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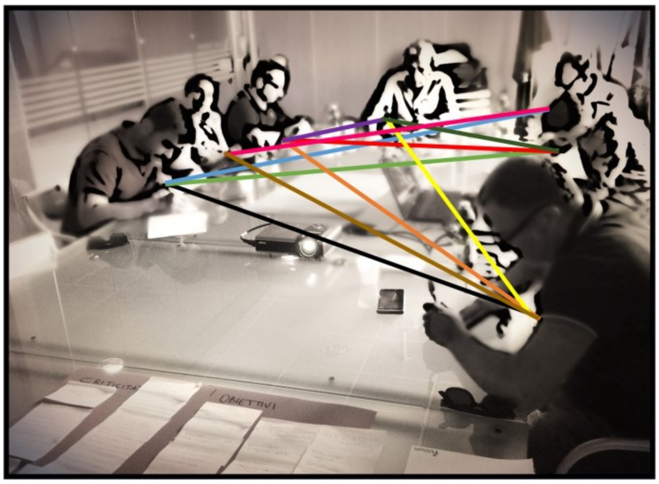
TOWARDS PARTICIPATORY DECISION-MAKING PROCESSES IN TRANSPORT PLANNING: AN AGENT-BASED APPROACH

Tesi di Dottorato in Ingegneria delle Infrastrutture Idrauliche, Sanitario-Ambientali e dei Trasporti (XXVIII ciclo)



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Dedicated to those who hold a stake,

in what really matters.

Abstract (EN)

The aim of the research is to give a contribution and an insight on the complex field of stakeholder involvement in transport planning, by analysing the role of decision-support methods and agent-based modelling in guiding a participation process.

The approach is twofold: from one side it is about to deeply understand the process of making a collective decision, by studying how the interaction among different actors can lead to a convergence of opinions towards a shared collective decision. From the other side, it is based on finding appropriate decision-support methods to help the group decision-making process.

Agent-based modelling and simulations have been used, in order to guide real participation processes and predict the results of an interaction process, and group multi criteria decision-making methods, to help taking consistent decisions based on several judgment criteria. The results of the research should help decision-makers and practitioners in dealing with multiple stakeholders and complex decisions and guiding the participation process.

Abstract (IT)

Lo scopo della ricerca è quello di dare un contributo nel campo della partecipazione pubblica alle decisioni nella Pianificazione dei trasporti, analizzando il ruolo dei metodi di supporto alle decisioni e i modelli ad agenti per guidare un processo di partecipazione.

L'approccio è duplice: da un lato si tratta di comprendere a fondo il fenomeno delle scelte collettive, studiando come l'interazione tra i diversi attori possa portare a una convergenza di opinioni verso una decisione collettiva condivisa. Dall'altra parte, si tratta di trovare adeguati metodi di supporto alle decisioni che possano guidare il processo di partecipazione.

La metodologia si basa sull'utilizzo di modelli ad agenti, con l'obiettivo di orientare processi di partecipazione reali e prevedere i possibili risultati di un'interazione, e metodi di supporto alle decisioni di gruppo, per aiutare a prendere decisioni coerenti sulla base di diversi criteri di giudizio. I risultati della ricerca possono essere d'aiuto a decisori e

tecnici ad affrontare decisioni complesse con più soggetti interessati e guidare i processi di partecipazione.

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List of papers

This thesis is based upon the following papers and publications:

I. Ignaccolo, M., Inturri, G. & Le Pira, M. (2013). The role of Public Participation in sustainable port planning. PORTUS: the online magazine of RETE, n.26, November 2013, Year XIII, Venice, RETE Publisher, ISSN 2282-5789. URL: http://www.portusonline.org/the-role-of-public participation-in-sustainable-port-planning/

II. Le Pira, M., Ignaccolo, M., Inturri, G., Pluchino, A., & Rapisarda, A. Modelling multi-stakeholder preference ranking for sustainable policies. Under review.

III. Le Pira, M., Ignaccolo, M., Inturri, G., Pluchino, A. & Rapisarda, A. Modelling stakeholder participation in transport planning. Under review.

IV. Le Pira, M., Ignaccolo, M., Inturri, G., Garofalo, C., Pluchino, A., & Rapisarda, A. (2013). Agent-based modelling of Stakeholder Interaction in Transport Decisions. Selected Proceedings of the 13th World Conference on Transport Research, 15th-18th July 2013. Rio de Janeiro, Brazil.

V. Marcucci, E., Gatta, V., Le Pira, M., Ignaccolo, M., Inturri, G. & Pluchino, A. Agent-based modeling of stakeholder involvement for urban freight transport policy-making. Under review.

VI. Le Pira, M., Inturri, G., Ignaccolo, M., & Pluchino, A. (2015). Analysis of AHP methods and the Pairwise Majority Rule (PMR) for collective preference rankings of sustainable mobility solutions. Transportation Research Procedia, 10, 777 – 787.

VII. Le Pira, M., Inturri, G., Ignaccolo, M., Pluchino, A. & Rapisarda, A. (2015). Simulating opinion dynamics on stakeholders' networks through agent-based modeling for collective transport decisions. Procedia Computer Science 52, 884–889.

VIII. Le Pira, M., Inturri, G., Ignaccolo, M., & Pluchino, A. Modelling consensus building in Delphi practices for participated transport planning. Under review. Available at: arXiv:1511.06127 [physics.soc-ph].

Glossary of terms

Here follows a glossary with the definitions of some basic terms:

Transport planning	Transport planning is a decision-making process based on rationality, aimed at defining and implementing transport system operations (Ortúzar and Willumsen, 2011) (p 29).
Public participation	*"'Public participation' means to involve those who are affected by a decision in the decision-making process"* (IAP2) (p 33).
Stakeholders	*"people and organizations who hold a stake in a particular issue, even though they have no formal role in the decision-making process."* (Cascetta et al., 2015) (p 35).
Complex system	*"Complex systems consist of diverse, adaptive actors who interact with their neighbors and over networks. These interactions produce both additive outcomes* [...] *as well as emergent phenomena"* (Page, 2015) (p 21).
Decision-support method	Quantitative methods that help the decision-making process (p 69).
Multi criteria decision-making/aiding method	Decision-support method that allows to include - in a comparative assessment of alternative projects - their contributions to different evaluation criteria, even if they are assessed by heterogeneous measures (p 70).
Analytic Hierarchy Process	Multi criteria decision-making method which belongs to the Multi-Attribute Value Theory methods (MATV), that rank the alternatives by means of numerical eigenvectors obtained from pairwise comparisons (Saaty, 1980) (p 70).
Social choice theory	*"Social choice theory is the study of collective decision processes and procedures. It is not a single theory, but a cluster of models and results concerning the aggregation of individual*

	inputs [...] *into collective outputs"* (List, 2013) (p 84).
Pairwise majority rule	It is a voting/aggregation method to derive collective preference rankings of alternatives by computing how many times each alternative in a pair is preferred to the other one (p 87).
Condorcet paradox	Given n alternatives (with n>2), the collective social preference order can be intransitive even if the individual preference orders are transitive (Condorcet, 1785) (p 90).
Multi-Agent system	*"A multi-agent system (i.e., a society of agents) is a community of autonomous entities each of which perceives, decides, and acts on its own, in accordance with its own interest, but may also cooperate with others to achieve common goals and objectives"* (Sun, 2006) (p 97).
Agent-based modelling and simulation	Agent-based modelling and simulation (ABMS) is basically a computer technique simulating a system whose main components are agents (p 97).
Opinion dynamics model	Model aimed at defining the opinion states of a population, and the elementary processes that determine transitions between such states (p 102).

List of acronyms

Here follows a list of the most recurrent acronyms:

ABM	Agent-based model/modelling
ABMS	Agent-based model/modelling and simulation
AHP	Analytic Hierarchy Process
DCM	Discrete choice model/modelling
DSM	Decision-support method
GDSM	Group decision-support method
MA-AHP	Multi-Actor Analytic Hierarchy Process
MAS	Multi Agent System
MCA	Multi Criteria Analysis
MCDM/A	Multi Criteria Decision-Making/Aiding
OD	Opinion Dynamics
PMR	Pairwise Majority Rule
PPGIS	Public Participation Geographic Information System
SH	Stakeholder
SNA	Social Network Analysis

INTRODUCTION

"So how do we start building cities that make us care? Cities that value their most important asset: the incredible diversity of the people who live in them? Cities that make us happy? Well, I believe that if we want to change what our cities look like, then we really have to change the decision-making processes that have given us the results that we have right now. We need a participation revolution and we need it fast."

Alessandra Orofino: It's our city. Let's fix it. TEDGlobal 2014

Background and motivation

Cities and transports are two inseparable elements of human life: transports exist to connect cities and to make them accessible, cities "pulse"[1] thanks to transports and they are both necessary for the evolution of human kind.

The challenges of modern cities must be tackled with an integrated global approach where transport planning should be driven by the idea that a good transport system improves the quality of life.

Transport systems are regarded as complex systems[2] that include multiple agents making decision and where aggregate system characteristics emerge from the aggregation of individual behaviours (Ettema, 2014). Such transport systems are elementary parts of the complex adaptive system "city", characterized by heterogeneity, interconnectivity, scale, circular causality and development (Bettencourt, 2014).

In this context, transport planning is not a simple task, in particular at the urban scale, because it involves decisions that affect multiple actors with conflicting interests, such as the users of the transport systems, the citizens, the transport operators, and all those who have an interest or

[1] to know more about the "pulse of the city", visit: http://simulacra.blogs.casa.ucl.ac.uk/2011/08/pulse-of-the-city/

[2] "*So what are complex systems? Complex systems consist of diverse, adaptive actors who interact with their neighbors and over networks. These interactions produce both additive outcomes – aggregate oil consumption or the average price of #2 red wheat – as well as emergent phenomena such as traveling waves in traffic patterns, stock market crashes, and even Spanish culture. These aggregate phenomena become part of the world and induce adaptations at the micro level. These in turn create new macro level phenomena*" (Page, 2015).

hold a stake in that particular decision: the so called “stakeholders”. If they are not properly involved in the decision-making process, this can cause protests and even the plan failures, wasting money and time.

Nowadays it is widely recognized the importance of involving citizens and stakeholders in a participatory planning process with different levels of growing involvement. The participatory approach helps to have better decisions supported by the public and to increase the transparency of the whole process, but still we are far from a comprehensive knowledge of effective participation techniques and procedures and from a satisfactory inclusion of them in the transport planning process as well.

This PhD research presents a methodological approach towards participatory decision-making processes in transport planning. It is not intended as a practical guideline on how to do participation in transport planning; conversely, it is aimed at providing a deep knowledge and comprehension of the complex phenomena emerging from social interaction and consensus building processes, suggesting how to tackle the complexity of participation in transport planning.

The approach is twofold: from one side it is about to deeply understand the process of making a collective decision, by analysing how the interaction among people can lead from diverging opinions towards a shared collective decision. From the other side, it is based on finding appropriate decision-support methods to help the group decision-making process.

To this aim, different agent-based models have been built to simulate real participation processes and predict the results of an interaction process where transport policy-makers and stakeholders compare and change their opinions, while different group multi-criteria decision-making methods have been used, to assure the consistency of decisions based on several judgment criteria. The final output is a toolkit of methods for decision-makers and practitioners to help them dealing with multiple stakeholders and complex decisions and guiding the participation process in the different phases of transport planning.

Research aim, basics and questions

The aim of this research is to give a contribution and a deeper insight on the complex field of stakeholder involvement in transport planning, by analysing the role of decision-support methods and agent-based modelling in guiding a participation process. Many research questions motivated the work and some of them still lack a complete answer, paving the way for further research.

To understand the meaning of the questions, it is necessary to make some premises about the basics of the participatory approach in transport planning:

1. Complex decisions-making processes in transport, when multiple criteria and multiple stakeholders are involved, require the use of decision-support methods.

This consideration is due to the evidence that transport systems are "complex social and technical systems" and that transport issues belong to the class of problems known as "wicked problems", characterized by the lack of a definitive formulation, of stopping rules and single objective evaluation criteria and the uniqueness of the problem (Cascetta et al., 2015). In this context, involving stakeholders in a participation process about complex decisions require the support of appropriate quantitative decision-making/aiding methods.

2. The consensus-based decision needs an appropriate aggregation of the individual preferences of the stakeholders into a collective one.

The problem of preference aggregation is not new in social choice theory (Arrow, 1951). This is because there are multiple different ways to put together single opinions into a collective one, that in the simplest case results to be an "average", which is not satisfactory or representatives of the individual opinions. Considering that different methods lead to different results, the problem of aggregation becomes worth to be analysed.

3. The consensus-based decision should be consistent and shared.

This assumption is a consequence of the previous one. Being different the aggregation methods that can be used, it is important that the decision derived from aggregation is (1) consistent, avoiding deadlock and unfeasibility of decisions due, for instance, to the possibility of intransitive results (Condorcet, 1785) and, most of all, (2) shared, meaning that it should satisfy to a certain level the individual opinions and expectations.

4. Interaction among people favours the convergence of opinions towards a shared decision.

Considering that the stakeholders involved cannot belong to a homogeneous community in terms of interests and objectives, it is clear that interaction among them becomes fundamental to "smooth" diverging opinions and find a compromise. In this respect, qualitative and quantitative methods have demonstrated that interaction and deliberation can change stakeholders' mind about public policy problems (Quick et al., 2015) and favour the success of a group decision-making process.

5. The participation process should be efficient and avoid time (and money) waste.

One of the big concerns of decision-makers and practitioners is time (and money) to be devoted to a participation process. Having clear (i) the problem to solve, (ii) the stakeholders to be involved, (iii) the methods to use is fundamental to guide effective participation processes. Besides, understanding in advance how to conduct an efficient process requires specific modelling tools that can help the planning of it.

From these considerations, the main research questions are presented:

1. **What is the role of Multi Criteria Decision-Making/Aiding (MCDM/A) methods in a participatory decision-making process?**

To answer this question, a literature review was done. In particular, there are many applications in the transport sector of traditional techniques to decision-making processes involving more than one decision-maker. Group MCDM/A (GMCDM/A) methods prove to be effective in making stakeholders understand the problem, eliciting their preferences and aiding the decision-making process.

2. **How to aggregate individual preferences into a collective one?**

To better understand the problem of preference aggregation, the suitability of some voting methods, which satisfy most of the requirements of social choice rules (Arrow, 1951), has been investigated, with the help of agent-based models and applying them to real participation experiments.

