Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 52 (2015) 884 – 889

Procedia Computer Science

The 4th International Workshop on Agent-based Mobility, Traffic and Transportation Models, Methodologies and Applications (ABMTRANS)

Simulating opinion dynamics on stakeholders' networks through agent-based modeling for collective transport decisions

Michela Le Pira[a]*, Giuseppe Inturri[a], Matteo Ignaccolo[a], Alessandro Pluchino[b], Andrea Rapisarda[b]

[a]*Department of Civil Engineering and Architecture (DICAR), University of Catania, Via Santa Sofia 64, 95100 Catania, Italy*
[b]*Department of Physics and Astronomy (DFA), University of Catania, Via Santa Sofia 64, 95100 Catania, Italy*

Abstract

In transport planning several actors with conflicting objectives are involved in the decision-making process. Though public participation is fundamental to legitimate a transport plan, some inconsistencies may arise when individual preferences are aggregated into a collective decision. In this work, we reproduce the process of collective preference ranking among plan alternatives using agent-based simulations of the opinion dynamics on groups of stakeholders linked in typical social networks. The results show the efficacy of interaction and the relevance of the network topology to find a transitive and shared collective preference ranking.

Peer-review under responsibility of the Conference Program Chairs

Keywords: public participation; transport planning; collective preference ranking; opinion dynamics model; agent-based modelling; intransitivity paradox

1. The participation process in transport planning

Public participation is an essential part of planning according to sustainability principles. Transport systems require special attention, since their planning affects the livability and economy of a city and usually there are many

* Corresponding author. Tel.: +39-095-738-2220.
E-mail address: mlepira@dica.unict.it

Peer-review under responsibility of the Conference Program Chairs
doi:10.1016/j.procs.2015.05.146

stakeholders with conflicting objectives. Identifying all the actors and collecting all the different points of view are the first two primary steps[1], followed by the real participation phases. The interaction among stakeholders and between them and the decision-maker is a crucial point, since it influences the final decision, and a good management of it is fundamental for the success of the plan. Thanks to the new technologies, nowadays it is easy to interact, express and exchange opinions via web (e.g., via forum, social network, blog). This kind of on-line participation is consistent with the principles of the "smart cities of the future"[2], where Information and Communications Technology (ICT) allows fast information flows and a high degree of connection through the networks of the involved actors. However, if this kind of participation is self-organized and not monitored, it can hide some pitfalls. Next paragraph will clarify this last sentence by explaining a classic paradox that can occur when people participating in a decision-making process are asked to rank different alternatives.

1.1. The "Condorcet paradox" in group decision-making process

The "Condorcet paradox" or "Condorcet cycle"[3] is one of the main paradoxes that may afflict voting procedures[4]. It can arise in a participation process, when more actors are involved in the decision-making process and the collective preference order among a set of alternatives, resulting from the aggregation of the individual ones, may be intransitive (e.g., among three alternatives A, B, C, the collective preference order can be A>B>C>A, see Table 1). If the aggregation of the individual preferences is based on the so called "Pairwise Majority Rule" (PMR), the collective ranking is obtained by computing how many times each alternative in a pair is preferred to the other one (majority rule). The pairwise preferences of each individual list are coded as components of a binary vector assuming the values of +1 and -1 (e.g., for the couple AB, if A is preferred to B then AB = +1, vice versa AB = -1) Finally, the collective preference list is derived by applying a majority rule to the binary vectors. Given n alternatives, the number of possible pairs is $n \cdot (n-1)/2$. For example, for three alternatives A, B and C ($n=3$), there are three pairs (3•2/2=3): AB, AC, BC.

Table 1. Example of the "Condorcet paradox" (adapted[5]).

voter	preference order	AB	AC	BC
1	A>B>C	+1	+1	+1
2	A>C>B	+1	+1	-1
3	C>B>A	-1	-1	-1
pmr result:	A>B>C>A	+1	+1	-1

In general, the PMR is mostly used because, in the largest domain, it satisfies all the requirements of a social choice rule[6]. It is easy to demonstrate that the probability of "Condorcet paradox" increases with the number of alternatives[5], but it has also been demonstrated that the occurrence of the paradox increases with the number of voters, i.e. in a large population of non interacting voters[6,7]. On the other hand, the result changes if voters interact before deciding. Besides, interaction is at the basis of most of the traditional participation tools[1,8], therefore, it is important to understand how to manage this kind of problems avoiding the unfeasibility of a decision that derives from a democratic but uncontrolled participation.

