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Analysis of AHP methods and the Pairwise Majority Rule (PMR) for collective preference rankings of sustainable mobility solutions

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Abstract

The aim of this work is to give a contribution in the field of stakeholder engagement in order to reduce the widespread conflicts arising when transport plans have to be implemented and understand the role of quantitative methods to support shared decisions. We present the results of a participation experiment, with university students as stakeholders, where the AHP method was applied to derive individual priority vectors, on the basis of their judgments of preference between all couples of alternatives regarding the mobility management of their university. The aggregation of the individual judgments was done by using different methods, some derived from AHP and other derived from voting methods, such as Pairwise Majority Rule (PMR). A discussion about the results of the different methods, before and after stakeholder interaction, and from an agent-based simulation in terms of respect of the consistency condition and degree of consensus of the collective decision will provide some recommendations that can be useful to guide effective and efficient participation process.

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1. Participative decision-making process in transport planning

Participation of citizens and stakeholders in transport planning is emerging as a basic component of the plan development to which human and financial resources have to be dedicated from the beginning of the decision-

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making process (Banister, 2008; Litman, 2009; Cascetta and Pagliara, 2013). The awareness of including the public in the decision-making process is a consequence of the failure of many projects because of lack of consensus building. Public involvement and participation become fundamental to find an alternative being the best trade-off between the "most shared" solution (based on consensus building) and the "optimal" one (based on the results of technical evaluations). This can determine a new rational and time saving decision-making process. In this respect, a new planning framework is proposed that draws on:

- the "ladder of citizen participation" (Arnstein, 1969) and different levels of growing involvement (Kelly et al., 2004);
- the "participation pyramid" (Le Pira et al., 2013), where experts, stakeholders and citizens contribute with different degrees of competence and interest to the decision-making process;
- the transport planning "bounded-rationality approach" (Cascetta and Pagliara, 2013), where quantitative evaluations of the planning alternatives are integrated with a participation process.

The proposed decision-making process identifies three main actors and their related roles (Fig. 1): planners and experts in charge of analysing and modelling the transport system by defining the plan structure for the final technical evaluations; stakeholders and citizens that are involved in all the planning phases for the definition of objectives, evaluations criteria and alternatives; decision-makers in charge of the final decision supported by a performance-based ranking and a consensus-based ranking of plan alternatives.

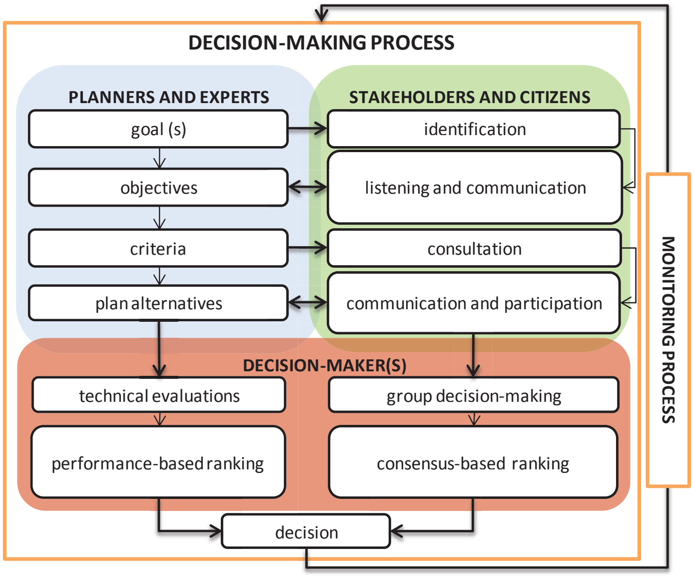

Fig. 1. Framework of the participatory decision-making process in transport planning.