3. **What is the influence of interaction in finding a shared decision and how to model it?**

The beneficial role of interaction is demonstrated in multiple ways. Some participation techniques, such as the Delphi method (Dalkey and Helmer, 1963), rely on an anonymous interaction among experts to find a convergence of opinions. Besides, the effectiveness of interaction has been demonstrated via models. In this respect, opinion dynamics models and agent-based models are very useful in reproducing the opinion exchange flows in groups of people, considering each individual as an independent agent endowed with specific properties and acting according to simple behavioural laws.

4. **How to guide an efficient and effective participation process in transport planning?**

The last question is maybe the most challenging one. First of all, because all the assumptions made so far and the previous questions can be easily extended to any decision-making process that involves multiple stakeholders and complex decisions. It is clear that, in order to analyse a topic that is recent for the discipline of transport planning and, therefore, quite unknown, it is necessary a multidisciplinary approach, ranging from sociology to economy, sociophysics and engineering. Nevertheless, it is also fundamental to link the topic with the specific case of participation in transport planning. To this purpose, case studies are the main elements to "shape" the methodology together with a solid reference framework of the transport planning process.

Guiding an efficient and effective participation process is not an easy task, because of the complexity and peculiarity of each decision to be made. Despite that, the attempt made with this thesis is to provide some tools that can help to understand the problem and have a clear insight on the main elements influencing a participation process.

Methodology

The methodology presented is mainly based on:

1) Agent-based modelling and simulations (ABMS), to reproduce participation processes involving stakeholders linked in social networks, understanding the role of interaction in finding a shared decision, with the help of opinion dynamics models, and investigating some important parameters such as stakeholder

influence, degree of connection, level of communication for the success of the interaction process.

2) Group multi-criteria decision-making/aiding (MCDM/A) methods, to assist the group decision-making process, by structuring the problem to include different criteria of judgments and points of views, in order to deal with the complexity of decisions regarding "wicked problems".

Thesis outline

The outline of the thesis is the following. Each chapter is based on one or more publications (see list of papers at p 15).

Chapter 1. The first chapter is an introduction to the topic of public participation in transport planning. The overall framework of the transport planning process including stakeholder engagement will be introduced together with normative references and guidelines about how to tackle public participation. Some of the methods to involve stakeholders and models to help the participation process will be described. In the paper of Appendix A1 the specific case of public participation in port planning will be presented.

Chapter 2. In this chapter an overview of traditional decision-support methods to aid transport planning and group decision-support methods to include public participation will be provided. In particular, the approach of multi-criteria decision-making methods for group decision-making will be presented.

Chapter 3. The problem of aggregating stakeholder preferences will be analysed with reference to some basics concept of social choice theory applied to transport planning. Two widely used voting methods that can be used to aggregate stakeholder preference in a participation process will be presented: the Pairwise Majority Rule (PMR) and the Borda Rule. The rationale of these methods and the potential pitfalls will be presented.

Chapter 4. In this chapter the usefulness of representing stakeholders in multi-agent systems (MAS) and using agent-based models (ABMs) to reproduce stakeholder involvement in transport decisions will be clarified. In particular, opinion dynamics models will be presented as a central component of the methodology.

Chapter 5. This chapter is a description of the methodology, with respect to the three implemented ABMs. Each of them captures a different aspect of the participatory decision-making process, from the simulation of the collective decision about a specific transport policy to the collective preference ranking with the possibility of decision deadlock, and the simulation of a cyclical interaction process with multiple levels of stakeholder networks.

Chapter 6. Case studies will be presented, that are basically applications of the ABMs; some are purely theoretical, others are grounded on empirical data from real experiences, where MCDM/A methods helped the design and carrying out of the participation processes and the implemented ABMs were tested and validated. Results will be commented and they will provide some considerations for further research.

Chapter 7. This chapter is intended as a sum up and conclusion of the research, with the aim to provide a framework of participatory decision-making process in transport planning, placing public engagement in the phases of the transport planning process and suggesting how to guide participation with the help of quantitative methods and agent-based models.

1. THE NEED OF PUBLIC PARTICIPATION IN TRANSPORT PLANNING

"Planning and designing transportation systems should expressly be recognized as managing complex, multi-agent decision-making processes in which political, technical and communication abilities should all be involved in order to design solutions which are technically consistent and, at the same time, maximize stakeholder consensus."

Cascetta et al., 2015

1.1. The complexity of the decision-making process in transport planning

Transport systems are complex systems because they affect the social, economic and environmental dimensions of a territorial community with several impacts and feedbacks not easy to be foreseen. Further complexity is added by the procedural issues related to construction and operation of the transport systems and mostly for the many actors involved with often conflicting interests. Public Administration, at the different territorial levels (national, regional, local) is the actor usually responsible to take decisions about the transport system. This is usually done through a set of documents that constitute a Transport Plan. It has the main objective to address the management of a sequence of decisions and actions about infrastructures, operation and regulations of the transport system and their impacts on the community. Transport planning is a decision-making process based on rationality, aimed at defining and implementing transport system operations (Ortúzar and Willumsen, 2011). It effectively means achieving aims and objectives as a result of a technical and political process, through a set of decisions that will inevitably favour some interests and expectations at the expense of others.

Just to have an idea about the complexity of decisions regarding transport systems, it can be helpful to think about the strict relationship between transport and land use, meaning that, in the long term, a change in the transport system can produce a change in the activity system and surely it can have an impact on the environment (Torrieri, 1990). "Urban Sprawl", i.e. the uncontrolled expansion of low-density, single-use suburban development, is one of the biggest issues that modern cities are facing, and it is mainly caused by car-dependency.

Several studies demonstrate the unsustainability of this settlement, not in terms of green areas or permeable soils, but in terms of urban quality (La Greca et al., 2011). Therefore, the "smart growth" of the cities can be pursued by mixing transport and land use policies that minimize sprawl (Kenworthy, 2010), such as the Transit Oriented Development (TOD) (Calthorpe, 1993), where transit nodes become central for the development of efficient activities and residential areas. In this framework, the concept of "smart city" becomes fundamental in modern society: the "smart city of the future", i.e. *"a city in which ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies"* (Batty et al., 2012), should be characterized by services which allow to optimize trips and to facilitate everyday activities, thus efficient transport systems are fundamental.

Besides, even small decisions made at a very fine scale can produce much larger effects and great reactivity: street pedestrianizations, although at the beginning can be strongly opposed by retailers who think that impeding car access would reduce street attractivity, in the long term produce great economic benefits. Parking pricing is a largely debated topic, from the theory of the "high cost of free parking" by Shoup (2005), suggesting that free parking costs much more than toll parking. He found out that the right price is the one that leads to a maximum rate of parking space occupancy of 85%, while higher values of occupancy, with less or no parking pricing, produce much more traffic congestion (and all the indirect effects such as pollution) due to the continuous search of a free space. These counterintuitive simple examples suggest that not only transport plans, but also small decisions have great impacts on the society and unpredictable effects.

It is also easy to understand why transport planning is not just about redacting a plan which contains long-term decisions, but it is a planning process, e.g. a sequence of elaborations (plans or system projects) aimed at different decisions made in different moments (Cascetta, 1998; De Luca, 2000).

Some authors claim the importance of adopting a "rational" approach (Cascetta, 1998), based on a quantitative evaluation of the effects that a certain decision will produce. In this respect, mathematical models play a crucial role, through their capability to simulate the transport system and to support the analysis of its performances under different scenarios and, in the end, to assist the decision-maker during the planning process.

Clearly models must be considered just as tools to support the planning process, but they cannot substitute it (Ortúzar and Willumsen, 2011). The traditional planning process can be subdivided in macro-activities (Cascetta, 1998) and they can be categorized in technical and decision activities on one side and analytical and modelling phases (functional to the previous ones) on the other. Decision-making models have been proposed to represent typical situations according to the "degree of rationality" on which they are based (Cascetta et al., 2015), i.e.:

- the "strongly rational" model, where the decision is the result of a maximization problem of some measures of utility or economic profit. It can be used in decision contexts with simple objectives and constraints expressed by quantitative variables;
- the "bounded rational" model, where *"the actors are still goal-oriented, but they implicitly take into account for their cognitive limitations in attempting to achieve those goals"*. Since there can be multiple decision-makers, the model aims to find a satisfactory compromise rather than the optimal value of a function. It is a dynamic process and it implies that objectives and constraints may be revised if a satisfactory solution is not reached;
- the "cognitive rationality" model *"makes the dynamic nature of the decision-making process explicit, ideally divided into subsequent stages, while retaining the realism and flexibility of bounded rationality within each stage"*. It is a "learning" dynamic process where the actors learn about solutions and their effects during the decision-making process.

The framework of the traditional rational model is presented in Figure 1:

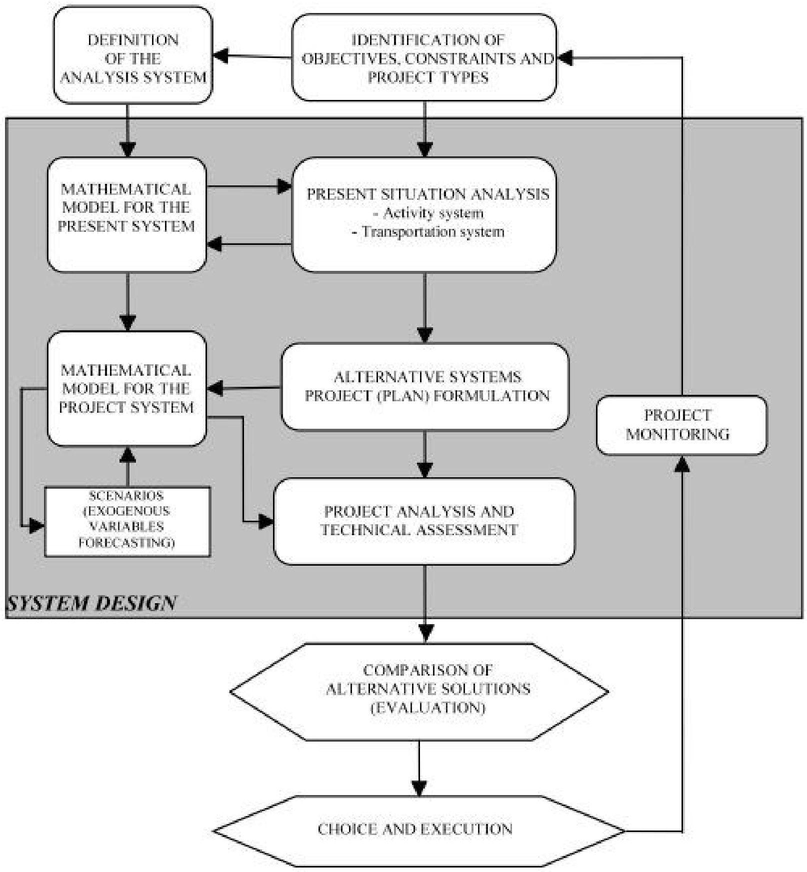

Figure 1 – The rational decision-making process in transport planning (Cascetta, 2009).

Starting from the definitions of the objectives and constraints, the analysis of transport demand and supply and traffic counts, in the present situation, is used to set up and calibrate a simulation model of the transport system; the model is then used to simulate and predict the impacts of alternative plans and projects, under different scenarios. The outcomes of the models form the basis for decision-making.

By comparing the results obtained from the model and from the technical assessment (evaluation phase) the final choice is made, and the process must be followed up by monitoring the project. Many decision-support methods (DSMs) can help this process and we will call them “the traditional methods” (see section 2.1).

Transport planning is going to lose its nature of a simple rational choice among technical alternatives and is more and more being included within a policy process. In facts, even if a transport plan is meant to increase the net welfare of a community, the benefits will never be equally distributed among its different actors and groups interested in influencing the planning process. Transport planning is therefore mostly to manage a public decision-making process.

1.2. The role of Public Participation in the decision-making process

According to the definition of the International Association for Public Participation (IAP2[3]): *"'Public participation' means to involve those who are affected by a decision in the decision-making process. It promotes sustainable decisions by providing participants with the information they need to be involved in a meaningful way, and it communicates to participants how their input affects the decision."*

The right of Public Participation when public decisions may affect environmental protection and human health is internationally recognized and legally guaranteed from the Aarhus Convention in 1998:

"Information is power, and environmental information in the hands of public enables it to play a meaningful role in shaping a sustainable future. For this reason, progress in sustainable development and in greening the economy is directly dependent on the meaningful engagement of civil society in decision-making. Effective access to information, public participation and access to justice are essential for transparent and accountable governance, for high quality outcomes of the decision-making and to strengthen trust of public in governing institutions" (UNECE[4], about public participation).

Public participation in transport planning is emerging as a basic component of the project to which human and financial resources have to be dedicated from the beginning of the decision-making process:

"Public Engagement (PE), or Stakeholders Engagement (SE) [...] *is a two-way communication process that provides a mechanism for exchanging information and promoting stakeholder interaction with the formal decision-makers and the transport project team. The overall goal of engagement is to achieve a transparent decision-making process* [...]*"* (Cascetta and Pagliara, 2013).

The social awareness of including the public in the decision-making process is a consequence of the failures of many projects because of lack

[3] http://www.iap2.org/

[4] http://www.unece.org/env/pp/welcome.html

of consensus building. A clear example of it is the project of the high-speed railway line connecting Lyon (France) to Turin (Italy), expected to cut across the Susa Valley in Italy, which caused the opposition of the inhabitants and gave birth to a movement named "No TAV" because of the environmental risk associated with it. The reasons of the opposition and the evolution of it are explained by Marincioni and Appiotti (2009). In general, the lack of consensus building is mainly due to the traditional approach of the decision-maker, known as the "DAD" ("Decide, Defend and Announce") approach (Cascetta and Pagliara, 2013). On the other side, among the "syndromes" that can "affect" citizens' reactions there are the so-called "NIMBY" ("Not In My Back Yard") syndrome, "BANANA" ("Build Absolutely Nothing Anywhere Near Anything") syndrome, "LULU" ("Locally Unwanted Land Use") syndrome, the last one referred to land use planning. In Italy a web forum monitors and records in a national database all the projects which have been interrupted by protests from the community: the latest update show that in Italy there are more than 350 infrastructures, mainly transport infrastructures, affected by the NIMBY syndrome[5]. Today, new forms of rationality oriented to problem solving and negotiation lead to put attention on the principle of inclusivity in the decision-making process. It is more and more recognized that participatory processes where experts and non-experts share their knowledge, can (i) lead to better decisions, (ii) determine an improvement of the resource management and (iii) promote more responsible conducts in the actors involved (Cucca, 2009). In this respect, talking about sustainable mobility, Banister (2008) states:

"The messages are clear. There is strong support for enlarging the scope of public discourse and empowering the stakeholders through an interactive and participatory process to commit themselves to the sustainable mobility paradigm. The open and active involvement of all parties would be far more effective than the conventional passive means of persuasion. Thus, broad coalitions should be formed to include specialists, researchers, academics, practitioners, policy makers and activists in the related areas of transport, land use, urban affairs, environment, public health, ecology, engineering, green modes and public transport. It is only when such coalitions form that a real debate about sustainable mobility can take place." (Banister, 2008).