This paper will present a quantitative approach based on an agent-based simulation to reproduce the interaction within a network of stakeholders in order to understand to what extent the degree of consensus and consistency of a final collective decision is increased by their participation in the decision-making process.

2. Methodology

An agent-based model has been built to simulate the interaction of a group of stakeholders. They are represented by the nodes of a network linked according with their social (or institutional) relationship. Each agent is endowed with its own properties (such as opinion or influence) and acts according to simple behavioral rules to reproduce the opinion exchange flows among stakeholders. The environment in which an agent acts consists of the opinions of other agents connected by a direct link. At each step of the simulation the state of the system changes by the update of the opinion of each agent on the basis of the state of his local environment and the environment itself is changed as a result of the interaction made possible by the topology of the network.

In a previous work[9] the authors used an opinion dynamics model on a particular stakeholder network, when a binary decision has to be taken about a single project, without any ranking of different alternatives: the various agents interact with each other and the conditions leading to the convergence of opinions according to a majority rule are investigated. An evolution of this approach is here proposed to study the opinion dynamics on networks with different topologies, where each stakeholder has an individual preference list over a set of (more than two) alternatives, and a collective preference list with a high convergence of opinions has to be found, whilst avoiding the intransitivity paradox. All the simulation models have been built and performed within the software environment NetLogo[10], particularly suitable for agent-based modelling.

2.1. The agent-based model

The implemented model consists of several routines, from the creation of the network of stakeholders to the simulation of their opinion exchange until a transitive and shared collective decision is obtained (Fig. 1).

At time $t=0$, N stakeholders S_i ($i=1,...,N$) are created as nodes of an undirected network, according to a selected topology. A set of alternatives is given and a preference list (an opinion) is randomly assigned to each stakeholder. In addition, an integer random variable I_i is assigned to each stakeholder S_i to represent the influence, i.e. the capability of influencing the opinions of his directly connected nodes (first neighbours) in the network. Each preference list is transformed into a binary vector (see section 1.1), and the collective binary vector (PMR) is calculated; finally it is once again converted into a collective preference list, which can be transitive or intransitive. In the latter case we fall into a "Condorcet cycle": it is assumed as the initial condition.

The main aim of the model is to understand what role interaction plays in escaping from the cycle and increasing the convergence of opinions towards a final decision, i.e. a collective list reflecting quite appreciably the individual preferences. In particular, at each step $t>0$, each stakeholder S_i interacts only with his N_i first neighbours. Due to the interaction, S_i has a certain probability of changing opinion, depending on both the influence of his neighbours and the similarity with their lists. Notice that our algorithm is based on a simultaneous update of all the opinions at each time step. This choice, on one hand does not imply, in general, any kind of synchronization of interactions; on the other hand, it can be considered more realistic than the serial update in a group decision-making process where stakeholders are called to express their opinion in specific moments (e.g., Delphi methods). Stakeholders have also different beliefs and needs reflected in their preference lists. Nevertheless, we assume they belong to a homogeneous community of people in terms of competencies on the issues of the decision to be taken and share a similar attitude in being influenced by the opinion of their neighbours, though they are endowed with different level of being influential. The more the opinion of an agent is similar to that of his neighbour the more he will be available to "align" to it. This attitude to change is quantified by the so called "overlap", meant as closeness between any two lists of preferences and calculated as follows:

$$O_{ij} = \frac{1}{m}\sum_{k=1}^{m} V_i^k \cdot V_j^k \quad (1)$$

where n is the number of alternatives, $m=n\bullet(n-1)/2$ is the number of the possible pairwise couples (i.e. the number of components of each binary vector), V_i^k and V_j^k are the *k-th* components of the two binary vectors $\mathbf{V}_i$ and $\mathbf{V}_j$ representing stakeholders S_i and S_j. From this definition follows that $O_{ij} \in [-1,1]$; if $\mathbf{V}_i = \mathbf{V}_j$ then $O_{ij}=1$; if all the homologous components V_i^k and V_j^k have opposite signs, then $O_{ij}=-1$; if $\mathbf{V}_i$ and $\mathbf{V}_j$ are uncorrelated, then $O_{ij}=0$.

