). SocLab: A Framework for the Modelling, Simulation and analysis of power in social organizations. *Journal of Artificial Societies and Social Simulation* 16 (4) 8, http://jasss.soc.surrey.ac.uk/16/4/8.html

Sibertin-Blanc, C. and El Gemayel J. (2013b). Boundedly Rational agents playing the social actors game - How to reach cooperation. Proceeding of *IEEE Intelligent Agent Technology*, V. Raghavan (Ed.), 17-20 nov. 2013, Atlanta.

Sibertin-Blanc, C. Roggero, P. and Baldet, B. (2013c). Interplay between stakeholders of the management of a river. *CoMSES, Computational Model Library,* http://www.openabm.org/ model/3760, it gives an extensive presentation of the case and the model.

Villa-Vialaneix, N. , Sibertin-Blanc, C. and Roggero, P. (2014). Statistical exploratory analysis of agent-based simulations in a social context. *CSBIGS*, 15(2).