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Role-playing games as a mean to validate agent-based models: an application to stakeholder-driven urban freight transport policy-making

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Abstract

Agent-based models (ABMs) are widely used to replicate transport environments accounting for interaction among stakeholders. Validation of ABMs implies assessing the extent to which the model, from assumptions to results, is capable of approximating reality. To this end, different methods have been proposed, but yet no widely accepted procedure has emerged. This paper addresses this problem and suggests using a procedure based on role-playing games (RPGs). A first application is described with the intent of providing a preliminary contribution to validate an ABM trying to mimic stakeholders' interaction in a multi-level decision-making process in the context of urban freight transport policy-making. The aim is twofold: (1) understand if the structure of the model and the opinion dynamics envisioned are consistent with a real negotiation process, (2) verify if the results derived from the ABM effort are in line with those derived from a real-life experiment. Results of the first preliminary experiment show that the model seems capable of reproducing real-world processes and confirm that well-thought-out RPGs can contribute to validating ABMs.

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Keywords: city logistics; stakeholder engagement; participatory simulation; model validation; discrete choice models

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1. Introduction

Agent-based models (ABMs) are well suited to reproduce complex phenomena involving human decision-making and behavior, including transport-related problems and interaction among transport stakeholders (Bazzan et al., 2005; Klügl et al., 2010). Transport systems are complex systems. In fact, they typically both include multiple agents taking decisions and have to account for collective emerging characteristics due to the aggregation of individual behaviors (Ettema, 2015). In general, ABMs are used to reproduce the effects of different policy scenarios in the transport network, related to either passenger or freight decisions. ABMs are also suitable to mimic interaction among stakeholders involved in decision-making processes about transport policies (Le Pira et al., 2016, 2017a, 2017b). In fact, not only decisions are complex since transport problems are "wicked", requiring the evaluation of plans/projects considering multiple criteria and points of view, but also because the participation of multiple actors in the decision-making process adds further complexity ascribable to the emerging dynamics pertinent to a social phenomenon characterized by consensus building issues. In this respect, stakeholder engagement is progressively considered an integral part of the transport planning process (Cascetta et al., 2015). Notwithstanding their potential in reproducing real-world processes, ambiguity arises with respect to ABM validation which is, indeed, fundamental for model results' credibility which is, in turn, necessary to use model results for decision-making support. ABM validation implies assessing the extent to which the model, from assumptions to results, is capable of approximating reality. Validation is desirable at multiple levels, going from knowledge validation, to process validation and, finally, to system validation (Anand et al., 2016). To this end, different methods have been proposed, but there is not yet a widely accepted procedure emerging. ABM validation is still controversial and considered challenging (Windrum et al., 2007; Moss, 2008; Darvishi and Ahmadi, 2014).

This paper addresses ABM validation by proposing a procedure based on role-playing games (RPGs). The use of RPGs in ABMs is not new and it is known as "companion modelling" (Voinov and Bousquet, 2010). This approach implies that stakeholders are directly involved in model definition and implementation (Barreteau et al., 2003). There is a wide literature about this approach in the field of natural resource management (e.g. D'Aquino et al., 2002; Etienne, 2003; Guyot and Honiden, 2006). Inspired by this approach, while adopting a different perspective, this paper describes a new procedure based on RPGs with strong behavioral data characterizing the player-agent (from discrete choice models) to reproduce a real social system which has been simulated via an ABM. The RPG (and the ABM) reproduces a multi-level decision-making process involving stakeholders in the definition of urban freight transport (UFT) policies. UFT is a complex world characterized by incomplete understanding of problems and solutions and scant coordination between heterogeneous actors with different interests (Comi et al., 2008; Gatta et al., 2017). In this respect, it is interesting to understand, predict and interpret stakeholders' behaviors and interaction with respect to policy interventions. The aim of the RPG is twofold: (1) understand if the structure of the model and the opinion dynamics envisioned are consistent with a real negotiation process, (2) verify if the results derived from the ABM are in line with those derived from a first real-life experiment that represents the first step of a full validation procedure. In this respect, it is worthy of notice that preliminary results are not intended to provide any reliable conclusions about model's predictive ability. Conversely, the intention of the paper is to investigate the potential of a validation procedure based on RPGs so to pave the way for further in-depth analysis aimed at a full ABM validation.

The remainder of the paper is organized as follows. Section 2 explains the rationale behind the use of RPG as a mean to pursue ABM validation. Section 3 presents the case study, with a description of the ABM (3.1) and of the RPG procedure (3.2) together with results and their discussion (3.3). Section 4 concludes the paper summarizing the main concepts, the results obtained and succinctly discusses future research efforts.