We assume that S_i will change his list with the one of a given neighbour S_j with a probability P_{ij} depending on the relative influence of S_j with respect to the total influence of the N_i neighbours of S_i:

$$P_{ij} = \frac{I_j}{\sum_{r=1}^{N_i} I_r} \quad (2)$$

This will happen only if the overlap $O_{ij}>0$; otherwise, S_i will maintain his list. It means that the opinion of a person can be influenced only if the other opinions are not too much different. After all the stakeholders update their lists at time *t*, a new PMR - and its corresponding collective preference list - is calculated. It should be noted that the calculation is done only to monitor the degree of collective consensus reached and that this does not affect in any way the behaviour of stakeholders. These retain their decision-making autonomy, independent of any centralized control mechanism. If the solution is once again intransitive it is discharged and the algorithm goes on. In general, after some steps of interaction, it is possible to find a transitive solution. At this point, the average overlap between the individual lists and the actual collective list, represented by $\boldsymbol{V}_{PMR}$ and resulting from aggregation of the *N* individual ones, is calculated as follows:

$$\overline{O}_{i,PMR} = \frac{1}{N} \cdot \frac{1}{m} \sum_{i=1}^{N} \sum_{k=1}^{m} V_i^k \cdot V_{PMR}^k \quad (3)$$

and represents a measure of the degree of consensus among stakeholders. The first transitive list found with this method does not show a high average overlap, therefore the interaction is repeated in order to find new more shared transitive solutions. The average overlap corresponding to each of them, in general, grows almost monotonically in time, until it reaches a stationary state, corresponding to its maximum value and to a final transitive list. This is assumed as the "most shared" collective solution, appreciably reflecting the individual preferences. In another work, the authors compared the interaction dynamics with other strategies to find collective decisions (e.g., a random strategy) and found out that, even if there are other easy ways to escape from the "Condorcet paradox", interaction is the only one leading to a good convergence of opinions[11].

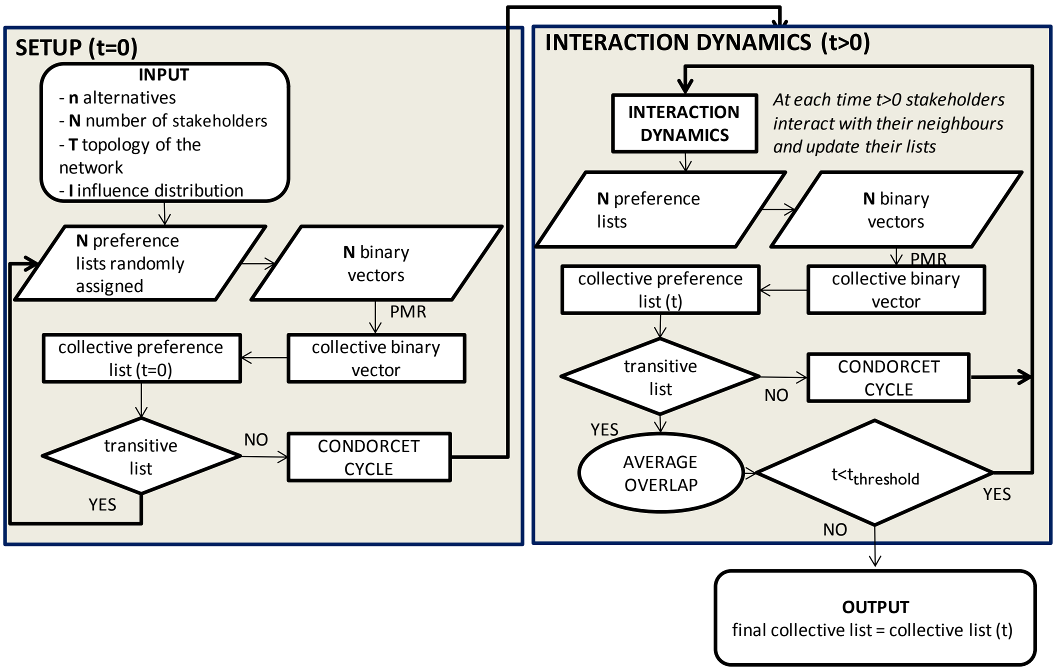

Fig. 1. The main routines of the agent-based model.