[5] http://www.nimbyforum.it/

The need to make the public participate in the decision-making process is clearly stated in lots of European documents (e.g. Directives 2003/4/EC; 2003/35/EC; COM(2005) 716; COM(2013) 913) and international treaties (Earth Summit, 1992; Aalborg Conference, 1994 (and Aalborg + 10), Treaty of Amsterdam, 1997; Aarhus Convention, 1998; Johannesburg Summit, 2002) (Laniado et al., 2005). Following EU directives, Italy adopted a compulsory public participation only for the Strategic Environmental Assessment (SEA) procedure, required for all plans and programmes that can have an impact on environment (D.L. 152/2006). While in other countries participation is regulated with clear procedures to be followed, e.g. in France, England and United States (Cascetta and Pagliara, 2013), in Italy it is not considered as a part of the planning process[6]. Nevertheless, there are some regional laws about participation (law 69/2007 in Tuscany, laws 8/2008 and 3/2010 in Emilia Romagna, laws 14 and 18/2010 in Umbria) and it is possible to find lots of examples of public participation experiences (Bobbio, 2007; Cucca, 2009; Cascetta & Pagliara, 2013). Recently, the 2014 law for Sicilian Regional stability (law 5/2014 modified by law 9/2015), states that at least 2% of funding assigned to municipalities which will be used for actions of public interest must be dedicated to participative democracy, under the penalty of restitution otherwise[7].

The word "public" is usually referred to all persons potentially affected by or interested in a decision, i.e. the potential "stakeholders". The concept of stakeholder has been evolving from the first definition in the economic field by Freeman (1984) ("*any group or individual who can affect or is affected by the achievement of the organization's objectives*"). Mitchell et al. (1997) report a chronology of this concept and the key constructs in the theory of stakeholder identification and salience. Stakeholders involved in transport decisions are defined as "*people and organizations who hold a stake in a particular issue, even though they have no formal role in the decision-making process. They may have an institutional, professional, or economic interest in the project, or their environment or livelihood may be affected in some way by the implementation of the project (i.e. conflicting interests)"* (Cascetta et al., 2015).

[6] Actually, in 1990, it has been introduced in the local administration with the national law 142/90 on the local entities' legal order (art. 6) but there is no penalty and it is not a common practice of local administration.
[7] Sicilian regional law 5/2014, art.6 par. 1, modified by regional law 9/2015, art.6 par. 2.

With regards to transport planning, the EU strongly encourages the Member States to adopt innovative plans such as Sustainable Urban Mobility Plans [8] (SUMPs) and Sustainable Urban Transport Plans [9] (SUTPs), where participation is considered as a key issue of success for the decision-making process and for the implementation of the plan itself [10]. As already stated, transport planning is characterised by lots of decisions concerning several issues and involving many stakeholders. Public involvement and participation become fundamental to find an alternative that should be the best trade-off between the "most shared" solution and the "optimal" one, determining a new rational and time saving decision-making process. Arnstein (1969) identifies different levels of growing involvement in a "ladder of citizen participation", from "Nonparticipation" to "Citizen Power". The five Public Engagement levels proposed by Kelly et al. (2004) ("Stakeholders identification", "Listening", "Information giving", "Consultation", "Participation") are integrated into the framework of the "three legs" model of transport planning proposed by Cascetta et al. (2015). It is based on three integrated processes, namely: cognitive decision-making, stakeholder engagement and quantitative analysis (Figure 2).

[8] *"A Sustainable Urban Mobility Plan follows a transparent and participatory approach. The Local Planning Authority should involve the relevant actors - citizens, as well as representatives of civil society and economic actors – in developing and implementing the plan from the outset and throughout the process to ensure a high level of acceptance and support."* (Annex to the COM(2013) 913 final)

[9] *"Transport planning should take account of safety and security, access to goods and services, air pollution, noise, greenhouse gas emissions and energy consumption, land use, cover passenger and freight transportation and all modes of transport. Solutions need to be tailor-made, based on wide consultation of the public and other stakeholders, and targets must reflect the local situation. The Commission strongly recommends local authorities to develop and implement Sustainable Urban Transport Plans."* (COM (2005) 718 final)

[10] Even if the terms "SUTP" and "SUMP" were introduced in different moments (respectively in 2006 and in 2009) they "basically describe the same concept. However, in spite of these definitions a common European understanding of SUMPs or SUTPs is currently still missing" (European Parliament, 2012)

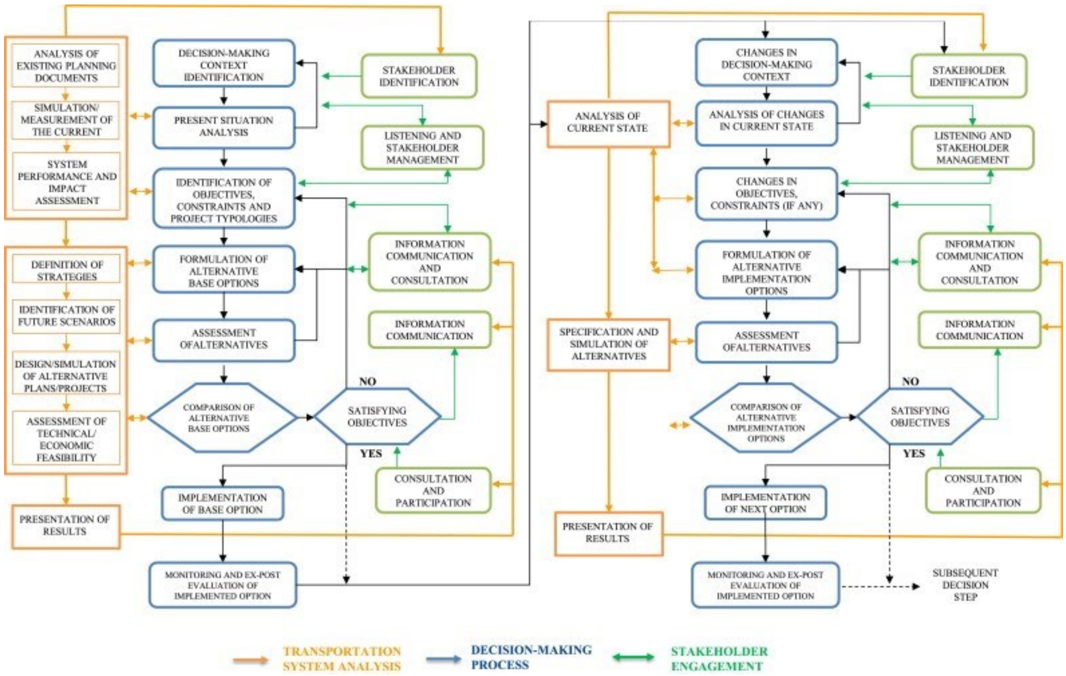

Figure 2 – Schematic representation of the overall transportation decision-making model or "three legs" model (Cascetta et al., 2015).

Based on this framework, Le Pira et al., 2015a propose a simple scheme to summarize and link the transport planning process with monitoring and participation:

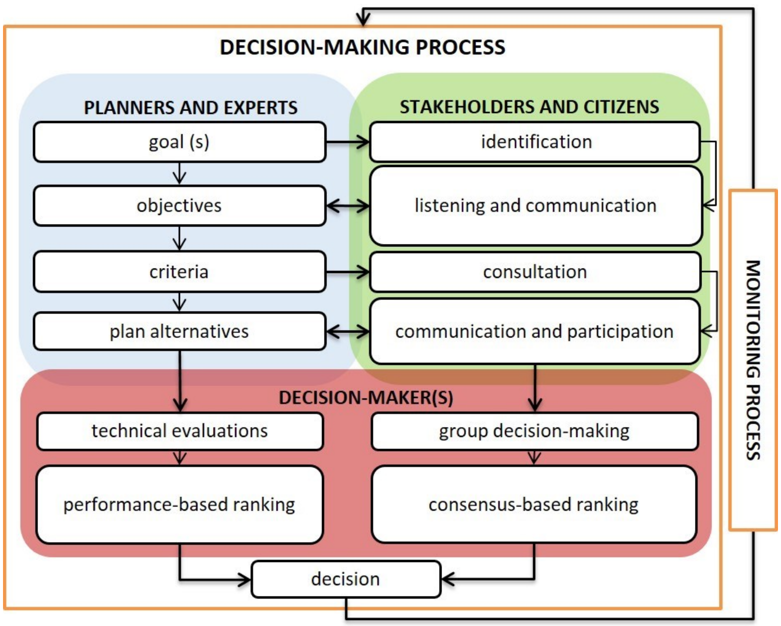

Figure 3 – Framework of the participatory decision-making process in transport planning (Le Pira et al., 2015a).

The proposed decision-making process identifies three main actors and their related roles: 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.

In order to implement an effective participatory approach, it is necessary to understand what kind of tools and methods can help to design and speed the process of taking a public decision, starting from the first essential phases of stakeholder identification and analysis.

1.3. Stakeholder identification and analysis

Identifying all the relevant stakeholders to involve in a decision-making process is not trivial. Decision context plays a fundamental role in understanding who to involve, therefore a good knowledge of it is required. Some authors classify stakeholders on the base of the type of interest they have in the plan/project: "primary stakeholders" are those who have a direct interest in the decision (e.g., transport operators or transport users) and "secondary stakeholders" are the ones who have an indirect interest (e.g. local communities) (Cascetta and Pagliara, 2013).

Similarly, the SUMP guidelines (Wefering et al., 2014) identify four types of actors to be involved in the decision-making process:

i. the "primary stakeholders", defined as those "*who will ultimately be affected – positively or negatively – by new transport measures*";
ii. the "key actors", i.e. "*who has political responsibility* [...] *who has the financial resources* [...] *who has the authority* [...] *who has the skills and expertise* [...] *– in transport and related domains*";
iii. the "intermediaries", defined as those "*who implements transport policy* [...] *who carries out major transport activities* [...] *who represents pertinent interest groups* [...] *who informs and reports on transport*";
iv. the "local champions", as "*key individuals who may play a significant role in mobilising resources, creating alliances, etc. because of their personal skills and the recognition they receive among local actors*".

In addition to the type of interest, it is also important to understand the degree of power associated with stakeholders. In this respect, the interest/power matrix by Gardner et al. (1986) identify four categories of stakeholders from marginal stakeholders (with low interest and weak power) to key stakeholders (with high interest and strong power) (Figure 4).

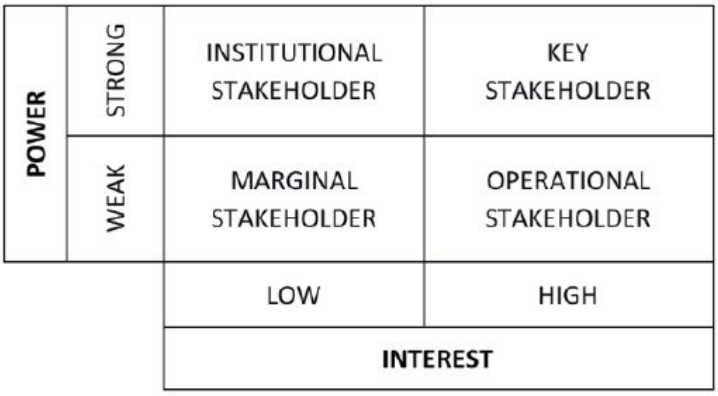

Figure 4 – The interest/power matrix (Gardner et al., 1986 in Cascetta and Pagliara, 2013).

For what concerns transport planning, Cascetta and Pagliara (2013) propose a classification based on seven categories (institutions/authorities, users, transport operators, business and unions, local communities, media and financial institutions) (Table 1).

Table 1. Stakeholder classification in transport planning (reproduced from Cascetta and Pagliara, 2013).

Institutions and Authorities	**Users**	**Transport operators**	**Business and Unions**	**Local communities**	**Media**	**Financial Institutions**
European Union	Direct users (pass)	Transport operators	National and local industry associations	Transport users associations	TV station	Banks
National government and authorities	Direct users (freight)	Transport operator associations	National and local trade unions	Local interest groups (e.g. borough associations)	Radio station	Funds
National parliament	Indirect users (pass)	Consultants	National and craft unions	Environmental associations	Newspapers	Insurances
Regional governments and Authorities	Indirect users (freight)		Retailers associations	Citizens		
Regional transport authority			Industry in public works	Visitors		

Institutions and Authorities	Users	Transport operators	Business and Unions	Local communities	Media	Financial Institutions
Local authorities (Provinces and Municipalities)			Industry in vehicles production			
Political parties and single members			Industry in technology production			

If we broaden the view in order to include all the actors involved in the planning process and we refer to the framework proposed in Figure 3 (p 37), they can be represented in a pyramid according to the level of competence and public interest (Figure 5): the "experts" (key informants), with high competence but low stake, the "stakeholders" (e.g. institutions, groups, environmental associations, transport companies), with competence and high stake, and the "citizens", with low competence but that act in the public interest (Le Pira et al., 2013). The decision-maker(s) is bounded with them and should take into consideration all the different points of view.

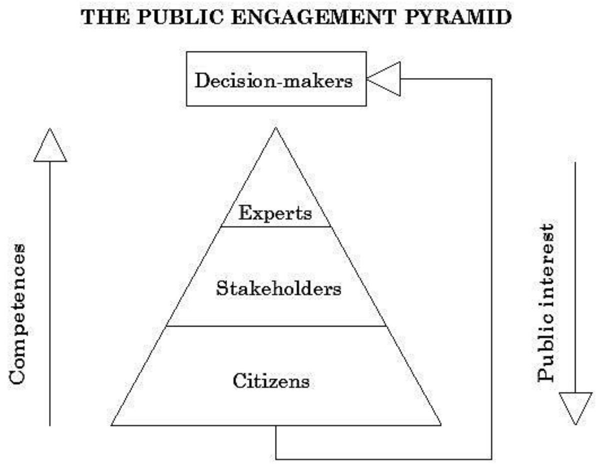

Figure 5 – The Public Engagement pyramid (Le Pira et al., 2013).