2. Role-playing games as a mean to validate agent-based models

A RPG is defined as "a game in which players take on the roles of imaginary characters who engage in adventures, typically in a particular computerized fantasy setting overseen by a referee"[2]. A RPG is characterized by an active role

[2] https://en.oxforddictionaries.com/definition/us/role-playing_game

of the players. In this respect, it is important to induce a realistic identification with the role they are asked to play. RPGs are used for different purposes, such as, for example, learning and education. The use of game mechanisms for teaching and learning support is also typical in "gamification", which has been defined as the use of "game design elements in nongame contexts" (Deterding et al., 2011). Its use is quite recent, in particular in the transport field, but quickly is gaining success thanks to its ability of inducing behavior change and shifting agents' behavior towards sustainability (Marcucci et al., 2016). Besides, the use of RPG for non-merely entertaining purposes, i.e. training, observation and negotiation support (Barreteau et al., 2001), is testified by the "companion modelling" approach, which is a process involving a combination of ABMs and RPGs to raise stakeholders' awareness with respect to the variety of points of view and their likely consequences in terms of actions. RPGs rest on three pillars: (1) construction of the model with the stakeholders, (2) transparency of the process and (3) adaptiveness of the process, with the model evolving as problems change during the study (Voinov and Bousquet, 2010). Designing a RPG based on an ABM implies following some pre-determined steps. First, objects, agents and rules included in the model have to be converted in a "playable" way: "the initial idea is to consider the RPG as a living MAS [multi-agent system] in which players are the agents and the set of roles is the rule base. But in some cases […] the number of agents and the number of rules available to them is too high. So certain size parameters of the MAS have to be changed, with the constraint of keeping what is interesting in the complexity of the MAS for the question in hand" (Barretau et al., 2001). In general, a RPG reproduces the initial model in a simplified way. This also implies a substantial reduction of the number of player-agents and, in general, a relaxation of some model assumptions, while focusing on the issues the researchers are particularly interested in (Guyot and Honiden, 2006).

Drawing on these concepts, but adopting a different perspective, this paper proposes a procedure based on RPGs to validate an ABM. The substantial difference between the "companion modelling" approach and the one proposed here resides in the different underlying RPG and ABM scope respectively. In the former approach, a real system (e.g. a natural resource management system) is reproduced via the ABM and a participatory process is simulated via the RPG so that stakeholders with different knowledge of the system (Barreteau et al., 2014) can participate in the construction of the model. In this paper, the ABM reproduces a participatory process aimed at consensus building among stakeholders with pre-assigned preferences derived from discrete choice models (DCMs) and the RPG focuses on mimicking the same process to test the ABM's predictive ability. In this respect, two are the main obstacles in ABM validation: (1) lack of data, in particular for future scenario planning; (2) autonomous nature of the individual agents, which most likely gives rise to complex emergent and hard-to-predict phenomena (Anand et al., 2016). The first point is here addressed by characterizing the agents using agent-specific utility functions, derived from DCMs based on an *ad hoc* developed stated preference survey (Gatta and Marcucci, 2014). This allows a clear characterization of stakeholder preferences and the modelling of their static behavior based on a sound econometric approach (Marcucci et al., 2017). Furthermore, the paper addresses the second point by reproducing via a RPG the dynamic behavior and interaction among stakeholders so to test its suitability for a future full validation process.

3. An application to stakeholder-driven urban freight transport policy-making

The case study refers to Rome's Limited Traffic Zone (LTZ) regulation. In particular, a survey was conducted in 2009 with the main agents involved in UFT distribution (i.e. retailers and transport operators) to gather data and information concerning their stated preferences so to infer their behavior in relation to potential policy changes. Results of the extensive analysis based on the survey results can be found in Marcucci et al. (2012, 2013) and Gatta and Marcucci (2016a). Inter and intra agent heterogeneity and nonlinear effects of the policy attributes were investigated via sophisticated discrete choice models (DCMs) (Gatta and Marcucci, 2014, 2016b; Marcucci et al., 2015). Based on the survey and the results of agent-specific DCMs, an ABM has been implemented to investigate interaction effects in a participatory decision-making process (Marcucci et al., 2017). Agents are endowed with individual utility functions, estimated via DCMs, and interact with each other in a multilayer social network according to opinion dynamics rules so to test if a convergence of opinions towards alternative policy packages emerges. Despite the fact that the model is fed with sound econometric results derived from real-world observations, its structure and the interaction process are defined taking literature findings as a reference (Boccaletti et al., 2014; Castellano et al., 2009). The model would benefit from a validation test to prove its ability to reproduce the outcomes of a real world participatory process. As a first step towards model validation, the RPG approach is explored in a pilot study. Further details on the ABM and the RPG are given in the following subsections.