A few attempts can be found in literature that effectively include the stakeholders' opinions into the final choice as a result of an effective group decision-making process. In this respect, the use of Decision-Support Methods (DSMs), such as participatory Multi Criteria Decision Analysis (MCDA), is essential to explicit the opinion and the role that different actors play in the selection of the plan/project among competing alternatives. The Multi Actor Multi Criteria Analysis (MAMCA) by Macharis (2005) is based on a sequence of MCA each carried out with a different stakeholder group, and it represents an interesting approach to include stakeholder groups' opinions in transport planning decisions (Macharis et al., 2010; Vermote et al., 2014). Nevertheless, there is no interaction among stakeholder groups, nor they are expected to change opinions on the transport alternatives, i.e. there is no collective decision emerging from the stakeholder involvement. Actually, a variety of qualitative and quantitative methods have demonstrated that interaction and deliberation can change stakeholders' mind about public policy problems (Quick et al., 2014) and favour the success of a group decision-making process. Moreover, the method to aggregate individual opinions into a collective one is important, because different methods can lead to different solutions. Based on these premises, the paper aims to define a method for investigating how a collective preference, resulting from the individual ones, can be changed by different aggregation procedures and by the stakeholder interaction in a participatory MCDA process.

The remainder of the paper is organized as follows: section 2 introduces the materials and methods used in the study; section 3 illustrates a case study and its related results; in section 4 the results are discussed and some general conclusions are provided.

2. Materials and Methods

According to the proposed framework (Fig. 1), stakeholders interact with each other and with the experts (e.g. transport planners) through a participative group decision-making process managed by the decision-maker (usually the public administration). The use of participatory MCDA methods is fundamental to elicit individual preferences that have to be aggregated into a collective decision.

In this paper it is assumed that an individual expresses his preferences by an ordered list of a set of prefixed alternatives. A further step could be to identify the alternatives together with the stakeholders, with the support of technical evaluations that usually derive from transport models to visualize and understand the consequences of each alternative. The order (or priority) of the alternatives can be the result of pairwise comparisons of each pair of them or it can be obtained by assigning a numerical score to each alternative. In both cases, the ordered list can be turned into a binary vector whose components assume the value +1 if the generic alternative A precedes B in the list or –1 if the opposite occurs. In addition, the Analytic Hierarchy Process method (Saaty, 1980) can be used to combine pairwise comparisons of the alternatives with an assigned score to measure the degree of preference of each alternative over the others.

The study reproduces a participation process through an experiment in which university students act as "sophisticated stakeholders" (Mau-Crimmins et al., 2005) of the mobility services provided by the university. Data collected from this experiment are used to derive collective preference rankings by different aggregation procedures and to evaluate to what extent interaction contributes to achieve a more shared decision.

Whatever is the aggregation method used, the final collective ranking must respect some important conditions:

- transitivity, i.e. if alternative A is preferred to B and B to C, then A is preferred to C;
- consistency, i.e. it derives from logical - non random - judgments;
- acceptability, i.e. it reflects the individual preferences at a reasonable level (or a good degree of consensus).

In this section, the aggregation methods used in this study are presented (2.1, 2.2) together with a new measure to evaluate the degree of consensus of the collective ranking (2.3). Finally, an agent-based model is used to simulate the same participation process (2.4). The final aim is to investigate the impact of different scenarios of interaction among stakeholders on the final degree of consensus.

2.1. AHP to elicit and aggregate stakeholder preferences

The application of the Analytic Hierarchy Process (AHP) by Saaty (1980) in transport planning is based on the representation of a decision-making problem into a tree structured decisions' hierarchy, about the general goal of the plan, sets of specific objectives, evaluation criteria (and possible sub-criteria) and finally plan alternatives aimed at achieving the general goal. A set of pairwise comparison matrices is built by comparing couples of elements at the same level, with respect to the elements of the upper level. The pairwise comparison is made expressing a judgment on a qualitative scale turned into a quantitative one (Saaty, 1987). At each level the pairwise matrices can be transformed into priority vectors with different methods (Saaty and Hu, 1998) and finally a ranking of alternatives can be obtained by combining all the levels.

It is known that pairwise comparisons can lead to some inconsistency, meaning that individual judgments can be affected by lack of rationality and violate the consistency condition of the matrix. For instance, if we have 3 alternatives A, B, C, all terms a_{ij} of the pairwise comparison matrix must satisfy the relation $a_{AC}=a_{AB}\cdot a_{BC}$. This means that judgments must be transitive and mutually correlated. The inconsistency can be measured (and, therefore, monitored) through the comparison between a Consistency Index derived by the matrix elements with the one obtained by purely random judgments (Saaty, 1980).

