STATE SPACE ANALYSIS FOR MODEL PLAUSABILITY VALIDATION IN MULTI AGENT SYSTEM SIMULATION OF URBAN POLICIES

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ABSTRACT
Multi-agent models have been increasingly applied to the simulation of complex phenomena in different areas, providing successfully and credible results, however, model validation is still an open problem. The complexity of the stochastic interaction between agents together with a large numbers of parameters can make validation procedures intractable.
Particular validation difficulties appear in social science using multi-agent models, when agents are defined as spatial objects to computationally represent the behavior of individuals in order to study emergent patterns arising from micro-level interactions.
This paper considers some of the difficulties in establishing verification and validation of agent based models, and proposes the use of colored petri net formalism to specify agent behavior in order to check if the model looks logical and the model behaves logical. Model plausibility is used to express the conformity of the model with a priori knowledge about the process. A proof-of-concept is presented by means of a case study for testing the robustness of emergent patterns through sensitivity analyses and can be used for model calibration.
The proposed methodology has been applied in the European Future Policy Modeling project (www.fupol.eu) to create trust and increase the credibility of the agent based models developed to foster e-participation in the design of urban policies by means of simulation techniques.

Keywords: model validation, state space, petri net, agents

1. INTRODUCTION

Urban policies can be understood as the different mechanisms arranged to reach the goals set by the urban authorities in which political, management, financial, and administrative aspects are involved. Active participation in the design of urban policies can be seen as the involvement either by an individual or a group of individuals in their own governance or other activities, with the purpose of exerting influence.

Unfortunately, despite a city should be driven by their inhabitants, considering the complexity in the interrelationship between the different urban policy domains, citizens use to participate scarcely in the decision making process, since citizen's knowledge has been often considered to be ''opinion'' or ''belief'' (ie. influenced by subjective elements) and thereby dismissed during the planning of urban policies, relying mostly on ''hard'' technical knowledge and professional expertise (Albeveiro et all 2004).

Digital simulation techniques could contribute to increase the citizen's participation in the urban policy design by transforming their opinion's in valuable knowledge by means of evaluating certain decisions in digital urban scenario which would allow to understand the impact of different choices not only in the urban problem under study, but also on different hidden indicators (i.e. dynamics not considered by a citizen due to its limited cognitive horizons). Furthermore, the try-and-error experimental approach inherent to simulation models could act as an Enabler of open deliberations between citizens to foster mutual learning process of the complex urban dynamics

To foster citizens' involvement in the design of urban policies by means of scenarios simulation, there are 2 key factors that a new urban modeling approach should consider in order to place citizens at the center of the decision making process:

1. Model Transparency: The use of overly ambitious computer simulation models has been up to now very limited and restricted to certain types of planning, e.g. delivering regularly forecasts for transportation capacity planning, in which scientific knowledge has been used to legitimize political arguments. Models based on complex mathematical computations are oriented to specialist and require trained users.
   The use of a causal formalism to specify well accepted social urban behavior together with a visualization tool to understand the cause-effect relationships described as rules in the simulation model, would contribute to embed local knowledge into urban planning processes

in such a way that a more comprehensive knowledge base for decision-making can be attained.

2. Scenario Acceptability: A formal and easy to understand scenario specification in which citizens will experiment their thoughts is a critical aspects to create trust and increase the credibility of the model and the results delivered during the simulation. Usually, scenarios are specified by means of hypothesis which constraints the numerical results to certain regions of bounded values. Citizen's should easily understand the scenario components and to perform the required changes to deal with new boundary conditions.

It must be considered that most urban policy simulation models do not take into account the citizen participation in democratic decision-making processes, instead there exist fears, expectations and prejudices among the practitioners against the models: quantitative models are monsters and do not capture the social aspects in an adequate way. A lack of credibility in the models is reported due to non-scientific actors being not aware of the uncertainty inherent in such models.

To create trust and increase the credibility of the model and the simulation results delivered, it is essential to deal with a validation approach in which non-simulation-trained end-users (i.e. practitioners) could feel comfortable and trust the simulation model.

By means of a Multi Agent System simulation platform, it has been developed in the FP7 project FUPOL, a library of causal models to allow citizens testing the benefits and shortages of different proposed urban policies and check new policies according to their own beliefs.

Model validation of urban policy models using Multi Agent Simulation is a complex task that plays an important role for model acceptability. Consider for example those models, which assign high levels of cognition to their agents, so that agents can act intuitively rather than rationally. In these contexts, model validation becomes a challenge.