2.2. Networks for simulations

Several simulations were performed for selecting a transitive and shared collective decision, with different numbers of stakeholders and different interaction network topologies[11]. The number of neighbours of a given node is fixed and called "degree" of the node. It is indicated with k. In this paper the focus is on three network topologies that, in the authors' opinion, share strong similarities with real participation processes and can likely reproduce them: star network, small world circle and fully connected network (Fig. 2). The star is a network with one central node (hub) directly linked with all the other *N-1* nodes. Every node has degree 1, except the hub that has *N-1*. It can represent a participation process where a single decision-maker directly communicates with all stakeholders. Small world circle networks are "highly clustered, like regular lattices, yet they have short characteristic path lengths, like random graphs"[12]. According to the model of Watts and Strogatz[12] nodes are linked with the first 4 neighbours in a circle, with a certain probability of rewiring, i.e. to remove some links with the first neighbours and replace them with links pointing to random nodes (in general $p=2\%$) and the average degree is 4. It is a typical structure of many real social networks, and it can adequately describe a participation process where an efficient exchange of communication flows exists among stakeholders. The fully connected network is a totally connected network where each node is connected with all the others (the degree is *N-1* for all nodes). Focus group meetings can be better represented through a fully connected network.

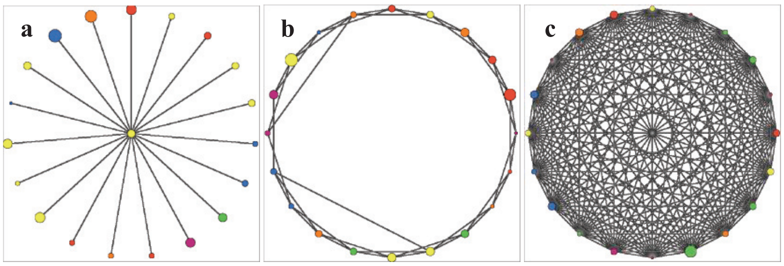

Fig. 2. NetLogo representation of: (a) star network, (b) small world circle and (c) fully connected network.

In all the networks considered for simulations, the influence of each node is an integer random variable with a Poisson distribution. The model was implemented in order to consider several simulation runs (events) with the same structure but different initial conditions. All simulations consider $n=6$ alternatives. A set of simulations is performed considering an increasing number of nodes (ranging from 20 to 120) and the three different network topologies. The result of each simulation is the final overlap averaged over 100 events, each of them running over 500 time steps, enough to reach a stationary state.

2.3. Results and Discussion

Fig. 3 shows the results of the simulations for the three network topologies in terms of final average overlap $\bar{O}^t_{i,PMR}$ (Fig. 3a) and interaction efficiency (*IE*) (Fig. 3b), dividing the overlap by the number of links n_L in order to include the "communication costs" to be sustained in highly connected networks $IE=\bar{O}^t_{i,PMR}/n_L$. In Fig. 3a, the average final overlap ranges between about 0.3 and 0.6 and it is quite high independently on the topology when the size of the networks is small ($N=20$). When the number of nodes *N* increases, the small world circle becomes the one with the lowest values of final overlap. The fully connected network shows good overlaps, probably because each stakeholder influences, and it is influenced, by all the others in the network. The star topology works well because there is just one degree of separation between any couple of nodes.

In Fig. 3b, where the final overlap is normalized with the number of links for each topology, for networks of small size ($N=20$) the fully connected topology becomes the worst if compared to the others, while the star shows the highest values. Increasing the number of nodes, differences among the topologies are less evident.

The results of the model show that the stakeholder interaction, on one hand, helps to escape from the cycle after few steps of interaction, avoiding the risks of pitfalls in non-monitored, self-organized surveys, as already demonstrated[6,7]; on the other hand, what is more important, if this interaction is more and more repeated, it also allows to find a transitive decision better reflecting, on average, the individual preferences. Moreover, it is shown that topology mainly affects the level of general consensus. In this respect, the simulation results can guide the topological structure of the stakeholder network in a real participation process, where interaction can be considered a key of success for a transparent and shared decision-making process.