AHP is widely used in transport planning and management, e.g. to measure the perception of public transport quality (Sivilevičius and Maskeliūnaite, 2010; Mahmoud and Hine, 2013), or for the evaluation of alternatives in transportation planning from a multi-stakeholders multi-objectives perspective (Piantanakulchai and Saengkhao, 2003; De Luca, 2014).

AHP is generally used to elicit single decision-maker opinions, but it can be extended to group decision-making. In the former case, the only condition to respect is judgments' consistency. In the latter case, it is also necessary to define an appropriate procedure to aggregate the individual judgments. A first issue is at which level aggregation is made (De Luca, 2014): Aggregation of Individual Judgments (AIJ), i.e. the elements of each stakeholder matrix are aggregated into a group matrix, and Aggregation of Individual Priorities (AIP), i.e. a group priority vector is calculated from the individual vectors. An alternative interesting approach is the Aggregation of Individual Preference Structures (AIPS) by Escobar and Moreno-Jiménez (2007) that evaluates the "holistic importance" of each alternative and of each possible ranking and finds the most representative preference structure distribution for the group rather than a single group ranking. In this paper, together with the traditional methods (AIJ and AIP), we aggregate the individual rankings derived from AHP by other two voting procedures.

2.2. Voting procedures to aggregate stakeholder preferences

In general, when a group of people is involved in a voting process, individual preferences' rankings have to be aggregated into a unique collective preferences' ranking in such a way to best reflect the "will of the group" (Pacuit, 2012). The "Borda Rule" (Borda, 1781) and the "Pairwise Majority Rule" (PMR) are among the most widely used voting methods to obtain the aggregation.

With the "Borda Rule" the collective ranking is obtained on the basis of the sum of different scores assigned to each preference in order to reflect the individual preferences' ranking (e.g., if an individual ranking is A>B>C, then A=3, B=2 and C=1).

With the "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 (e.g., in the previous case, A is preferred to B and C according to the couples AB and AC). 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 ranking is derived by applying a majority rule to the binary vectors (e.g., if there are five voters and three of them prefer B to A, then we have AB = -1 three times and AB= +1 two times, therefore according to the majority is B>A).

The two methods can lead to different results (Dasgupta and Maskin, 2004), therefore one could ask what is the best one. In general PMR is mostly used because, in the largest domain, it satisfies all the requirements of a social choice rule (Raffaelli and Marsili, 2005). Nevertheless, the aggregation of individual preferences' rankings by PMR does not exclude the possibility of intransitive collective rankings as result, i.e. the risk of the "Condorcet paradox". It was studied for the first time in 1785 by the Marquis de Condorcet (1785) who demonstrated that, for a number of alternatives $n>2$, the collective social preferences' order can be intransitive even if the individual preferences' orders are transitive (e.g. the collective preference order can be A>B>C>A). The final consequence is the impossibility of taking an aggregated consistent decision. The probability of the "Condorcet paradox" decreases in a large population if they are allowed to interact by exchanging their opinions before voting (Raffaelli and Marsili, 2005; Columbu et al., 2008).

The Borda and PMR voting methods will be used to aggregate the individual rankings derived from AHP and the results, in particular with regard to the degree of consensus, will be compared with those derived from the traditional AHP techniques.

2.3. How to measure consensus through preference overlap

Measuring consensus and effectiveness of public participation is a big concern of practitioners. For this purpose, several indicators and models have been proposed to assess "stakeholder satisfaction" (Li et al., 2013), consensus among experts (Herrera-Viedma et al., 2002), e.g. those involved in Delphi studies (von der Gracht, 2012).

In this study a simple indicator of consensus is proposed to measure the similarity of a collective preference list with the individual ones. If n is the number of alternatives and $m = n(n-1)/2$ is the number of the possible couples of alternatives (i.e. the number of components of each binary vector), the overlap between two lists is defined as:

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

where V_i^k and V_j^k are the k-th components of the two binary vectors $\boldsymbol{V}_i$ and $\boldsymbol{V}_j$ representing the preference lists of stakeholders S_i and S_j. From this definition follows that $O_{ij} \in [-1;1]$; if S_i and S_j have the same opinion, then $\boldsymbol{V}_i=\boldsymbol{V}_j$ and $O_{ij}=1$; if all the homologous components V_i^k and V_j^k have opposite signs, then $O_{ij}=-1$; if $\boldsymbol{V}_i$ and $\boldsymbol{V}_j$ are uncorrelated, then $O_{ij}=0$. The overlap of two stakeholders' opinions about the preference order of n alternatives can be interpreted as the scalar product of the two binary vectors with m components, that is the degree of alignment of two opinions in a m-dimensional space. If N is the number of stakeholders involved in the decision, the concept of overlap can be extended to represent the average similarity between the collective list c and the N individual ones:

$$\overline{O}_{i,c} = \frac{1}{N} \cdot \frac{1}{m} \cdot \sum_{i=1}^{N} \sum_{k=1}^{m} V_i^k \cdot V_c^k \qquad (2)$$

The concept of average overlap will be used to measure to what extent different aggregation methods of individual preferences or the level of stakeholder interaction may affect the degree of achieved consensus towards the final decision.

2.4. Agent-based model of stakeholder interaction

Representing stakeholders in multi-agent systems (MAS) and using an agent-based modelling (ABM) approach is considered helpful to "model complex phenomena that involve human or institutional behaviour" (Voinov and Bousquet, 2010). In this context, an agent-based model was set up to reproduce a participatory group decision-making process (Le Pira et al., 2015). In this respect, the main aim of the model is to understand what role interaction plays in escaping from intransitive cycles and if it favours the convergence of opinions towards a final decision, i.e. a collective list reflecting quite appreciably the individual preferences.

Stakeholders are the nodes of a social network and their interactions through the available links is investigated by means of an opinion dynamics model; the consensus formation depends upon critical variables such as the network topology and the degree of interaction. Stakeholders (agents) are endowed with own properties (such as opinion and influence) and act according to simple behavioural rules to reproduce the opinion exchange flows.

The simulation model has been implemented and performed within the software environment NetLogo (http://www.ccl.northwestern.edu/netlogo), particularly suitable for ABM. It 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. A list of ordered alternatives is initially randomly assigned to all stakeholders, to represent their individual preferences. Then, each stakeholder is allowed to know the lists of his neighbours (i.e. the directly connected nodes in the network) and, at each interaction step, he decides to change his preferences' list according to the overlap between his list and the one of the majority of his neighbours, weighted by their influence. Then, a collective list is obtained aggregating all individual lists by PMR and a check of its transitivity is carried out. The algorithm goes on until a transitive list is found.

Generally, the first transitive list found with this method does not have a high average overlap (i.e. degree of consensus), therefore the interaction is repeated in order to find new more shared transitive solutions. The average overlap in general presents a growing trend as far as the interaction goes on, until it reaches a stationary state, corresponding to its maximum value. The final list is assumed as the transitive "most shared" collective solution, appreciably reflecting the individual preferences.

In this study, the simulation results obtained through the above described model are compared with analogous results derived from a real participation experiment, in order to see to what extent they are similar for a given topology of stakeholder network. Furthermore, simulations give some suggestions about other possible topologies which can increase the efficiency of the interaction process.

3. Case study

The study is based on a public participation experiment where a given number of master students were asked: (i) to express their opinions about possible mobility management alternatives to be adopted in their university, (ii) to motivate the alternatives' order derived from their judgments and to share their opinions interacting with each other, (iii) to reformulate their judgments after interaction. The AHP method was applied - before and after interaction - to derive a priority list of alternatives for each student, on the basis of their judgments of preference between all couples of alternatives in a "local context", i.e. the alternatives were compared upon a unique criterion (Escobar and Moreno-Jiménez, 2007). The aggregation of the priority lists was done by using the different methods described in section 2. The group decision-making process was carried out in two steps, but the whole experiment took four meetings. Participants were 17 students in total, corresponding to 2^{nd} year master students in Transport Engineering of the University of Catania (Italy). After a short description of the mobility management of the University of Catania, the experiment will be described and the results presented.

3.1. Mobility Management of the University of Catania

The professional role of the Mobility Manager has been established in Italy by law in 1998 with the so called "Decreto Ronchi" (Ministero dell'Ambiente, 1998), one of the main Italian law on sustainable mobility. It requires enterprises with more than 300 employees to adopt a home-to-work travel plan, following the approach of Transport Demand Management (TDM), a valid strategy to overcome the problems connected with road congestion and all other transport externalities (Litman, 2003; Ignaccolo et al., 2006).