1.3.1. The "participation cube"

A new simplified framework is here proposed to combine the interest/power matrix (Gardner et al., 1986), the seven stakeholder categories in transport planning (Cascetta and Pagliara, 2013) and the public engagement pyramid (Le Pira et al., 2013). It can be considered an "exploded" three-dimensional matrix where the axes represent respectively public interest (x), power (y) and competence (z) and where it is possible to build a cube which represents different combinations of the three variables, from 0 (minimum) to 1 (maximum) (Figure 6).

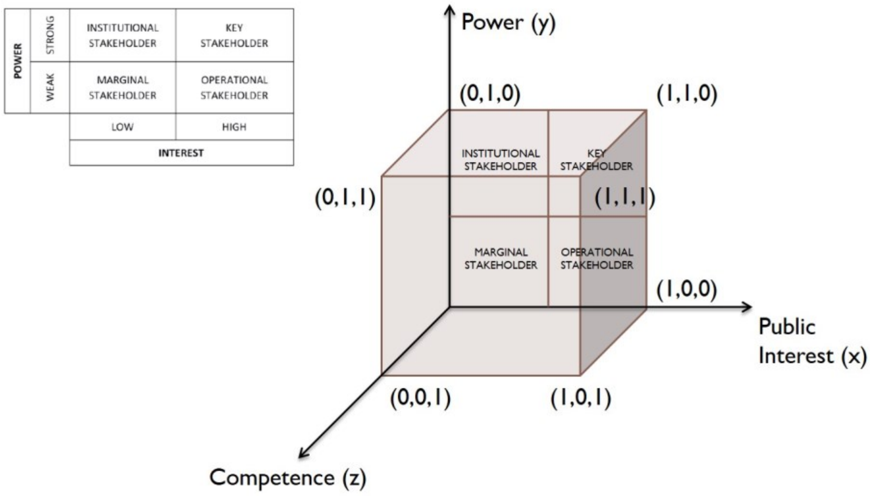

Figure 6 – The three-dimensional public interest/power/competence matrix the participation cube (own setup).

This cube can be considered as a "participation cube" where the different actors and stakeholder categories can be placed according to the level of public interest, power and competence (Figure 7, Figure 8).

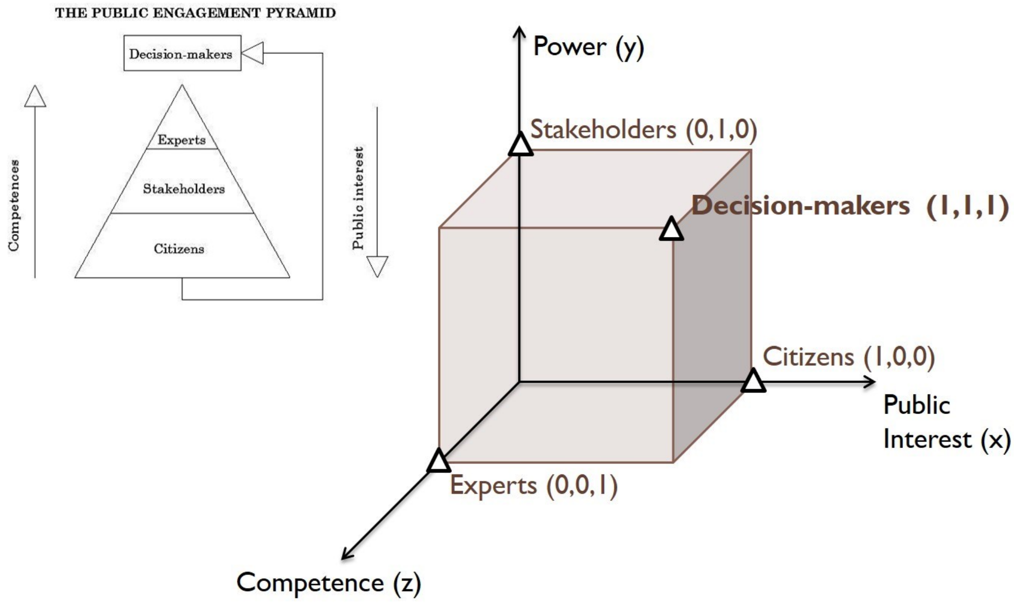

Figure 7 – The participation cube with the actors of the public engagement pyramid (own setup).

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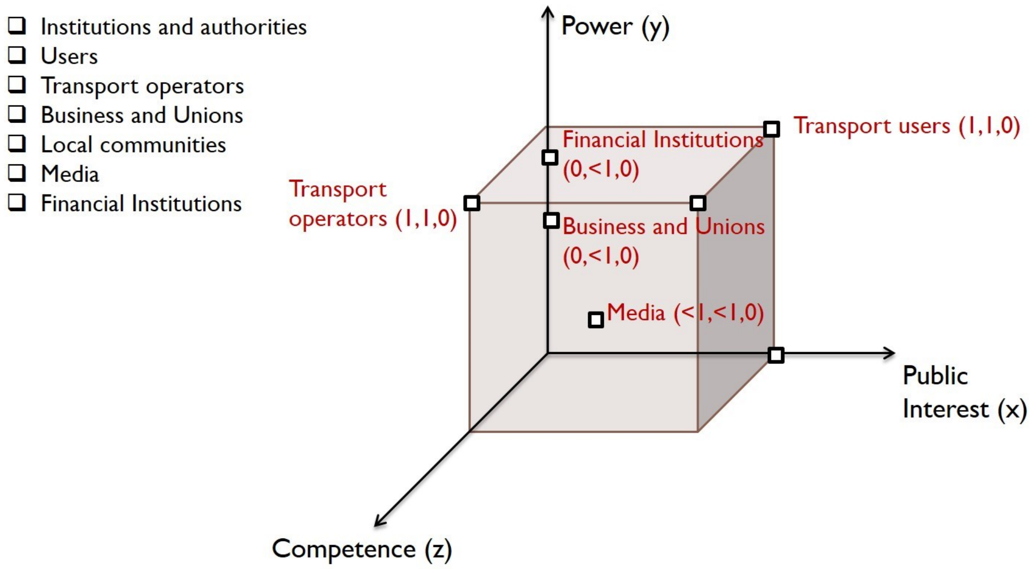


Figure 8 – The participation cube with the seven stakeholder categories in transport planning (own setup).

Figure 7 and Figure 8 present some overlap, so they can be merged in such a way that the vertexes of the cube represent the main typical actors involved in transport planning (i.e. institutions and authorities, local communities, transport users, generic stakeholders, transport operators, experts). Actually, there is one vertex which remains bare, i.e. the one representing high level of competence, high public interest and low power. In the author's opinion, it can be represented by a new actor of the decision-making process, which is a professional figure that should help the decision-maker in coping with public interests (i.e. citizens) and with experts' evaluations and that have no decisional power. According to Quick and Zhao (2011): *"As conveners of participatory design processes, transportation professionals must be responsive to other perspectives, help lay participants understand the technical aspects of the policies, be competent facilitators and cede some of their decision-making power."* This seems to introduce a new role in transport planning, i.e. the "Public Participation Practitioner" (Figure 9).

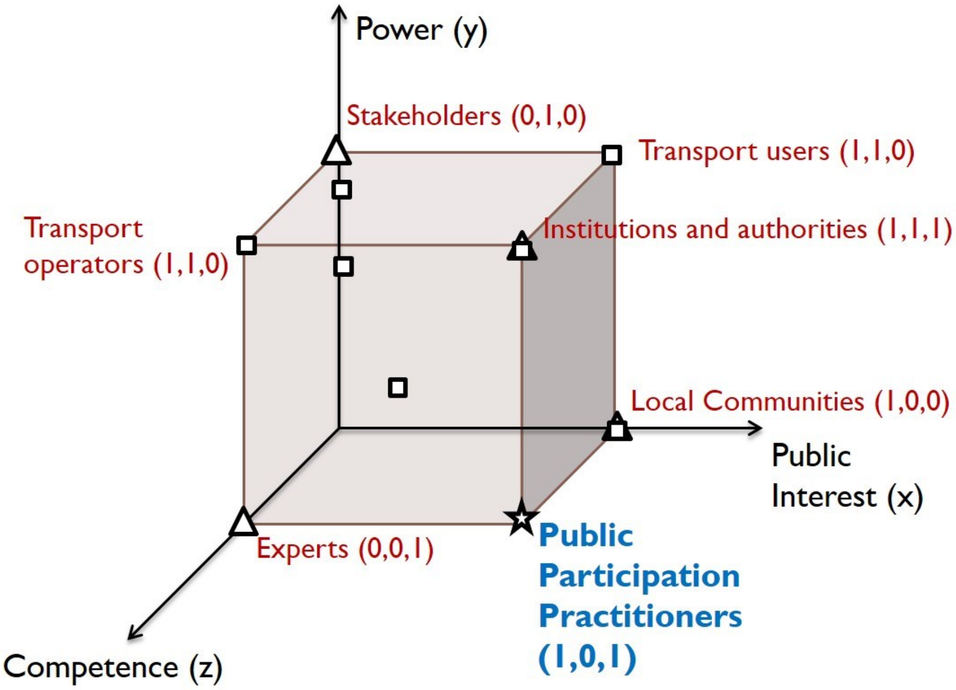


Figure 9 – The participation cube with the identification of the "Public Participation Practitioners" (own setup).

To summarize, this simplified representation allows a generic but somewhat comprehensive classification of the main actors to involve in a decision-making process in transport planning (Table 2). Nevertheless, it should be considered just as a reference framework and a starting point for stakeholder identification and analysis. Next subsections will show some useful techniques that can be used to analyse stakeholders and to have a clear insight on their role in the decision-making process.

Table 2. Main actors involved in a transport planning process.

	Public interest	Power	Competence
Institutions and Authorities (i.e. decision-makers)	✓	✓	✓
Transport users	✓	✓	
Transport operators		✓	✓
Local communities (i.e. citizens)	✓		

	Public interest	Power	Competence
Stakeholders		✓	
Experts			✓
Public Participation Practitioners	✓		✓

1.3.2. Social Network Analysis (SNA) applied to stakeholder analysis

A social network of stakeholders is a graph consisting of nodes (i.e. the social agents) and links (i.e. the relationships among them). Representing stakeholders in social networks can be helpful to have a clear insight on the actors involved in the decision-making process and the interactions among them.

Social networks fall within the category of complex networks, whose structure is irregular, complex and dynamically evolving in time (Boccaletti et al., 2006) and adequate methods are needed to study their structure and dynamics. Social Network Analysis (SNA) allows to quantify the social importance of a given individual in a network via centrality indexes and understand the potential problems due to topology.

Once stakeholders have been identified, it is important to understand what role they play in the decision-making process and how to engage them. There are different methods to elicit stakeholder objectives and preferences, e.g. from in-depth interviews with few key actors to stated preference questionnaires to multiple diverse stakeholders.

In this respect, Social Network Analysis (SNA) is here presented as a potential tool to analyse the role of the stakeholders involved in transport decisions.

SNA is an approach to the analysis of social structure which found its development in the last forty years. Scott (1988) describes its development since the 1930s with the term "sociometry" that came up with Moreno, *"as a way of conceptualizing the structures of small groups produced through friendship patterns and informal interaction"*. The studies on SNA involved both American and British researchers, with a particular attention on the concept of "centrality" of different actors for social psychologists, while "density" or "connectedness" of large social network was investigated by sociologists and anthropologists. Nowadays SNA has grown up with an intense research, e.g. the works of Jackson (2008) on social and economic networks, Granovetter (1973) on the "strength of weak ties", Watts and Strogatz (1998) on the concept of "small world".

The uses of social network analysis in theoretical and empirical planning are emphasised in the work of Dempwolf and Lyles (2010). They define SNA as "*both a theoretical perspective on how the interactions of individual autonomous actors form the social structures of community, and a set of analytical tools to analyze those interactions and social structures as networks of nodes (actors) and ties (relationships)".*

SNA can be considered as a strategy for investigating social structures and it can help to shorten the process of analysing stakeholders, by characterizing them through indicators of centrality, according to their role in the network.

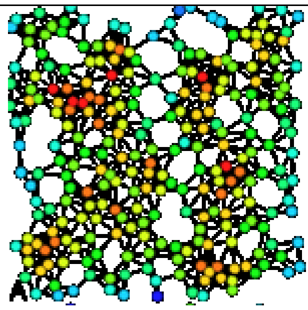
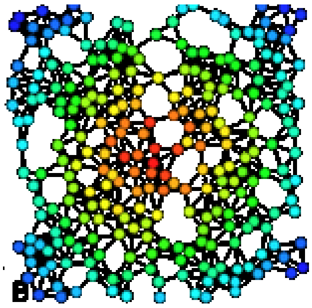
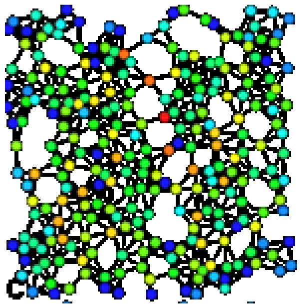
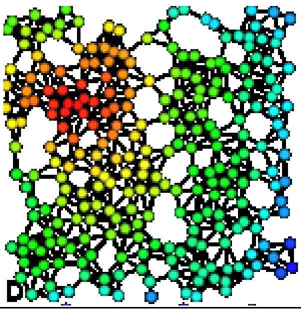
It can also be useful to analyse the relationships among organizations and stakeholders involved on a network basis, such as information flows, patterns of relationships and whether involvement in the network affects these relationships. It can allow to know how the actors involved in the planning process are related to in networks and communicate with each other.

The use of SNA in the field of Stakeholder Engagement can simply consists of stakeholder mapping or it can include centrality measures (Prell et al., 2009; García Melón et al., 2013). According to Schonk et al. (2011) project managers of construction works can use social network visualization to identify which stakeholders to engage, while stakeholders have clear insights on their positions in relation to the others.

There are automatic tools which can create a network and extract information from it, such as UCINET (Borgatti et al., 2002) or StakeSource, a web-based tool that uses social networks, a "crowdsourcing" approach to identify and prioritise stakeholders and their requirements (Lim et al., 2011).

Here follows some of the main centrality indexes that can be used to analyse stakeholder importance from Wikipedia[11] (Table 3).

Table 3. Main centrality indexes in a social network (increasing values of centrality from blue to red) (source: Wikipedia).