In this paper it is introduced in section II present shortages in the validation of Agent Based Models, while in section III it is proposed a model plausibility approach to improve the acceptability of the model. Section IV provides a short background on the use of colored petri net modeling formalism which is used to open the state space of the system to better understand the model causality and evaluate the reachability of some system states. Finally, section V illustrates the proposed validation approach by means of a real case study in Zagreb.

2. ABM VALIDATION SHORTAGES

Assessment in modeling and simulation confidence is considered a critical issue. One of the primary methods for building and quantifying this confidence are Verification and validation (V&V) of computational simulations. Verification can bee seen as the assessment of the accuracy of the solution to a computational model by comparison with known solutions, while validation can be seen as the assessment of the accuracy of a computational simulation by comparison with experimental data.

According to (Ormerod and Rosewell 2009) in social science, no firm conclusions have been reached on the appropriate way to verify or validate Agent Based Models, due to several aspects, such as agent capacity to take decisions autonomously.

In the field of Multi-agent Systems (MAS) an Agent can be seen as actor/entity with sensing capabilities (representing the means of collecting information), decision making capabilities (representing the means of transforming the sensed information/inputs into a meaningful action), and actuation capabilities (representing the means by which the agent can execute the selected action).

For software engineers the agent concept is related to the concept of objects in Object Oriented Programming (OOP), since agents has properties, functions, and possesses the ability to be abstracted and to integrate with other objects, and so forth. However there is an important difference for model validation is that agents are "autonomous" while objects are "obedient" (Grimshaw 2001).

One of the main problems of ABMs verification process is its sensitivity to replicate statistical results in a multirun approach:

- Numerical Identity: the original and replicated model should produce exactly the same results. This is the case in discrete event system simulation and also in continuous process simulation, however, behavioral rules in many ABMs typically contain stochastic elements designed to provide a wider agents behavior scope.
- Distributional equivalence: the properties of the original and replicated model should be statistically indistinguishable from each other. Note that when scaling the amount of agents, using the same distribution rate, the results obtained usually differs since one of the properties of the agents is their learning capacity which depends somehow on the amount of interactions (ie. Critical mass).
- Relational alignment: if input variable x is increased in both models by a given amount, the distribution observed in the changes in output variable y should be statistically indistinguishable. In ABM, the different affinities that can be generated randomly between the agents, do not guarantee relational alignment.

The process of validation requires a clear view of what the model is attempting to explain and for what purpose. Even when the modeler has a clear mind of what are the key facts that the model needs to explain, it is a hard task to clearly formalize how ABM can do it. An aspect of problem description in ABMs which is much more critical than with other modeling strategies is the time representation. ABMs are typically solved in steps, but there is no clear equivalent in real time with the step in any given ABM. The difficulty of translating steps in a model into real time sometimes is seen as a weakness of ABMs, however if provides an important strength: mapping a step into a real time equivalent can be a useful part of the model calibration process.

3. ABM VALIDATION IN URBAN POLICY DESIGN

Generally speaking, the quality of an urban policy model can be judged with respect to several features. One of the most widely used features in some modeling domains is related to direct comparison of input–output data from the model and from the real system. Unfortunately, in urban policy design simulation domain, the main problem of this approach is that real system data are, by definition in complex systems, numerous, and their units and types (e.g. qualitative or quantitative) are different. In this context, the proximity determination of a simulation from a reality can be difficult, particularly because the quality of their information may be very imperfect (i.e. uncertain, imprecise).

Urban policy complexity inevitably leads to a difficult access to parameter values, e.g. it seems rather difficult to observe and know certain policy acceptability by each citizen at a given time. It is well known that, citizens' affinities and priorities are influenced by several aspects that range from urban context changes (i.e. worsening economy), citizens interactions (i.e. opinion leaders, lobbies, etc.), or media information. Real parameters can only be observed occasionally and usually at so called ''simple'' or ''obvious'' moments. Within the framework of the agent based simulation validation, the lack of citizens status knowledge with respect to a certain urban policy, makes difficult to use classical comparison of input-output data in which agents status could be compared with citizens status.

A different feature to validate a model which better fits the urban policy modeling domain using ABM is Plausibility, also referred to as "conceptual validity" or "face validity", which expresses the conformity of the model with a priori knowledge about the process.