The University of Catania was founded in 1434 and it is one of the oldest universities in Italy. It has about 53,000 students and 2,500 employees that daily commute to the University sites, quite distributed in the city. In 2009 the home-to-university travel plan (MOMACT, 2009) was issued, whose main contents are the analysis of the status quo of the student and staff mobility, the identification of the main criticalities, main objectives and the proposal of some mobility management measures to improve the present situation. Traffic congestion, limited public transport use, little diffusion of cycling and walking for systematic trips, inefficiency of the parking management, absence of city logistics measures are the main critical issues of the transport system of Catania.

The participation experiment described in this study can be considered part of the updating of the existing plan. Indeed, the involved students can be regarded both as stakeholders and experts, being master degree students in Transport Engineering. This also implies that they have similar interests, goals and level of competence, therefore the results must be considered specific and representative of homogeneous communities of stakeholders.

3.2. The public participation experiment

The experiment is an iterative and interactive participation process and it can be summarized in four steps:

1st step: questionnaire. All students were asked to consult the home-to-university travel plan. Then, they were trained to fill in an online questionnaire mainly regarding the different action alternatives. The proposed alternatives were: (1) establishment of public transport (PT) lines dedicated to students and staff; (2) facilitation for using local public transport (LPT); (3) better management of the University parking spaces; (4) car pooling promotion; (5) bike-sharing service dedicated to University members; (6) rescheduling of working and studying hours and telecommuting.

2nd step: motivations. From the results of the questionnaire and, in particular, from the pairwise comparisons of all alternatives, it was possible to derive a preference order among the alternatives for each student with the geometric mean method (Ishizaka and Nemery, 2013). Students were sent emails with the results of their preference orders among alternatives and they were asked to make a short report to explain the motivations of their preference.

3rd step: session on AHP. This session was done to increase students' awareness of the relevance of MCDA and AHP methods to support transport decisions. In particular, they were trained to solve a numerical example aimed to calculate and understand the meaning of consistency of judgments.

4th step: interaction and 2nd questionnaire. The interaction was done to see if it could lead to an opinion change towards a convergence of opinions. Each student was given a few minutes to briefly support his/her choice and the debate among all students was also encouraged. Finally, after having listened to the opinions of the others and being more conscious about the importance of consistent judgments, they were asked to make once again the pairwise comparisons among the alternatives. In this case we repeated the questionnaires twice, but the same process could be iterated a number of time *N* according to the situation and the desired degree of consensus that one wants to reach.

3.3. Results of the experiment

The individual preferences were aggregated with different methods, to investigate their influence on the overlap of the collective list with the individual ones. According to the method used, in some cases the individual pairwise comparisons (PWC) were used for the aggregation procedure, in others the individual vectors of priorities derived from AHP. Table 1 summarizes the results of the average overlap calculated before and after interaction with different aggregation methods, sources of individual preferences to be aggregated (from PWC or AHP), aggregated collective lists of preferences.

Table 1. Results of collective orders and average overlap before and after interaction using different aggregation methods.

Aggregation method	**Source of individual preferences**	**Description**	**Collective Preference Order**		**Average Overlap**	
			before	**after**	**before**	**after**
PMR	PWC	PWC transformed in binary vectors[1] (+1 and -1); PMR applied	2>3>4>5>6>1	2>3>4>5>**1>6**	0.43	0.59
Borda	AHP	Scores assigned to alternatives according to the ranking from AHP; total scores summed	2>3>4>5>6>1	2>3>4>5>**1>6**	0.43	0.59
AHP-AIJ-gm	PWC	PWC aggregated into a group matrix (AIJ) using the geometric mean (gm); AHP applied	2>3>4>5>6>1	2>3>4>5>**1>6**	0.43	0.59
AHP-AIP-gm	AHP	Geometric mean (gm) of the weights derived from AHP for each alternative (AIP)	2>3>4>5>1>6	2>3>4>**1>5**>6	0.42	0.55

[1]in case of equal importance between two alternatives we do not consider this term in the computation of the pairwise majorities.