Centrality	Description	Example
A. Degree	The number of ties that a node has	
B. Closeness	The inverse of the sum of its shortest path to all other nodes	
C. Betweenness	The number of times a node acts as a bridge along the shortest path between two other nodes	
D. Eigenvector	It is a measure of the influence of a node in a network. Connections to high-scoring nodes contribute more to the score of the node	

[11] https://en.wikipedia.org/wiki/Centrality

Together with SNA, discrete choice models can help to provide further insight on stakeholder behaviour and preferences.

1.3.3. Discrete choice models (DCMs) applied to stakeholder analysis

Discrete choice models (DCMs) are basically econometric models aimed at analysing the behaviour of a decision-maker when choosing among different (discrete) alternatives, assuming that he/she tends to maximize his/her utility (rational decision-maker). They can be used to investigate stakeholders' preference heterogeneity in order to forecast their individual choice behaviour related to policy-making, i.e. as an additional tool to stakeholder analysis.

Economic analysis of individual discrete choices makes use of concept of the random utility maximization model (RUM), proposed by Block and Marschak (1960) and Marschak (1960). The decision-makers can be people, households, firms, or any other decision-making unit, and the alternatives might represent competing products, course of action, or any options or items over which choices are made (Train, 2003). Discrete choice analysis consists of (i) the specification of a behavioural model and (ii) the estimation of the related parameters. The utility U_{nj} of the decision-maker n related to the alternatives j is composed by two elements (Train, 2003): a deterministic or "representative utility" $V_{nj} = V(x_{nj}, s_n)\ \forall j$, as a function that relates some attributes of the alternatives j ($x_{nj}\ \ \forall j$) and some attributes of the decision-maker (s_n) to his/her utility and a random component ε_{nj} , which captures the factors that affect utility but that are unobserved, thus not included in V_{nj} :

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

The researcher does not know $\varepsilon_{nj}\ \forall j$, therefore these terms are treated as random with a certain density $f(\varepsilon_n)$, allowing to make probabilistic statements about the decision-maker's choice. According to the distribution of density, different models can be obtained. The Multinomial Logit Model (MNL) (McFadden, 1974) is widely used in transport planning to estimate the travel demand in the four step model, given a set of transport alternatives (i.e. mode choice or route choice) defined by certain attributes (Ben-Akiva et al., 1985; Cascetta, 2009).

Stated choice (SC) experiments are useful as a base for DCM to study policy acceptance, i.e. stakeholders' reaction to policy change. A choice experiment aims at acquiring high quality data to generate reliable and useful estimates of the parameters of interest, with different response format among choice, ranking or rating (Marcucci et al., 2011; 2012). There are many examples of studies across different sectors that relate community and stakeholder acceptance of public policies with discrete choice theory, as a way to facilitate improved community (stakeholder) analysis (Kelly et al., 2007; Hackbarth and Madlener, 2013; Huh et al., 2014; Que et al., 2015; Rijnsoever et al., 2015). Marcucci and colleagues use DCMs for behaviourally consistent policy evaluation in the field of urban freight transport (UFT) policy-making (Stathopoulos et al., 2011; Marcucci and Gatta, 2012; Marcucci et al., 2012; Gatta and Marcucci, 2013). Separate and joint stakeholder meetings are the basis for understanding their concerns about the main problems with respect to urban freight (Stathopoulos et al., 2011). Moreover, they allow for the identification of the most appropriate attributes and levels to be used in the analysis. Relevance, credibility and high level of shared support are the main criteria for attribute selection.

An agent-specific approach is fundamental to deal with heterogeneity of preferences; it is needed not only when acquiring data (Gatta and Marcucci, 2013; 2014) but also when estimating DCMs, through sophisticated approaches.

In conclusion, DCMs can be useful tools for stakeholder analysis, providing input to decision-makers about stakeholder preferences based on sound micro-economic theory.

Once stakeholders have been identified and analysed, it is important to know what methods choose to involve them in the decision-making process. Next section will show some of the methods (and models) that can be used for stakeholder engagement.

1.4. Methods and models for public participation in transport planning

Many guidelines describing techniques for stakeholder involvement are available in literature. They are basically based on vis-à-vis meetings, interviews, focus groups, but also on online engagement tools (Rucker et al., 2014). These techniques allow the decision-maker to know the diverse perspectives in advance and to avoid objections afterwards

(Roden, 1984; Wilcox, 1994; Rowe and Frewer, 2000; Kelly et al., 2004; Whitmarsh, 2007; Wefering et al., 2014).

In general, participation processes require time and money and they are often regarded as compulsory and quite formal steps of the decision-making process. The selection of the right methods is fundamental, since *"not only can the use of inappropriate techniques give poor results, but in some circumstances, it can create unnecessary barriers to the project as a whole, if it appears that the decision-makers are being selective in who or how they engage"* (Cascetta and Pagliara, 2013).

Quick and Zao (2011) provide an interesting review on the existing methods for public engagement in transport policy-making. Based on their work and on the "most formalized Public Participation methods" described by Rowe and Frewer (2000), Table 4 summarizes some of the main methods that can be used in transport planning.

Table 4. Some of the participation methods that can be used in transport planning based on (a) Rowe and Frewer (2000) and (b) Quick and Zhao (2011).

Method of involvement	Nature of participants	Time Scale/Duration	Description
Citizen/public advisory committee	small group of representatives of public	extended period of time	*"Group of stakeholders recruited to provide guidance on a policy area or project.* [...] *They do not generally have policy-making authority, and their influence on policy agenda and outcomes is mixed"* (b)
Project Review Teams	small group of representatives of public	extended period of time	They *"help transportation professionals to evaluate possible transportation projects. They may rank projects from a pool of proposals, or simply share comments and raise questions for transportation professionals to incorporate into their reviews"* (b)
Focus groups and workshops	small group of representatives of public and stakeholders	single event	They *"help professional staff or political leaders formulating policies to gain additional perspectives on a problem. These consultations may be with stakeholders with a particular interest in the issue*

Method of involvement	Nature of participants	Time Scale/Duration	Description
			or with members of the general public" (b)
Consultations with interest groups	small group of interested parties	small number of meetings	They *"generate input from groups recognized to have an interest in the issue. This may be the result of an intentional stakeholder analysis used to bring representatives of key constituencies into the discussion, or it may be a non-intentional result of outreach policies that fail to reach marginalized groups or emphasize organized constituencies" (*b)
Consensus conferences	Generally, 10 to 16 members of public (with no knowledge on topic)	extended period of time	They *"aim to take advantage of a diversity of opinions.* […] *Their common design feature is that they involve diverse stakeholders in interactive, iterative processes in which networks of people with divergent interests in an issue work together to define the problem, create a vision, identify appropriate pathways, and evaluate the impact. A consensus-oriented process requires consistent political and logistical commitment to share decision-making authority with the public over the duration of the project"* (b)
Deliberative polls	small group of randomly selected citizens	small number of meetings	It is a *"trademarked method for identifying the questions that the general public would have about a policy issue if they became better informed and discussed them in depth with people with differing viewpoints. Participants are randomly selected, prepared with a briefing packet, and attend a deliberative forum in which small, facilitated groups discuss the issue and decide together upon the questions about the policy that they would like to pose to experts and decision makers*" (b)

Method of involvement	Nature of participants	Time Scale/Duration	Description
Planning Charrettes	groups of stakeholders	small number of meetings	They *"involve stakeholders in directly experiencing and manipulating components of policy design, through games, simulations, maps, field trips, or other objects or experiences"* (b)
Structured Pubic Involvement (SPI)	general public	extended period of time	It *"involves the public in every decision phase, from defining the nature of the transportation problem, to creating the scope for the policy, setting design goals, and refining the options together. Recommended as a best practice for involving the public in design decisions, it occurs through iterative, focused explorations and strategizing about disaggregated aspects of the policy"* (b)
Referenda	Potentially all members of national or local population	single event	*"Vote is usually choice of one of two options. All participants have equal influence. Final outcome is binding"* (a)
Public hearings/ inquires	Interested citizens, limited in number by size of venue	extended period of time	*"Entails presentations by agencies regarding pans in open forum. Public may voice opinions but have no direct impact on recommendation"* (a)
Public opinion surveys	large sample (100-1000), usually representative of population segments of interest	single event	*"Often enacted through written questionnaire or telephone survey. Used for information gathering*" (a)
Citizens' jury/panel	12-20 members of public selected by stakeholder panel	small number of meetings	*"Lay panel with independent facilitator questions expert witnesses chosen by stakeholder panel. Meetings not generally open. Conclusions on key questions made via report or press conference*" (a)

Among the variety of available methods, those that focus on the convergence of opinions among stakeholders through their interaction (e.g. consensus conferences, deliberative polls, SPI) deserve a particular attention. It has been demonstrated through a variety of qualitative and quantitative methods that interaction and deliberation can change stakeholders' mind about public policy problems (Quick et al., 2015). In this context, also the Delphi method (Dalkey and Helmer, 1963) has the potential to be applied in transport planning. It is a widely used procedure when a panel of experts have to converge on a shared opinion. It is based on some solid assumptions (Pacinelli, 2008), i.e.:

- iterative structure, meaning that participants are called to express their opinions in more rounds;
- anonymity, to avoid bias due to leadership and reciprocal influence of the participants;
- asynchronous communication, with the possibility for the members of the panel to interact remotely and in different times.

At each round of anonymous interaction the members of the panel are asked to align their opinions within a range where 50% of the opinions stands (between the first and the third quartiles). The iterations are aimed at mitigating radical positions and finding a collective decision which is shared from the panel. The method has been primarily used to elicit experts' opinions about the future, with the aim to find "real" values, but it can also be used to explore the conditions of consensus building in a group.

The practical approach based on traditional methods should be combined with a theoretical one, meaning that the participation experiences should be monitored and the results investigated in order to understand the dynamics of interaction and consensus building and help the planning and guiding of a participation process.

A modelling approach can be used to reproduce participation processes. An agent-specific approach is necessary to deal with the heterogeneity of stakeholders with often diverging interests and avoiding bias due to aggregated measures. A comprehensive review of the main approaches of modelling with stakeholders can be found in Voinov and Bousquet (2010). According to the phases of the planning process and the levels of involvement, different models can be used.

Table 5 summarizes some of the approaches that can be used (Cascetta and Pagliara, 2013), and divides models into "static" and "dynamic".

Static models can give an insight on the participation process, by analysing the relationships among stakeholders (e.g. with SNA) or investigating their preferences (e.g. with DCMs). Static models can be used in the phases from stakeholder identification to consultation, nevertheless they cannot capture the dynamic nature of interaction among people nor the potential opinion changes that can lead to consensus building. A dynamic approach is more adequate to model the participation process in decision-making phases.

In this respect, agent-based models are a powerful tool to *"model complex phenomena that involve human or institutional behaviour* […]. *MAS* [Multi-Agent Systems] *describe the observed world in terms of actors (agents) that are characterised by certain rules (behaviour) that depend on the state of the environment, the state of the agent and its spatial location. Each agent is represented as an independent computerised entity capable of acting locally in response to stimuli or to communicate with other agents"* (Voinov and Bousquet, 2010).

In this thesis, an agent-based modelling (ABM) approach is presented to study public participation and reproduce stakeholder interaction in group decision-making processes in transport planning. Due to the complexity of transport decisions, which belong to the class of problems known as "wicked problems", the use of appropriate quantitative decision-making methods may support the involvement of different stakeholders in a group consensus building process. Next chapter will present an overview of decision-support methods for collective decisions.

Table 5. Practical and modelling approaches to participation processes as a function of the involvement levels and the phases of transport decision-making process (DMP).

Phases of Transport DMP	Levels of Involvement	Practical approach	Modelling approach
Decision-making context identification and present situation analysis	Stakeholders identification	Forum/chat, direct surveys, public meetings	***Static*** *(e.g. SNA applied to stakeholder analysis)*
	Listening and stakeholders management	Telephone, radio and TV shows, forum/chat, questionnaire, direct surveys, public meetings, focus group, technical tables, stakeholders conference	

Phases of Transport DMP	Levels of Involvement	Practical approach	Modelling approach
Identification of objectives, constraints and project typologies and alternative systems projects (plans) formulation	Information communication and consulting	Letter, poster, brochure and newsletter, technical reports, telephone, radio and TV shows, internet sites, forum/chat, exhibition, public meetings, stakeholders conference	***Static*** *(e.g. DCMs applied to stakeholder analysis)*
Project simulation and technical assessment	Information communication	Internet sites, questionnaire, direct surveys, focus group, technical tables, stakeholders conference	
Alternative solutions comparison (evaluation) and interventions choice	Consulting and participation	Telephone, internet sites, forum/chat, stakeholders conference, citizens' jury, referendum	***Dynamic*** *(e.g. ABM of stakeholder interaction)*

A1. The role of Public Participation in sustainable port planning[12]

Matteo Ignaccolo, Giuseppe Inturri, Michela Le Pira

Abstract

Ports play a strategic role in the development of domestic and international trade and have a strong impact on the liveability of the local community hosting the port as well. They face many problems related to the multitude of actors directly and indirectly involved and the variety of interests they represent. For these reasons port planning requires appropriate skills and procedures to be successful. One of the biggest issue is the need of Public Participation (also referred as Community Involvement or Public Engagement) into the decision-making process, in order to make the planning practice effective and (cost) efficient. What is important is to engage all the stakeholders from the very beginning of the planning process with different levels of involvement during all the relevant phases. Taking into consideration the stakeholders' needs and concerns it will be easier to find the most shared solutions pursuing port sustainability.

Keywords

Public Participation, Community Involvement, public participation. Stakeholders Engagement, Sustainability, Port Planning, Port-City relationships

Introduction

Transport infrastructures are complex systems for the many actors involved, their conflicting interests and for the procedural issues, particularly when a choice has to be taken among different alternative plans or projects.

When the decision making process is not well managed, the dilation of times among the phases of planning, designing, tendering and building

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new transport infrastructures and systems is a main risk. In the worst case the "do-nothing" alternative may be the most probable outcome.