Assessment of model plausibility is tightly related to expert judgment of whether the model is good or not. The level of plausibility, or better said the expert opinion about it, is basically related to two features of the model:

- The first one considers the question whether the model "looks logical". This question concerns characteristics of the model structure (type of equations/rules, connections between equations/rules, etc.) and its parameters, and is relevant when the model is derived from first principles or well accepted hypothesis. If the structure and the parameters are feasible, which means comparable to what experts know about the real process, then the confidence into the model is greater.
- The second one is related to the question whether the model "behaves logically". This part concerns assessment of the reaction of the model outputs (dynamics, shape, etc.) to typical events (scenarios) on the inputs. If the model in different situation reacts in accordance with expectations of the experts, then again our confidence about its validity is increased.

3.1. Model Structure: Simple rules.

Simplicity of behavior is an important criterion that can contribute drastically to answer whether a model looks logical. If simple agent rules can produce a good description, this is better than having complicated ones. By ensuring that agents are only required to have the minimum necessary ability to process information or to learn, ABM model plausibility is facilitated. Indeed one way of testing an ABM in the social sciences is to assign increasing levels of cognition to agents to see at what point the model ceases to provide a description of reality. Thus, it is important to design agents with low, or even zero, cognition capacity and minimize the amount of agents with a high level of cognition to those which need special justification rather than those which do not.

In Section IV it is illustrated how to obtain simple rules to describe agents behavior by formalizing the system dynamics using colored petri net formalism.

3.2. Model Outputs: Expected Behavior

The different states that could be reached in an ABM describes the scope of the agent dynamics. Thus, it is proposed to compute the state space of the ABM without considering particular time constraints (time events), neither particular stochastic factor constraints. The full state space of the system can be computed providing all the rules specified in the different agents, considering different sequence rule combinations together with the evolution of the state variables defined in each agent.

State space analysis tools allows the evaluation of the different states that can be reached, and in case a feasible final state is never reached (i.e. for example the swings zone in a green park is never used), it is possible to check why the agents rules defined has not been executed, and add or modify the rules in order to achieve an acceptable representation of the system.

4. COLORED PETRI NET FORMALISM: AGENT RULES

The causal models developed for FUPOL are based in a set of rules generated using the information obtained from the cities. These rules are defined in such a way that models are more understandable for people without modelling background, as could be citizens without modelling skills. A proper visualization will also contribute to achieve a level of transparency good enough to allow a better understanding of the models for any kind of user.

The specification of a system dynamic by a set of rules would lead to a poor modelling approach lacking of the most essential modelling analysis tools that would lead to unpredictable simulation results. Colored Petri Net formalism (Jensen and Kristensen 2009) allows the specification rule based system dynamics as a formal language in which it will be possible to determine if the rules are consistent with the observed system dynamics, which dynamics has been properly formulated, which system states can be reached using the rules and check which rules should be added to reach certain final system states.

Rules can be seen as a relationship between precedent conditions and a consequent body. This form of rules can be interpreted in CPN formalism as a set of pre-conditions, which must be satisfied in order to fire an event, and a set of post-conditions, which represent the new state of the system reached after firing the event. Each rule can be formulated as a transition, in which the pre-conditions will be formulated by means of input arc expressions of the place nodes connected to the transition, and the post-conditions will be computed by means of output arc expressions connected at the output place nodes.

This one-to-one representation between rules and CPN transitions is a positive feature to improve simulation transparency.

The coloured Petri net formalism (CPN) has been widely used by the simulation community for different purposes. It has characteristics that allow modelling true concurrency, parallelism or conflicting situations present in dynamic systems. The formalism allows not only developing dynamic discrete-event oriented models without ambiguity and in a formal way but also it allows modelling the information flow, which is an important characteristic and very useful in systems modelling and decision making.

Traditionally in CPN, the place nodes are used to model resource availability or logic conditions that need to be satisfied. The transition nodes can be associated to activities of the social system or social actors.

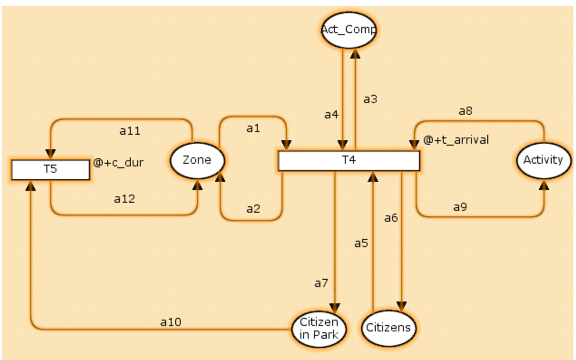

Figure 1: Citizens Activities in a Green Park

In the case of social systems these transition nodes could represent activities or decisions to be taken by each agent. Thus, the information attached to each transition is used as a base to define the agent behaviour rules. These rules will depend on the tokens attributes, and they will define the activities to be performed, the time frame and the companion when performing the activity. For example, Figure 1 shows the events related to the use of a specific zone in a green park.