PMR, Borda and AHP-AIJ-gm lead to the same results (before and after interaction) and the collective list resulting from them shows the maximum values of overlap. This can be considered a sound result, both because different aggregation procedures lead to the same collective list and for the good overlap related to it. In any case, with all the methods there is a general increase in the convergence of opinions and this confirms the efficacy of interaction in the group decision-making process. The same result is visible with the radar diagram in Fig. 2a, where the overlap of each stakeholder list with the collective list is evaluated. The ratio between the areas covered by the overlap and the maximum possible area (represented by the red circle in Fig. 2a corresponding to the ideal case in which the average overlap is equal to 1) measures the increase of consensus due to interaction (from 0.50 to 0.62 with a 19% increase).

The Consistency Ratio (CR) is used to evaluated judgments' consistency in terms of the deviation of the individual pairwise comparisons from random judgments (Saaty, 1980). Values lower than CR=0.10, represented by the red circle in Fig. 2b, are suggested in literature. The majority of stakeholders' judgments resulted inconsistent after the first questionnaire (only 2 out of 17 were consistent) and after the second questionnaire - with the explanation of AHP - the total amount of consistent judgments was only 6 (out of 17) and the average CR remained almost the same. This is because, even if there is a general decrease of CR, some of the values are clearly outliers (Fig. 2b).

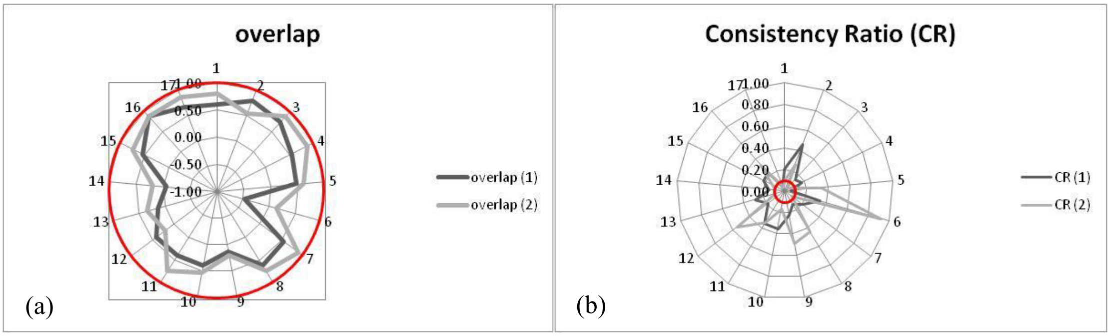

Fig. 2. Consistency ratio (a) and overlap (b) for the 17 students before (1) and after (2) interaction; the red circles represent the limit of consistency (CR≤0.10) (a) and the maximum reachable overlap (O(i,c)=1) .

At first glance this result is surprising, but in reality it depends on how the experiment was carried out: students were only asked to assign preference scores for each couple of alternatives, without being too much aware of how this would have affected their judgments' consistency, nor of the impact of each alternative on the general objective of the plan. Moreover, they filled in the questionnaire in a short time if compared with similar experiments (Mau-Crimmins et al., 2005) that show better values of consistency.

Fig. 3 shows that there is a good correlation between the overlap among stakeholders (named as "stakeholder overlap") and the average overlap of each stakeholder with the collective list (i.e. group overlap). On average, the consensus towards the collective list is higher than consensus among stakeholders, meaning that the collective list can be considered a good compromise between more diverging opinions.

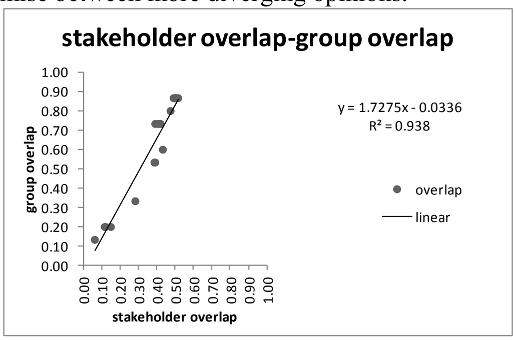

Fig. 3. Linear correlation between stakeholder overlap and group overlap considering resulting from PMR (after interaction).