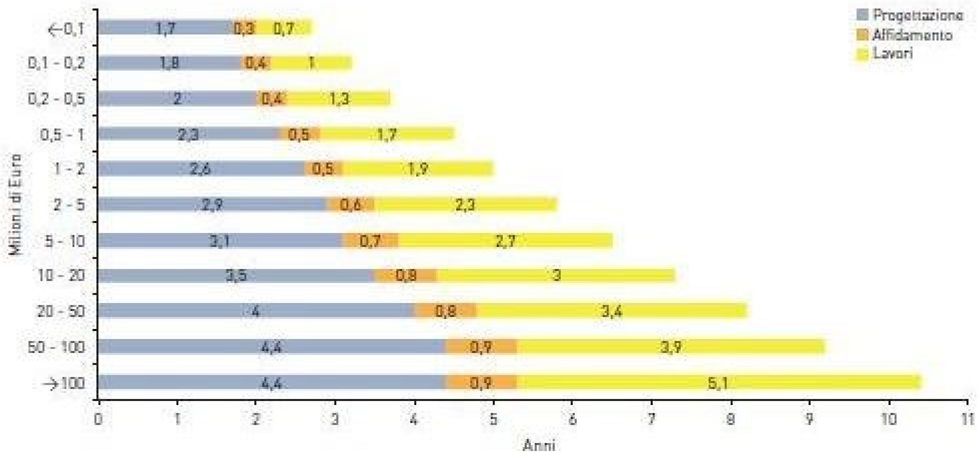

Image 1. Transport infrastructures construction times by cost range and implementation steps

Source: TEH – Ambrosetti (2012)

The main decision-maker in transport planning is the Public Administration which is supposed to interpret the collective preferences of the represented community, usually assisted by expert planners. The results of the decisions, in the form of a transport plan, affect in a direct way the so-called "stakeholders" and in an indirect way the social, economic and environmental dimensions of the whole community living in the reference area.

Port Planning

In the context of maritime transports, ports play a strategic role in the development of domestic and international trade and have a strong impact on the liveability of the local community hosting the port as well.

The objectives of a port are highly dependent on the mission statement, the regional market and the institutional context. They can be very different: from maximizing throughput, to maximizing net profit, operating at least cost, reaching financial autonomy, maximizing employment, or promoting regional economic development, maximize quality of service to shippers, just to give a few examples.

Port planning is a decision-making process based on the forecasting of transport demand and supply, as shown in Image 2. It is mostly a public-oriented activity, based on the evaluation of alternative options according to different criteria (economic, financial, environmental, social, functional) and to the assessment of priorities. The long term strategic equilibrium of the port activity is largely affected by the institutional framework (Port Ownership Model), by the Stakeholder Relationship Management (SRM) able to take into proper consideration the opinion of all actors involved in the port community.

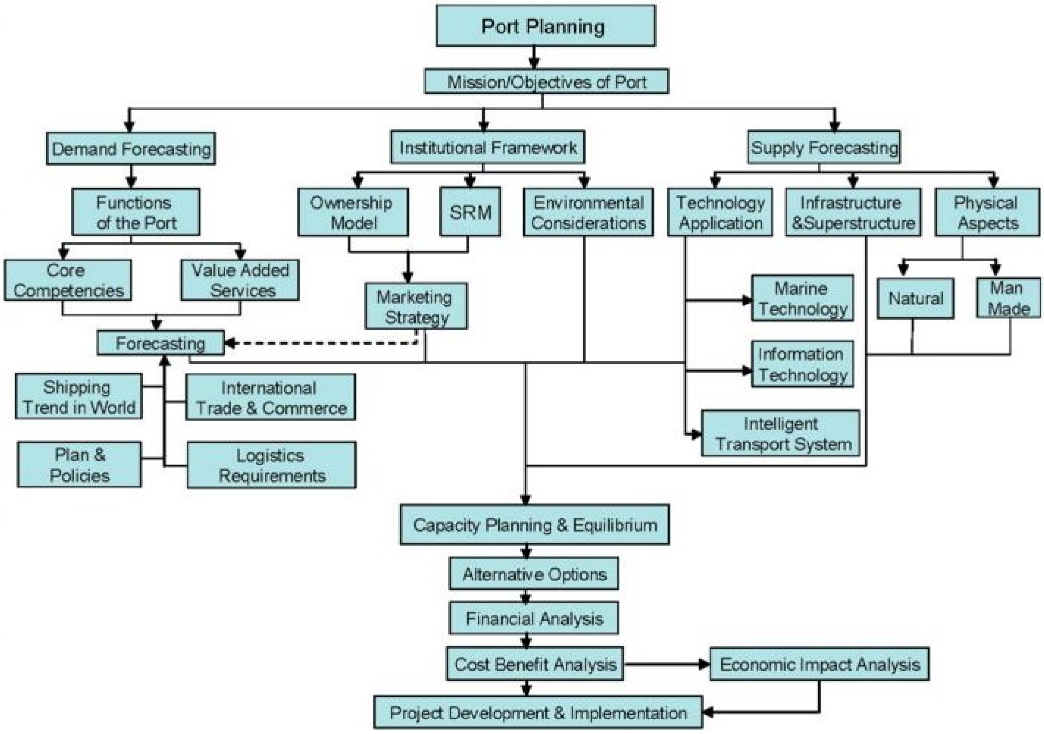

Image 2. Port planning framework (Gaur, 2005)

The success of a port and its competitiveness depend largely on the way the port manager succeeds in directing the interactions between different stakeholders.

Public Participation

There can be different types of barriers to the decision-making process as described by Cascetta (2011):

- barriers of context, which in turn can be institutional (i.e. who is responsible for what), legal (i.e. what is allowed by the law) and financial (i.e. lack of resources);
- barriers of the decision-making process due to the traditional approach of the decision-maker DAD (Decide – Announce – Defend) and the frequent consequence of contrasting new projects, also known as NIMBY syndrome ("Not In My BackYard"), or the

more extreme BANANA ("Build Absolutely Nothing Anywhere Near Anyone").

The NIMBY syndrome is so widespread in Italy, that a web forum has been set up to monitor the phenomenon (http://www.nimbyforum.it): in 2012 more than 300 NIMBY-syndrome-affected public works which caused protests and resistance from local communities has been recorded.

Image 3. Example of NIMBY syndrome: Gioia Tauro, despite the protest, the Port Committee gives go-ahead to the regasification terminal

Source: www.contropiano.org/ambiente/item/14982

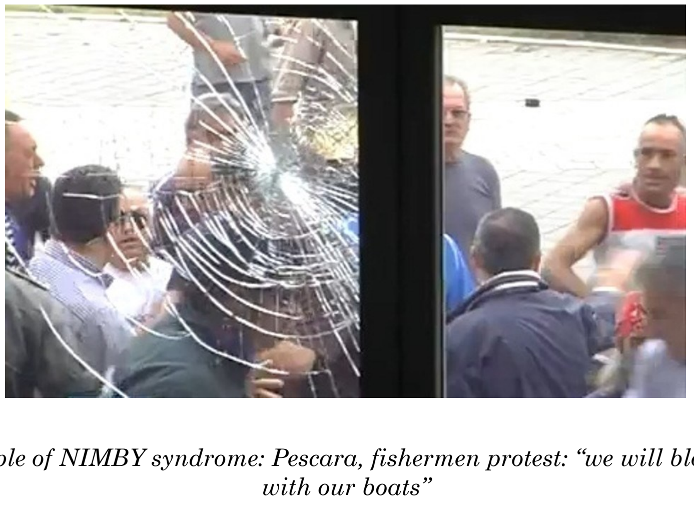

Image 4. Example of NIMBY syndrome: Pescara, fishermen protest: "we will block the harbour with our boats"

Source: www.ilpescara.it/cronaca/protesta-marineria-pescara-bloccheremo-il-porto-con-le-barche.html

Though EU policy already promotes PP whenever plans and programmes have an impact on the environment (Aarhus convention

(1998), Directive 2003/35/EC, Agenda 21, Directive 2001/42/EC on the Strategic Evaluation Assessment), only 17% of ports involved local communities and stakeholders in port development plans (Brooke, 2002 cited in Henesey et al., 2003).

Nowadays, because of globalisation of production and consumption which induced structural changes in the inter-port/intra-port relations, the success of a port and its competitiveness depend more and more on the way the port manager succeeds in directing the interactions between different stakeholders and the concept of stakeholders has become a key term in any port management strategy (Henesey et al., 2003; Winkelmans and Notteboom, 2007). Involving all stakeholders from the beginning and during all the planning phases assures a transparent and (probably) shared decision-making process. Moreover, a greater focus on external stakeholders may increase the port activities' legitimacy at the city and regional levels, and may also contribute to sustainable development (Dooms et al., 2004).

Public Participation (PP) is the formal procedure aimed to involve citizens and stakeholders into the decision-making process.

It should favour a shift from the traditional planning approach, where the decision-maker with the experts makes the decision and then announces (and defends) it to the community (the above-mentioned DAD), to a deliberative approach, with the engagement of the interested parties at the beginning of the process, which leads to a deliberation (and a decision) and finally to the implementation of the decision, following an approach called EDD: Engage – Deliberate – Decide (Walker, 2009).

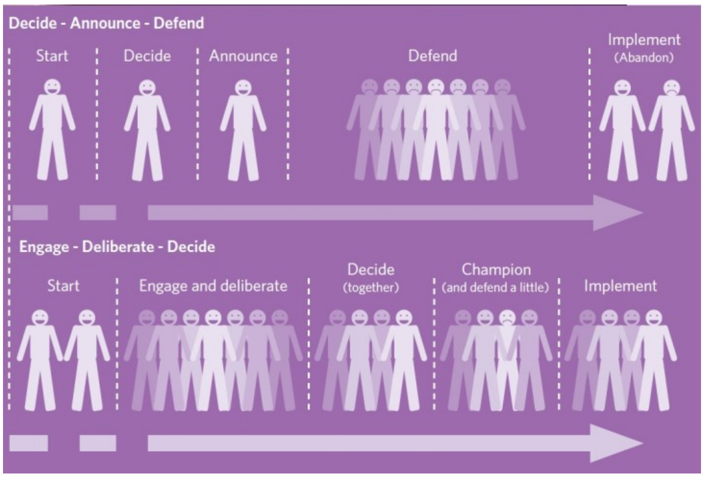

Image 5. Shift from DAD to EDD approach (Walker, 2009)

Taking properly into account the 'strategic intent' of different stakeholder categories by assuring a public participatory process, can facilitate the convergence to a shared solution, avoid waste of time and money, help the inclusion of the sustainability principles in the port mission, raise the responsibility of local communities towards projects, enlarge the coalitions on the choices, give to planners a clearer awareness of needs and constraints, help to find more effective solutions, provide a better understanding of the potentiality of the plan and its possible economic opportunities.

Building the participation process

There are different levels of participation, as stated by Arnstein (1969) in the so called "ladder of citizen participation" which shows the different types of participation and "nonparticipation" dividing them into eight different rungs. "Civil Society" and "Citizen Control" are the highest levels of involvement, where citizens are responsible for the implementation of plans. It is necessary to choose the appropriate type of involvement related to the plan and the background, avoiding the lowest levels which correspond to the "Nonparticipation", making the participation process useless and time (and money) wasting. The "participation pyramid" is derived from the previous ladder and represents the different levels of participation (Holstein, 2010). According to Holstein choosing the appropriate level of involvement is the first step in order to "guarantee a proper connection between participation as a process, the input and proposals of all participants in this process, and the final decision stage".

Image 6. The participation pyramid (Holstein, 2010)

Cascetta and Pagliara (2011) propose to include PP in all the basic phases of a transport planning process, according to five levels of participation:

- stakeholder identification, at the early stage of decision-making context assessment;
- listening, during the analysis of the present situation and the identification of plan objectives;
- information giving and consultation, while formulating and evaluating the alternative systems' projects;
- participation in the final choice.

Stakeholder identification in port planning

Thanks to the specific functions that are located inside the port it is possible to identify stakeholders and categorize them according to three main categories:

- Institutions and authorities (public sector), which in turn can be
    - Internal stakeholders
    - Public policy stakeholders
- Companies and operators (private sector), which can be considered as internal stakeholders
- Local communities (or community stakeholders), which can be considered as external stakeholders.

The categorization proposed is inspired to the four categories described in Henesey et al. (2003), where the internal stakeholders are part of the comprehensive port authority organization, while the external stakeholders are the in situ and ex situ economic players.

Typical stakeholders involved in port management and planning			
Internal stakeholders		External stakeholders	
Institutions /Authorities PUBLIC SECTOR	**Companies/Operators PRIVATE SECTOR**	**Legislation and p. policy sh PUBLIC SECTOR**	**Local Communities**
• The Port Authority, composed of: - The President of the PA - The Port Committee - The General Secretariat - The board of Auditors • Maritime Authority • Local Advisory Committee • Customs • Maritime health • Fire department • Police • Financial Police Marine police • Harbour Master's Office - Coast Guard	• Shippers • Maritime agencies • Companies carrying out the industrial activities • Companies carrying out the service activities • Service providers: – Corporation of pilots – Moorings – Towing • Ship owners • Transport operators/ providers • Maritime agents • Freight forwarders • Port Terminals • Railways • Multimodal Transport Operator (MTO) • Truck drivers • Stevedores • Warehouse • Other mobility providers	• Ministry of Infrastructure and Transport • Regions • Local authorities • Local transport authorities • Carabinieri • Police	• Citizens • Visitors • Local community organizations • Universities • National business associations • Transport users

Image 7. Typical stakeholders involved in port management and planning

Tools for the Public Participation

Traditional tools to support a participatory process are meetings, focus groups and interviews with the relevant stakeholders. They are sometimes regarded as compulsory moments of the decision-making process, time and money consuming, often depriving participation from its effectiveness. Whatever the approach chosen, it is fundamental to deliver a clear identification of the stakeholders to be involved, the role they have in the decision-making process, the nature of their relationships, building a real network, where each node is a stakeholder and each link represents the relation between two nodes. To this aim Social Network Analysis (SNA) can be used (Dempwolf and Lyles, 2010), with different techniques such as interviews with the stakeholders (Kazmierczak, 2012; Pitt, 2008) or the snowballing technique (e.g. with automated software such as StakeNet, StakeSource (Lim et al., 2011). Then adequate centrality indicators can be calculated to measure the importance of the actors in the network, to identify the stakeholders who are the most critical for an effective participatory process.

For example, in the network of the image 8 the stakeholder C has a degree centrality of 4 because it is connected to 4 nodes; the stakeholder

E has a high betweenness centrality, as it lies on the paths connecting most of the nodes; at last stakeholder F has a high eigenvector centrality because it is connected to the most nodes that are also highly connected.