There are 5 different entities (agents) that take part when evaluating this driving force:

- The activity to be performed (Place node **Activity**)
- Citizens profile: potential users of the park with preferences for certain activities and time scheduling (Place node **Citizens** and **CitizensinPark**)
- A description of the zones in the green park where different activities can be performed, considering also the incompatibilities between simultaneous activities (Place node **Act_Comp**).
- A description of the surface and the capacity of the different zones (Place node **Zone**)

As a consequence of this driving force, when a citizen agent try to perform an certain activity in the green park under study according to the citizen time scheduling availability, their preferences, if the zone occupancy is above a certain threshold value or present activities in the zone are incompatible with the one the agent would like to perform, a conflict is generated.

Well-used (and well-maintained) city parks are likely to be perceived as safe places to visit, sit on the grass, etc., but this may not be true for emptier or poorly maintained spaces, or where there is no surrounding land use that provides informal policing of the area. A CPN based agent model would contribute to a better understanding of the conflicts that could be generated in a green park and design policies for their mitigation.

4.1. ABM State Space Analysis

One of the most powerful quantitative analysis tools of PN and CPN is the coverability tree (Mujica et all 2010). The goal of the coverability tree is to find all the markings, which can be reached from a certain initial system state, representing a new system state in each tree node and representing a transition firing in each arc. The coverability tree allows:

- All the urban policy ABM states (markings) that can be reached starting from certain initial system conditions M0.
- The transition sequence to be fired to drive the system from a certain initial state to a desired end state.

Figure 2 illustrates the first two levels of a coverability tree, the state vector of the CPN model with 8 Places is represented. In each position of the vector, the tokens and its colours stored in each place node are represented. Given this initial marking, the only enabled events are those represented by transition T1 and transition T2. It should be noted that transition T2 could be fired using three different combinations of tokens (i.e. different entities). Once a transition has been fired, a new state vector is generated. Thus, a proper implementation of a CPN model in a simulation environment should allow automatic analysis of the whole search space of the system by firing the different sequences of events without requiring any change in the simulation model.

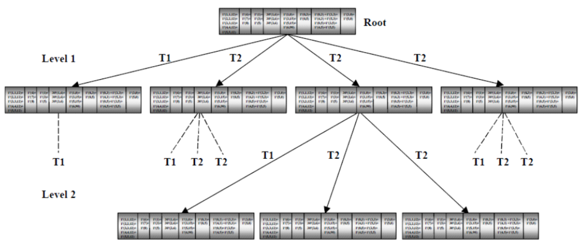

Figure 2: First Two Levels of the Reachability Tree

The coverability tree of the green park CPN model has been analysed for a reduced amount of entities, obtaining as main results:

- The sequence of actions obeys to the logic reaction of the model outputs to the different events activated by the context. Thus, for example, when all the zones are above their capacity the new citizens arrivals are not allowed to perform no one of their preferred activities.
- The state change behaves as it was reported by the fieldwork. The different real context specifications (i.e. early morning no kind in the play a round zones, only people walking with a dog and walking through the park pathway) have been obtained in the coverability tree.

This validation provides the confidence that the ABM model will be complete. Thus, by the proper tuning of the parameters, it should be possible to obtain a good prediction of the reality (i.e. validation for model falseness).

5. CASE STUDY: GREEN PARK DESIGN

The simulation objective for a green park design in Zagreb is to provide the best solution for the facilities that would be included in the 30000 m2 of green area situated near the Autism Centre. The design must satisfy most of the potential users demands and must encourage interactions between autism people and non-autism users, while avoiding possible conflicts between them. At the same time, possible conflicts between all kinds of users must be avoided. For example, nobody likes to have dogs around kids while these are playing in a playground. In Table 1 some modelled activities are summarized.

Table 1: Some Green Park Activities

ID	Activity	ID	Activity
A1	Walking through the park pathway	A21	Walking with a dog
A2	Sitting on a bench	A22	Touching objects and surfaces
A5	Playing in the Sandbox	A24	Playing with a dog
A7	Sitting and playing on the grass	A25	Playing bocce ball
A8	Swinging	A27	Playing in the labyrinth
A9	Sliding down the toboggan (slide)	A29	Standing with a parm
A10	Spinning on roundabouts	A30	Watching water movement and/or listening the sound of the water
A11	Climbing on monkey bars	A31	Following the paths with motoric tasks
A13	Playing ball on the grass	A32	Walking through the labyrinth
A14	Playing rackets on the grass	A33	Sitting in the aromatic herbs garden
A15	Riding a bicycle	A34	Walking through the aromatic herbs garden
A16	Playing football	A35	Listening bells sounds
A17	Playing basketball	A38	Playing theatre games
A19	Playing social games sitting around a table	A39	Playing in the Sensory Park

Some of the activities can be grouped depending, for example, on the age of people doing them. For each activity, the main characteristics of the citizens that could be candidates at different affinity levels together with the most expected time-frame are formalized in CPN. In Table 2, some agent attributes formalized in CPN are summarized.