3.1. The agent-based model

The ABM reproduces a multilayer participation process, with different levels of interaction and negotiation among agents (Marcucci et al., 2017). The structure is a multiplex network, i.e. in each layer the agents are the same, while the connections between them can change (Boccaletti et al., 2014). In particular, the participatory process is structured in a three-layer network, where the bottom layer reproduces the everyday interaction within different agent categories, the middle layer represents the formal meetings within categories with a spokesperson and the top layer mimics the negotiation process among the spokespeople of the three categories considered. The three stakeholder types, in accordance with those identified in Marcucci et al. (2013), are: retailers, transport providers and own-account transport operators, i.e. retailers who themselves organize the freight transport service. Each stakeholder-agent is endowed with an individual agent-specific DCM-based utility function. Three spokesperson-agents are created to represent the interest of each category at the top layer. Each simulation reproduces the decision-making process between the *status quo* and a given policy change, obtained by changing the attribute levels used in the experimental design developed for the stated preference exercises. In this respect, the attributes and levels considered for policy scenario analysis are: (1) number of loading/unloading bays inside the LTZ (from 400 of the *status quo* to 1200), (2) probability to find bays free (from 10% representing the *status quo* to 30%), (3) time windows to access the LTZ (three time windows are considered: the *status quo* one, i.e. 20-10/14-16, 18-8 and 4-20), annual entrance fee (from 600 € of the *status quo* to ± 400 €). The interaction process is based on opinion dynamics rules, following the approach proposed by Le Pira et al. (2016, 2017b) that reproduces opinion dynamics on stakeholder networks with different network topologies. The opinion dynamics is cyclical and follows bottom-up/top-down phases: each agent at the bottom layer influences and can be influenced by her neighbors (i.e. the directly linked nodes). At the middle layer, the agents of each category communicate to the spokesperson the opinion of the majority. The spokespeople negotiate between each other at the top layer by exerting a pressure which can, in principle, depend on the influence of their category (assuming influence can be heterogeneous). After this phase, they try to convince their category about the result of the negotiation. The process goes on until a stationary state is reached, i.e. no more agents are willing to change opinions. In this respect, their willingness to change opinion depends on the respective utility they associate with the two policies under consideration. The process is followed in real-time, by monitoring (1) the degree of consensus and (2) the level of "satisfaction" of the stakeholders related to the utility perceived, as a function of the policy simulated. Simulations of a set of policies provide information on their relative acceptance/rejection with respect to the *status quo* and the level of satisfaction they can produce for the agents involved. Results of this first application show that the policies that involve an improvement of the LTZ conditions (e.g. increase in the number of bays) are accepted by stakeholders if this implies only a slight increase in the entrance fee. More results can be found in Marcucci et al. (2017).

3.2. The role-playing game

The validation procedure based on RPG was tested and performed in a first pilot case, with the aim to: (1) understand if the structure of the model and the opinion dynamics envisioned are consistent with a real negotiation process; (2) verify if the results derived from the ABM are in line with those of a real-life experiment. The next step will be to replicate the RPG more times with different stakeholder groups and different initial conditions so to produce more robust and, possibly, credible results. In this respect, it is worthy of notice that the novelty of the paper stands in the procedure adopted to test the ABM and not in the final (preliminary) results of the pilot study. The first test involved nine students of a Master Program in "Sustainable Mobility and Transport" and the total process lasted about three hours (including general description of the case study and of the RPG, agent characterization, negotiation and reporting). RPG was implemented following the steps described below:

1. <u>Role assignment (approximate duration: half an hour)</u>. Each player acted as a real UFT actor and the group was equally divided in three categories: retailers, transport providers and own-account operators. Extracts from real interviews (with specific information, e.g. firm dimension and type of transported freight for

transport providers) were provided to players to help them empathize with their role. Besides, they were asked to infer the role other participants were playing on the base of the answers they gave to prefixed questions related to urban, infrastructure and traffic conditions inside the LTZ (Table 1). It was assumed, from *a priori* knowledge about agents' preferences, that each agent had different priorities with respect to the LTZ, e.g. retailers were more interested in the urban decorum, while transport providers were more interested in control and information about the traffic and the level of occupancy of loading/unloading bays. This step was aimed at ensuring that participants, even if not actually freight operators, had acquired a good knowledge of the priorities, interests and main concerns that real life operators have.