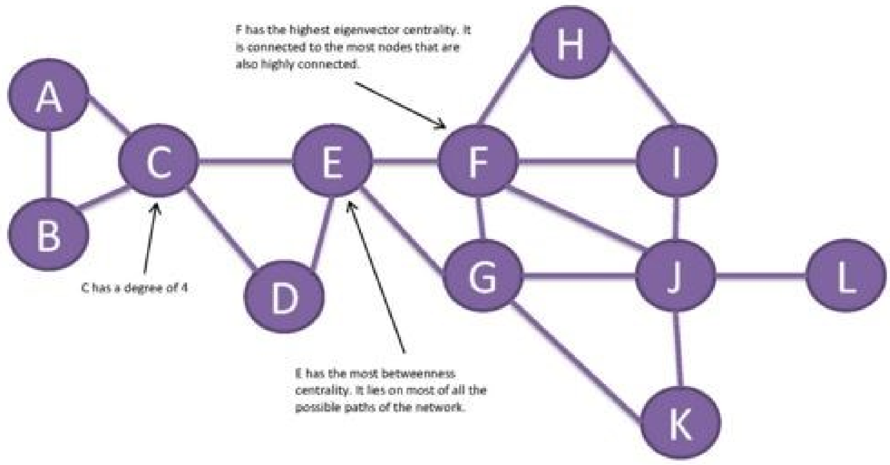

Image 8. Centrality indexes in a stakeholders' network

To this network, lying in the space of stakeholders' relationships, it is possible to associate another stakeholders' network, in the space of opinions. This enables the interaction process to be reproduced through simulation models of the opinion dynamics on the network, able to investigate how the information exchange among stakeholders endowed with different opinions. Le Pira et al. (2013) built a multi-agent based simulation model to investigate to what extent the interaction among the stakeholders and the exchange of information can affect the majority's opinion, as a function of the topology of the network, the initial distribution of opinions and the relative influence of stakeholders.

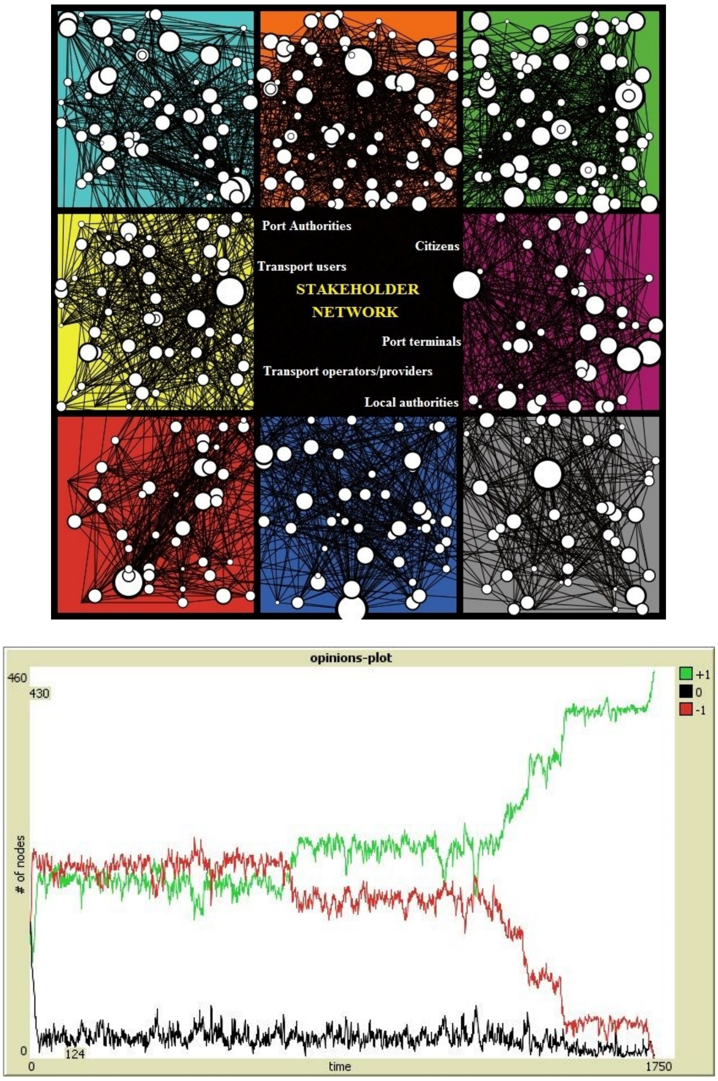

Image 9. Stakeholders' network (top) and opinions' plot (bottom) using NetLogo[13] (Le Pira et al., 2013)

Public Participation in a Port Action Plan

The University of Catania, as partner of the PORTA project (www.porta-project.eu) supported by the European Regional Development Fund within the MED Programme, experimented the relevance of public participation of the diverse stakeholders involved in the preparation of a Port Action Plan and in particular the relationships between Port Authority and city/citizens. According to the proposed planning model, based on the Deming cycle PDCA (Plan-Do-Check-Act), a Port Action Plan should consider the community involvement in all the phases. The

13http://ccl.northwestern.edu/netlogo/

five levels of involvement below described can be coupled with the different phases of the PDCA cycle:

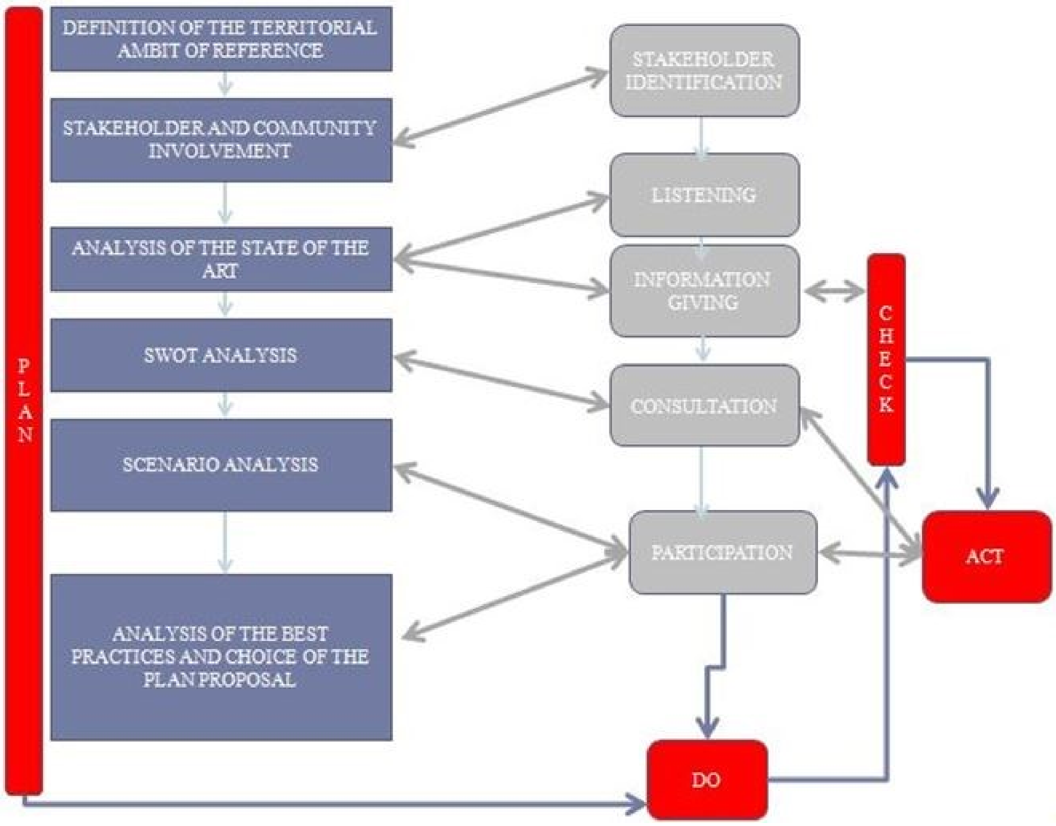

Image 10. The role of PP in the port planning process

Conclusions

Community Involvement can contribute substantially to the acceptance of long term strategies in port planning. It is an integral part of the plan and adequate resources have to be devoted to it. It must be performed following a procedure along the entire decision making process. Suitable tools have to be developed to assure the decision making process will be effective, efficient, transparent and flexible.

Stakeholder network analysis and opinion dynamics modelling have proofed to be promising tools to assist who is in charge to lead the participatory process.

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2. OVERVIEW OF DECISION-SUPPORT METHODS FOR COLLECTIVE DECISIONS IN TRANSPORT PLANNING

"How far should we go in the use of quantitative and mathematical methods in transportation planning? The answer depends on what politicians and planners require from the planning process. In an open participatory process democratic paradigms are forcing the planners to reconsider their analytical tools."

Sager, 1979

2.1. Traditional decision-support methods (DSMs) in transport planning

In conventional transport planning, the decision-maker assigns priorities to a set of projects composing the plan, through the assessment of their effects and contributions to the pursuing of the general objectives of the plan. Several types of analysis are needed to assess the impact of the plan on the different evaluation criteria (De Luca, 2000):

i. a <u>financial analysis</u>, to measure the financial sustainability, from the point of view of a private enterprise;
ii. a <u>socio-economic analysis</u>, to measure the impact on the community welfare;
iii. a <u>fiscal analysis</u>, from the point of view of the public administration;
iv. a <u>political analysis</u>, to evaluate the social acceptability in terms of public consensus.

The public nature of the transport investments makes the socio-economic analysis (in terms of costs-benefits) more suitable than the financial analysis (in terms of costs-incomes). The **Cost-Benefit Analysis** (CBA) (Dasgupta and Pearce, 1972; Layard and Glaister, 1994) has been widely used to support the decision-making process in transport planning. It is required according to the Regulation (EU) No 1303/2013[14] regarding the European Regional Development Fund for the approval of a major project and in Italy it has recently become the main method to evaluate public investments according to the D.P.C.M. 3/8/2012[15]. A recent and comprehensive study of benefits and costs of

[14] Official Journal of the European Union, L 347, 20 December 2013
[15] Gazz.Uff. 22 novembre 2012, n. 273

transport measures, with guidelines for applying the information given in planning and policy analysis was done by Litman (2009).

CBA postulates the choice of the project with the highest increase of the net utility on the related community, among a set of competing alternatives. Nevertheless, the method is charged of many limitations: (1) one is that all benefits and costs have to be turned in monetary terms; (2) though consumers' willingness to pay (WTP) and contingent analysis have reached progress to include social and environmental issues (which are not reflected in the market prices), in CBA the idea of applying these techniques when the value of landscape or of the human life have to be introduced in the computation is still questionable; (3) besides, as the increase of the community welfare is calculated as net difference between benefits and costs, distributional issues are not taken into a proper account, especially when some stakeholders have interests in the social and environmental domain. Despite the drawbacks, CBA is a widely used tool and it could be combined with participation processes. Some useful recommendations on how to include a CBA in participatory planning are provided by Sager (1979).

To overcome the limits of CBA, the classical method used to include more than one objective is the **Multi-Criteria Analysis** (MCA) or **Multi-Criteria Decision Making/Aiding** (MCDM/A) methods, which allows to include in a comparative assessment of alternative projects their contributions to different evaluation criteria, even if they are assessed by heterogeneous measures (monetary, physical and linguistic). MCA can be used both *ex ante*, to assess the impacts of strategic choices, and *ex post*, to evaluate a programme or a policy through the appraisal of its impacts with regards to several criteria (European Communities, 2006). It is well suited to incorporate the social, environmental and economic aspects which are affected by decisions about the transport system of a community. Next subsection will present an overview of the methods that can be used to perform a MCA.

2.1.1. Review of MCDM/A methods

MCA technique is based on a decision matrix, whose rows are the alternatives and the columns are the evaluation criteria related to the different objectives able to reflect the decision-maker preferences. Each element of the matrix measures to what extent a given alternative contributes to the achievement of the relevant objective (i.e. a measure of compliance), which can be represented through one or more criteria. The measures can be qualitative (e.g. poor-average-good) or quantitative (e.g. tons of CO_2). The phases of a MCA are:

i. definition of the alternatives;
ii. definition of the objectives, the criteria able to measure the impact on the objective, the actors to be involved in the decision and the weight to assign to each criterion;
iii. building of the decision matrix with the measures of compliance;
iv. comparison among the alternatives and final choice.

If a value is assigned to each measure of compliance c of the alternative a with respect to the criterion j, for instance trough a utility function, $u_j[c_j(a)]$ and w_j is the weight of the criterion j, an overall utility of the alternative a can be computed as:

$$U(a) = \sum_{j=1}^{J} w_j u_j[c_j(a)] \quad (1)$$

There is a huge number of methods that can be used to perform a MCA. A comprehensive review of the state of the art of the most commonly used methods can be found in Figuera et al. (2005).

A first distinction can be made between **Multi-Objective Decision-making** (MODM), when the alternatives are not enumerated and make use of mathematical programming to find the optimal alternative, and **Multi-Attribute Decision-making** (MADM), when a set of alternatives is specified and one must determine to what extent each alternative complies with a set of criteria (Buchholz et al., 2009, see Figure 10).

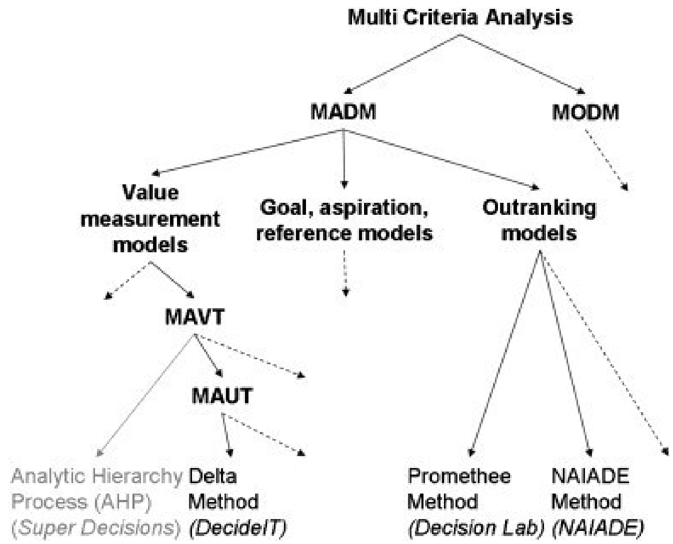


Figure 10 – Classification of MCA methods (Buchholz et al., 2009).