3.4. Results of the agent-based simulations

In order to reproduce the same experiment with the agent-based model, a network with exactly the same number of stakeholders (17 nodes) is considered. The network is "fully connected", i.e. each node is linked with all the others. This can represent quite well the interaction process among students, where each of them expressed his opinion in front of the others. Actually, the model simulates a repeated interaction, starting from an intransitive collective list, where at each step of interaction stakeholders can change their opinion and a new PMR is evaluated, until average overlap reaches a stationary state. The final values of both the overlap and the overlap/links, averaged over 500 simulation runs starting from different initial conditions, are shown in Fig. 4a: the final overlap is very similar to the one obtained with PMR from the participation experiment (i.e. 0.59), but the ratio overlap/links - that can be considered as a measure of the interaction efficiency, which takes into account the "cost" of each interaction – is very small. This suggests that other topologies, e.g. a star network (where only one central node is linked with all the others), could be more efficient (see also Le Pira et al., 2015). The same simulations are therefore repeated for this kind of network and, as shown in Fig. 4b, while the average overlap remains the same, the average ratio overlap/links is sensitively higher than before.

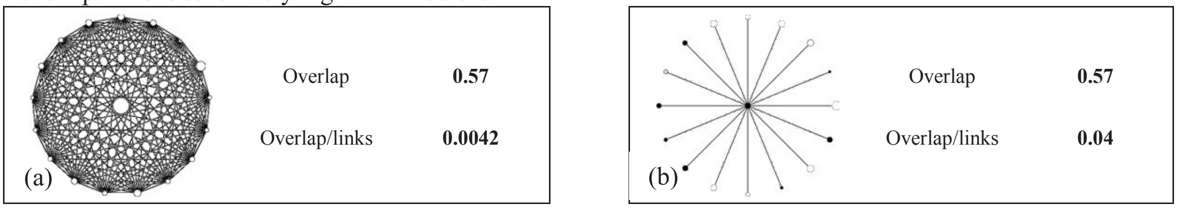

Fig. 4. Results of the simulations: (a) fully connected network; (b) star network.

It is worthy of notice that different initial conditions lead to the same result: while the real experiment was carried out with a quite "homogeneous community" of stakeholders, the model starts from a random assignment of initial preferences among stakeholders, i.e. reproducing "heterogeneous communities". This implies that the same result is obtained after just one step of "real" interaction among students, and much more steps of repeated interaction in the model, until the final overlap becomes stable. In our case, the homogeneity of stakeholders simplified the carrying out of the experiment, but further experiments will consider different groups of stakeholders to reproduce more realistic situations and to see to which extent it is possible to reach a good convergence of opinions.

4. Discussion and conclusions

In this paper we presented the results of a public participation experiment with students and of an agent-based simulation that reproduced it. The aim was to analyze different aggregation procedures starting from the elicitation of the individual preferences with the well-known MCDA method known as AHP. This was done to see if there are methods that are better than others in giving a collective opinion with a high degree of consensus, respecting the transitivity and consistency condition.

The results show that, whatever the method used to aggregate preferences, interaction is fundamental to increase the degree of consensus of the collective decision, measured through the average overlap. In particular, the results using the voting methods known as PMR and Borda were the same and the collective list showed the highest overlap (i.e. the highest degree of consensus). For what concerns the AHP methods, the aggregation of individual preferences with geometric mean gave the best results in terms of overlap. Using AHP to elicit subjective preferences in a "local context", i.e. making judgments upon a unique criterion, the consistency condition was not respected, which is not an obvious result. Finally, the outcome of the real experiment has been compared with the analogous one obtained through agent-based simulations. The final results suggest that computer-aided analysis of consensus building processes can be useful, on one hand, to anticipate the behavior of a real network of stakeholders with a given topology in terms of degree of consensus, on the other hand, to select the more appropriate topology in terms of efficiency of the interaction process.

In conclusion, in the framework of the participatory decision-making process in transport planning, the role of quantitative methods is important to elicit stakeholder preferences and to aggregate them. Interaction is fundamental for the success of the participation process because it allows to reach more shared decisions; agent-based simulation can be a very useful tool both to reproduce and manage a real process of stakeholder interaction.

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