2. Group formation (approximate duration: ten minutes). Roles were unveiled and three different sub-groups formed. The correspondence between the envisaged roles and the actual ones was tested to check how much each player had identified with her/his role.
3. Participatory process simulation (approximate duration: one hour and a half). Once the groups were formed the simulation game could start. A policy package was confronted to the *status quo*. Each player evaluated the utility associated with each of the two policies considered and autonomously decided which one to support. Participants then reported their choice to the group trying to justify their position and expressing their degree of satisfaction with it (see e.g. Table 2). The same holds for the spokespeople that, after collecting their group's opinions, negotiated with the other spokespeople by expressing the will of their group. The process was performed for maximum three times when players knew a decision had to be taken (i.e. convergence towards *status quo* or policy change). The degree of satisfaction of all the agents was recorded for all the simulation steps, thus understanding how much each agreed with the final decision.

Table 1. Questions to identify the players' roles.

According to the role you are playing, please answer to the following questions that can help the other players to unveil your role:

Question	Please state how much the following LTZ characteristics affect your business on a 1 (very low) - 5 (very much) scale:	1	2	3	4	5
Q1	LTZ's urban decorum					
Q2	Traffic congestion inside the LTZ					
Q3	Presence of polluting vehicles and, thus, pollution inside the LTZ					
Q4	Presence of reserved lanes for freight vehicles					
Q5	Control and information about the traffic and the occupancy level of loading/unloading bays					

Table 2. Example of stakeholder preferences in one RPG interaction step (SQ = Status Quo; PC = Policy Change).

Agent	SQ	PC	Why? Please justify your choice	Satisfaction level (1-5)
9		x	The policy proposed is accepted since it globally increases the perceived utility	3
4		x	The policy proposed is accepted since it foresees an increase in the number of bays	4
2		x	The policy proposed is accepted since it implies a reduction of congestion	4
Group		x	The policy proposed is accepted since it implies a reduction of congestion and an improvement of deliveries	4

3.3. Results

Results of the RPG are reported below.

Role assignment. Fig. 1 reports the results of agents' preferences concerning alternative LTZ characteristics. Retailers (RET) stated that urban decorum and congestion inside the LTZ were the most important characteristics affecting their business. Transport providers (TP) declared they were more interested in (1) receiving information on traffic and loading/unloading bays occupancy levels, (2) having freight vehicles the opportunity to use bus-reserved lanes and (3) reducing congestion levels inside the LTZ. Own-account (OA) communicated they were more affected by congestion inside the LTZ and the use of reserved lanes.

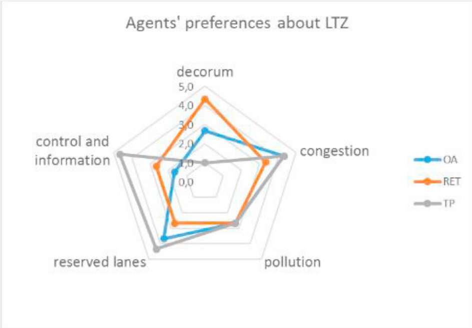

Fig. 1. Agents' preferences about LTZ (OA = own-account; RET = retailers; TP = transport providers).

Group formation. These results helped players identifying the roles others had with a good degree of precision especially with respect to retailers and transport providers. Some difficulties arose in identifying own-account operators, probably due to their double nature of retailers who self-produce the needed transport service. In more detail, 2 out of 3 transport providers were clearly identified by all the other players, 2 out of 3 retailers were identified by the majority of them (89%), while the three own-account were identified by approximately 70% of the players.

Participatory simulation process. Players were faced with a binary decision: *status quo* vs. a given policy change. Table 3 reports the details of the policies considered.

Table 3. Policies under consideration.

Policy elements	Status quo	Policy change
Number of loading/unloading bays	**400**	**1200**
Probability to find bays free	10	10
Time window to access the LTZ	20-10/14-16	20-10/14-16
Annual entrance fee	**600**	**800**