Specific citizen behavioral rules that has been formalized in CPN and later on codified in Repast are:

S1: Kids between 3 and 5 years of age are mostly interested on playing (i.e. swings, sand area); however, sometimes they could prefer to sit on a bench or around a table to have some snack or even to have lunch.

S2: Kids between 6 and 12 years of age are also mostly interested on playing (i.e. playing ball) ; however, their plays are quite different than kids between 3 and 5.

S3: Young people between 13 and 19 years should have other concerns and responsibilities. Some of them can be really interested in sports (individual and collective), and they can be responsible of a dog. And preferences can vary between males and females. However, if they don't like sports, males and females share preferences (it will implies to include them in the same rule), and these are sitting (could be on the grass, around a table, on a bench,...) or some pair situations like walking or sitting together. Due to the fact they can move around by themself, walking pass through the park can be also one of their activities. Regarding sports, they have different preferences that can be summarized using statistics.

Table 2: Some Agent's Attributes

Data (attribute)	**Meaning and Ranges**
Age	Age of the citizen. Range: 0 - 120
Gender	Gender of the citizen. Range: M (male) or F (female)
Dog	Having or not having a dog. Range: 0 (no dog) or 1 (dog)
CultLevel	Cultural level. Range: from 1 (no studies) to 5 (Master or PhD level). This information is useful to describe how the affinities can affect or can be influenced by their neighbourhood´s opinions.
HouseType	Type of house. It is different to live in an apartment than in a house. Range: 1 (Apartment), 2 (Town house without too much garden) or 3 (House with garden)
CitizenOrigin	Type of citizens depending on where they live. Range: 1 (Autism centre), 2 (Surrounding neighbourhood), 3 (Closest districts), 4 (Other town parts) or 5 (Outside the town)
Personality	Level of personality of the agent. High personality indicates that it can influence the other agents. Low personality indicates that other agents with higher personality can influence it. Range: 0 to 100.

By means of a multirun approach, the agent observer computes the best surface distribution between different zones that should allocated the different described activities, while minimizing the potential conflicts between activities in the same zone.

Different output parameters have been used for the simulation model acceptability. Thus, in Figure 3, it has been represented the occupancy of the different zones considering a reduced size scenario with a particular neighborhood profile. By introducing extreme scenario conditions (i.e. Only elderly citizens or only young couples without kids, or only teenagers, …) it has been possible to involve end users in the model acceptability.

6. CONCLUSIONS

Under the framework of the FUPOL project one challenging task is the policy modelling and analysis. The proposed methodology has been performed through a novel approach which models the different actors in a policy process as agents whose behaviour is governed by a causal modelling developed in coloured Petri nets. The translation of the CPN models into the Repast environment allows a novel way of understanding the causal relationships that are behind decision making in society. With the use of CPN it is possible to implement the causal relationships that govern the agent behaviour in such a way that more transparency is achieved during the evaluation of a particular policy.

Inherent difficulties of ABM verification and validation has been tackled by formalizing agents behavior using CPN and analyzing the state space to determine model plausibility. In general, we consider that simpler agents with simpler rules are to be preferred. The simpler the rule, the easier it becomes to test the model and discover its implications.

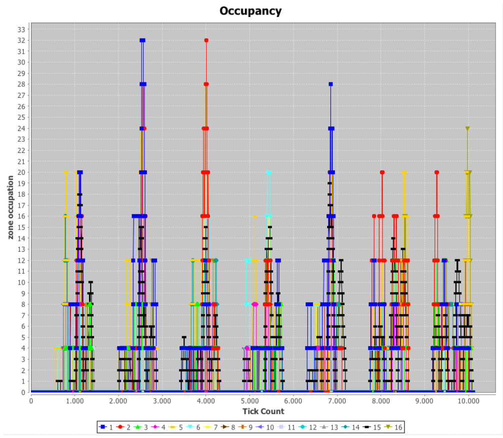

Figure 3: Occupancy of Green Park Zones

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