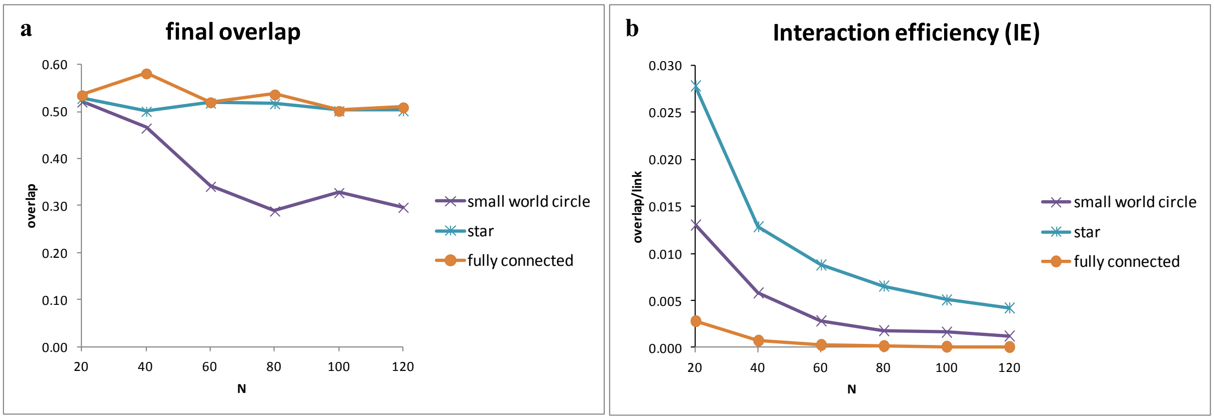

Fig. 3. Plots of the final overlap (a) and the normalized final overlap (b) resulting from the interaction dynamics.

4. Conclusions

An agent-based model has been proposed to reproduce and analyze the complex phenomenon of a group decision-making process in a network of interacting stakeholders who have to decide the priorities of a prefixed set of alternatives to be implemented in a transport plan.

The model has shown that stakeholder interaction, nowadays largely enhanced by the new ICT technologies, allows to circumvent the "Condorcet paradox" independently on the topology, while the latter strictly affects the final degree of consensus in terms of average overlap between the individual preference lists and the collective one.

Even though the network topologies considered for simulations and their dynamics are quite idealized, they can reasonably capture the emergent features of a real world participation process in transport planning, as far as it can be considered similar to a complex system.

In conclusion, the model can represent a useful tool for decision-makers and planners to support participation into the whole transport planning process, avoiding time (and cost) waste and supporting the delivery of sustainable and shared plans.

References

1. Cascetta E, Pagliara F. Public engagement for planning and designing transportation systems. SIDT Scientific Seminar 2012. *Procedia - Social and Behavioral Sciences* 2013;**87**:103–116.
2. Batty M, Axhausen KW, Giannotti F, Pozdnoukhov A, Bazzani A, Wachowicz M, Ouzounis G, Portugali Y. Smart cities of the future. *Eur Phys J* 2012; Special Topics **214**: 481-518. DOI: 10.1140/epjst/e2012-01703-3.
3. Condorcet Marquis de. *Essai sur l'Application de l'Analyse à la Probabilité des Décisions Rendues à la Pluralité des Voix*. Paris; Imprimerie Royale; 1785.
4. Felsenthal DS. Review of paradoxes afflicting various voting procedures where one out of m candidates ($m \geq 2$) must be elected. In: *Assessing Alternative Voting Procedures*, London School of Economics and Political Science, London, UK; 2010.
5. Giansanti A. Remarks on the Condorcet's paradox. AIP Conference Proceedings 12/2007; **965**(1):308-314. DOI:10.1063/1.2828749.
6. Raffaelli G, Marsili M. A Statistical Mechanics Model for the Emergence of Consensus. Phys Rev E 2005; **72**, 016114.
7. Columbu GL, De Martino A, Giansanti A. Nature and statistics of majority rankings in a dynamical model of preference aggregation. *Physica A: Statistical Mechanics and its Applications* 2008;**387**:1338-1344.
8. Kelly J, Jones P, Barta F, Hossinger R, Witte A, Christian A. Successful transport decision-making – A project management and stakeholder engagement handbook. Guidemaps consortium 2004.
9. Le Pira M, Ignaccolo M, Inturri G, Garofalo C, Pluchino A, Rapisarda A. Agent-based modelling of Stakeholder Interaction in Transport Decisions. Selected Proceedings of the 13th World Conference on Transport Research (WCTR), 15th-18th July 2013, Rio de Janeiro, Brasil. ISBN: 978-85-285-0232-9.
10. Wilensky U. NetLogo. http://www.ccl.northwestern.edu/netlogo. Center for Connected Learning and Computer-based Modeling. Northwestern University, Evanston, IL.
11. Le Pira M, Inturri G, Ignaccolo M, Pluchino A, Rapisarda A. Avoiding the "Condorcet paradox" through stakeholder interaction for shared transport plans: an agent-based approach. *Submitted to Envirnomental Modelling & Software*.
12. Watts DJ, Strogatz SH. Collective dynamics of 'small-world' networks". Nature 1998;**393**:440-442.