As can be noticed, the policy change differs from the *status quo* due to a huge increase in the number of loading/unloading bays (from 400 to 1200) and an annual entrance fee rise (from 600 to 800 €). This policy was one of the eight simulated using the ABM and one of the five preferred to the *status quo* (Marcucci et al., 2017). The aim of the RPG was to understand how stakeholder interaction could lead to a convergence of opinions towards policy change (or *status quo*). Three steps of bottom-up/top-down dynamics were followed before reaching a decision. The facilitators let the process evolve without forcing it in any direction or fashion so to test the interaction process envisioned in the model. Surprisingly, players in each interaction step modified the elements of the policy considered to meet all categories needs, even if they were initially instructed to reach a convergence of opinion towards a specific policy combination (against the *status quo*). This process was clearly different from the one envisioned in the ABM, where each simulation reproduces the decision-making process between the *status quo* and a given policy change, with the agents having no chance to change the policy considered. Nevertheless, it can be agreed that, in a real life negotiation process, this is a more spontaneous and effective way to directly obtain a unique policy which satisfy all stakeholders, instead of a number of policies that are potentially accepted with different degrees of satisfaction and consensus. In this respect, the RPG final result foresees a policy combination which is very similar to one of the first ranked by the ABM, characterized by a high degree of consensus and a high level of satisfaction. It is clear that the model is a simplified version of reality, but its strength relies on its ability to reproduce a complex participatory process adopting simple behavioral rules. The results of the first RPG, even if they are preliminary and do not allow to validate the model, are satisfactory since they are in line with the ones obtained via the ABM. Fig. 2 summarizes the 3-step negotiation process developed during the RPG: own-account-players were, at the beginning, in favor of the *status quo*. They claimed that the improvement induced by policy change (i.e. the increase of the number of loading bays) would not affect them since they were more interested in changing time window (which remained the same of the *status quo* and was considered too restrictive). In the second interaction step, the policy was changed by reducing the number of additional loading bays, reducing the increase in the entrance fee and changing the time window (Fig. 2). This last change was not approved by retailer-players that, being still in favor of the policy change, were not satisfied at all with time window change and asked for an additional revision of the policy. The main motivation was linked to the concern about congestion and possible illegal parking by truckers during the day. In the third, and last, interaction step the policy was refined maintaining the same time window while increasing the probability to find bays free. This was considered sufficient to avoid the possibility of illegal parking. The group was overall satisfied with the final policy configuration (87% satisfaction level). It was evident that the negotiation process occurred mostly between retailers and own-account players. This could be ascribed to the fact that the original policy (Policy 1) was actually favoring transport providers, according to the econometric results used to help players getting accustomed with their role. In the next process validation attempts, different policies will be tested and the game controlled – without forcing it – to see if one can reproduce the same process envisioned in the ABM (i.e. decision-making processes between the *status quo* and a given policy change, without having the possibility to modify the policy components). In any case, the first RPG can be considered satisfactory both in terms of the procedure adopted and the results obtained, in line with the one from the ABM. In this respect, the ABM developed can be useful to pre-screen the policies to be considered for further evaluations and helps policy-makers making a final decision.

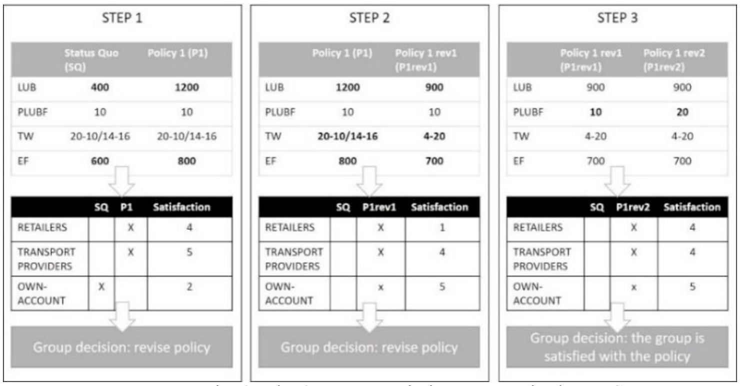

Fig. 2. The 3-step negotiation process in the RPG.

4. Conclusion

Agent-based models (ABMs) are typically used to reproduce complex systems involving human decision-making characterized by macroscopic phenomena emerging from microscopic interactions among agents. The complexity of these systems makes ABM validation a daunting task. This paper proposed a procedure based on role-playing games (RPGs) and illustrated a first step with an application in a first pilot study to test its suitability for ABM validation. In particular, a participatory decision-making process about urban freight transport policies was reproduced via an ABM and a RPG conducted to test the ability of the model to reproduce a community of interacting stakeholders trying to find a convergence of opinions. Results of the first experiment show that the ABM developed seems capable of reproducing real-world processes and confirm that well-thought-out RPGs can provide valuable insights into model performance and contribute to ABM validation. In future research the RPG will be replicated more times with different stakeholder groups and by changing the policies under consideration so to provide a pathway for a comprehensive model validation.

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