MADM approaches differ for the method by which the comparison and the final choice among the alternatives is carried out:

- **Outranking Methods** establish a ranking based on preference relations between alternatives (such as Electre, Promethee, Regime, Oreste, Argus);
- **Multi-Attribute Utility Theory methods** (MAUT) use utility functions represented by formula (1) to select the alternative with the highest utility;
- **Multi-Attribute Value Theory methods** (MATV) rank the alternatives by means of numerical eigenvectors obtained from pairwise comparisons (AHP, ANP, SMART, TOPSIS, MACBETH);
- **non classical methods**, such as the fuzzy set approaches, are able to deal with imprecise knowledge and vague preferences; e.g., the Dominance-Based Rough Set Approach (DRSA) proposed by Greco et al. (1999) deals with multi-criteria classification according to the dominance principle.

Table 6 summarizes some of the main MCA methods according to Ishizaka and Nemery (2013) based on the problem classification of Roy (1981):

1. "***The choice problem***. *The goal is to select the single best option or reduce the group of options to a subset of equivalent or incomparable 'good' options. For example, a manager selecting the right person for a particular project.*

2. ***The sorting problem**. Options are sorted into ordered and predefined groups, called categories. The aim is to then regroup the options with similar behaviours or characteristics for descriptive, organizational or predictive reasons. For instance, employees can be evaluated for classification into different categories such as 'outperforming employees', 'average-performing employees' and 'weak-performing employees'. Based on these classifications, necessary measures can be taken. Sorting methods are useful for repetitive or automatic use. They can also be used as an initial screening to reduce the number of options to be considered in a subsequent step.*

3. ***The ranking problem**. Options are ordered from best to worst by means of scores or pairwise comparisons, etc. The order can be partial if incomparable options are considered, or complete. A typical example is the ranking of universities according to several criteria, such as teaching quality, research expertise and career opportunities.*

4. ***The description problem**. The goal is to describe options and their consequences. This is usually done in the first step to understand the characteristics of the decision problem."* (Ishizaka and Nemery, 2013).

Table 6. MCDM/A methods with related references (based on Ishizaka and Nemery, 2013):

	Reference	Input	Output	Choice problem	Ranking problem	Sorting problem
MAUT	Roy, 1974; Hwang and Yoon, 1981	utility function	Complete ranking with scores	✓	✓	
ANP	Saaty, 2001	pairwise comparisons on a ratio scale and interdependencies	Complete ranking with scores	✓	✓	
MACBETH	Bana e Costa and Vansnick, 1999	pairwise comparisons on an interval scale	Complete ranking with scores	✓	✓	
AHP	Saaty, 1980	pairwise comparisons on a ratio scale	Complete ranking with scores	✓	✓	
ELECTRE	Roy, 1968	indifference, preference and veto thresholds	Partial and complete ranking (pairwise outranking degrees)	✓	✓	
PROMETHEE	Brans and Vincke, 1985	indifference and preference thresholds	Partial and complete ranking (pairwise preference degrees and scores)	✓	✓	
Goal Programming	Flavell, 1976	ideal option and constraints	Feasible solution with deviation score	✓	✓	

	Reference	Input	Output	Choice problem	Ranking problem	Sorting problem
TOPSIS	Hwang and Yoon, 1981	ideal and anti-ideal option	Complete ranking with closeness score	✓		
DEA (data envelopment analysis)	Charnes et al., 1978	no subjective inputs required	Partial ranking with effectiveness score	✓	✓	
UTA (utilities additives)	Jacquet-Lagreze and Siskos, 1982	utility function	Classification with scoring			✓
AHPSort	Ishizaka et al., 2012	pairwise comparisons on a ratio scale	Classification with scoring			✓
ELECTRE-TRI	Roy and Bouyssou, 1993	indifference, preference and veto thresholds	Classification with pairwise outranking degrees			✓
FLOWSORT	Nemery, 2008	indifference and preference thresholds	Classification with pairwise outranking degrees and scores			✓

All the above described methods have supporting software programs (Ishizaka and Nemery, 2013) and some of them have been extended to incorporate multiple viewpoints in the decision.

Though stakeholders can be involved both to select the criteria and to assign the relevant weights, the "rational" approach based on transport planning choices made by analysts and experts is not always sufficient to assure that the final choice will be supported. Therefore, it is necessary to involve the stakeholders all along the decision-making process with the support of adequate MCDM/A methods.

Next section will introduce the problem of making collective decisions with some use of MCDM/A methods that can be useful to support group decision-making processes.

2.2. The role of group decision-support methods (GDSMs) in participatory transport planning

Even if public participation is considered critical for the success of a decision-making process, nowadays there are few attempts to effectively include the stakeholders' opinions into the final choice. Maybe this is due to a general lack of group decision-support methods (GDSMs) and systems (GDSSs)[16], where the role of different actors is individually and explicitly included in the selection of the plan/project among competing alternatives.

MCDM in transport can largely benefit from the support of Geographic Information System (GIS), due to the intrinsic spatial nature of transport systems and the capability of GIS maps to easily visualize the impacts of transport choices on land use, environment and communities. Public Participation GIS (PPGIS) or Participatory GIS (Sarjakoski, 1998; Tang and Waters, 2005; Zhong et al., 2008; Jankowski, 2009) has been developed as powerful tools for supporting non-experts' involvement in transport decision-making process because of the power of visualization which increases the awareness about the decision to be made. The term PPGIS originated in 1996 at two meetings of the National Center for Geographic Information and Analysis (NCGIA), where attendees argued that the next generation of GIS should have been embedded in social and political contexts. A comprehensive review from the origin to a roadmap for future PPGIS research and practice be found in Sieber (2006). According to Piantanakulchai and Saengkhao (2003), GIS based transport models combine Engineering Model (i.e. mathematical model that relates physical quantity regarding the impact being considered in space) and Weight Decision Model (i.e. model that relates physical quantity in engineering model with social preference). The spatial information in GIS and the result of objective weights can help the participation of stakeholders to the decision-making process.

Therefore, a transport plan should be built with the help of quantitative methods to make a transparent, participatory decision-making process. These methods must include the stakeholders' perspectives and judgements in all the phases of the planning process. Besides, it is necessary to integrate different tools, that is to say:

- MCDM/A methods,
- engineering models,
- participatory GIS.

Though these tools can support a group decision-making process, the problem of determining a unique collective (and shared) preference, derived by the different individuals' judgments, still remains. To this

[16] The first ones are quantitative methods, such as the MCDM/A methods, while the second ones are informatics tools that can integrate different modules (database, models, DSMs), aiding the decision-making process.

aim, several studies suggest the opportunity of integrating stakeholders' analysis with DSMs that use pairwise comparisons, such as the Analytic Hierarchy Process (AHP) (Piantanakulchai and Saengkhao, 2003; Rosso et al., 2014; De Luca 2014). Even with these methods, the results of aggregating different opinions could be not unique. In the case of AHP, for example, individual judgments can be aggregated by different methods and the result is always a compromise among the different preference lists (see subsection 2.2.1).

Macharis (2004) proposes a method, called Multi Actor Multi-Criteria Analysis (MAMCA) that, starting from single-stakeholder analyses, evaluates the different alternatives through an overall MCA to derive stakeholder-driven priority rankings among different alternative projects. The methodology was performed with the Expert Choice software platform [17] and recently a specific software has been implemented[18].

The MAMCA method was used in different contexts of transport decisions, e.g. to assess judgments about alternatives in transport projects (Macharis et al., 2010; 2012; De Brucker et al., 2013), to derive a framework for city freight distribution (Macharis et al., 2013), to evaluate different scenarios of regional light rail (Vermote et al., 2014), to assess stakeholder support for different biofuel options (Turcksin et al., 2011). Though stakeholder groups are explicitly involved in the decision process, they do not interact with each other, nor they are expected to change their opinion on the transport alternatives, i.e. there is no collective decision emerging from stakeholder involvement and the last choice remains up to the decision-maker.

Next subsection will show the basic principles of AHP and its extension to include multiple actors in the decision-making process and find a collective decision.

2.2.1. Multi-Actor Analytic Hierarchy Process (MA-AHP)

The Analytic Hierarchy Process (AHP) was developed by Thomas Saaty (1980). It is a process based on pairwise comparisons through the building of matrixes to derive priority scales and weights. The pairwise judgement is used because "*comparative judgement is the identification*

[17] http://expertchoice.com/

[18] http://mamca.be/

of some relation between two stimuli both present to the observer. […] *To make the judgements, a person must compare an immediate impression with impression in memory of similar stimuli"* (Blumenthal, 1980 in Saaty, 2008).

AHP can be synthesized in 4 steps:

1. Problem structuring;
2. Priority calculation from pairwise comparisons ("relative verbal appreciations");
3. Consistency check;
4. Sensitivity analysis.

The use of AHP in transport planning is based on the decomposition of a decision-making problem into a tree structured decisions' hierarchy that contains: the general goal of the plan, a set of specific objectives represented by evaluation criteria (and possible sub-criteria) and finally the decision alternatives aimed at achieving the general goal (Figure 11). In general, the problem structure derives from brainstorming sessions with experts or from the analysis or similar problems.

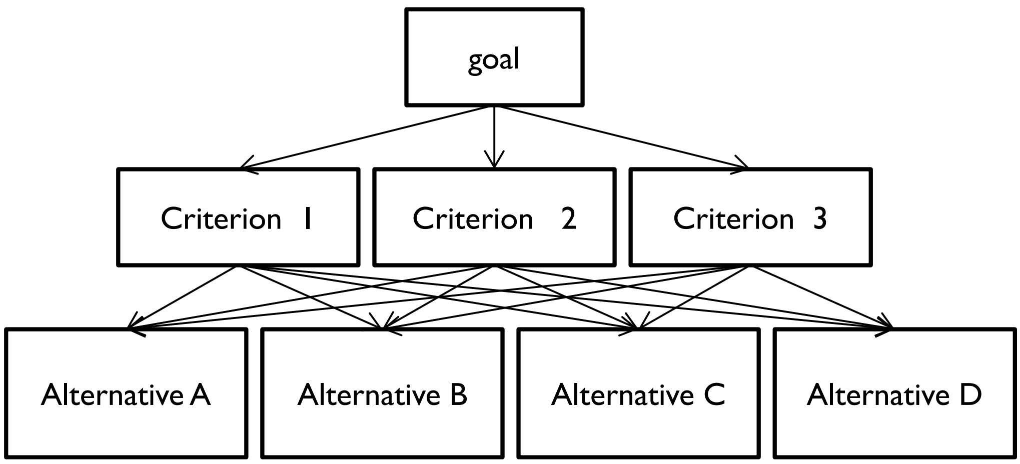


Figure 11 – Basic hierarchy of a decision problem in transport planning.

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 that is turned into a quantitative one (Saaty, 1980) (Table 7). The numerical scale goes from 1 to 9 and it is widely used because it is considered more detailed than the smaller ones (e.g., 1-5) and more appropriate than the larger ones (e.g., 1-100), which are more difficult to be used by decision-makers. Being a ratio scale (and not an interval scale), it allows to aggregate more judgments with the same measurement unit.

Table 7. Scale of pairwise comparisons (adapted from Saaty, 1980).

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one element over another
5	Strong Importance	Experience and judgment strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values, 1.1, 1.2, etc. for elements that are very close in importance		

At each level of the problem structure the pairwise matrices can be transformed into a set of local priority vectors with different methods (Saaty and Hu, 1998), e.g. the approximate method, the eigenvalue method, the geometric mean method (Ishizaka and Nemery, 2013). Finally, a ranking of alternatives is obtained by combining all the levels into a global priority vector.

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, given 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). In general, an inconsistency less than 10% is accepted.

A sensitivity analysis is carried out to test the robustness of the results, in terms of elasticity of the final ranking to the criteria weights.

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-stakeholder multi-objectives perspective (Piantanakulchai and Saengkhao, 2003; De Luca, 2014). When AHP is used to elicit single decision-maker opinions, the only condition to respect is judgments' consistency; when its use is extended to group decision-making an appropriate procedure to aggregate the individual judgments has to be defined.

There are four ways to combine multiple preferences into a consensus rating (Ishizaka and Nemery, 2013), according to the level of aggregation (from judgments or from priorities) and the type of aggregation (mathematical or based on consensus vote).

The consensus vote can be used with "synergistic" groups that agree on the values of the matrices or on the priority vectors. In general, if a consensus cannot be reached, a mathematical aggregation can be adopted.

An important issue is at which level of the decision process the aggregation is made (Dong et al., 2010): 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 any case, the problem of aggregation is that the final result consists of an "averaged" ranking that could not be representative of the individual points of view. Besides, according to Ishizaka and Nemery (2013) it can lead to some bias in the judgments:

"A group decision may be skewed due to collusion or distortion in the judgements to secure the preferred outcome. This problem does not arise when there is a single decision maker because the first choice will always remain the first. In a group decision, a participant does not have this certitude as the results are aggregated with those of the other

stakeholders. One decision maker may overweight their preferred alternative and bias the group decision. As individual identities are lost with an aggregation, early aggregation is not recommended.”

Therefore, the problem of preference aggregation remains still open. While mathematical aggregation implies transparency of the calculation and clarity of results but it could not reflect the individual preferences, consensus vote is a more democratic and fair way to find a group ranking that could have a low rate of acceptance, being supported only by a relative majority.

According to the author, the optimal solution should be based on a mixed procedure that combines mathematical aggregations with consensus building, through an interaction process among stakeholders that allows a convergence of opinions to increase the acceptability of the final results while at the same time guaranteeing transparency of the decision process (Table 8).

Table 8. Group aggregation procedures.

	Transparency and reproducibility	Fairness of the process	Probability of acceptance
Mathematical aggregation	✓		
Consensus vote		✓	
Consensus building process with the help of mathematical aggregation	✓	✓	✓

In reality, the problem of combining individual preferences into a collective decision has been widely studied by the social choice theory (Arrow, 1951) that originates from Condorcet’s formulation of the homonymous voting paradox (1785).

Next chapter will present the basics of the social choice theory and two voting methods to aggregate stakeholder preferences into a collective decision, that satisfy most of the social choice rules: the pairwise majority rule (PMR) and the Borda rule.

3. THE PROBLEM OF AGGREGATING STAKEHOLDER PREFERENCES FOR SHARED TRANSPORT PLANS[19]

"Aggregating the opinion or the preferences of voters or individuals of a community into collective or social preferences is quite similar a problem to devising comprehensive preferences of a decision-maker from a set of conflicting criteria in MCDA [Multi-Criteria Decision Analysis]. *Despite the importance of Ramon Llull's (1232-1316) and Nicolaus Cusanus's (1401-1464) concerns about and interests in this very topic, the origins of voting systems are often attributed to Le Chevalier Jean-Charles de Borda (1733-1799) and Marie Jean Antoine Nicolas de Caritat (1743-1794), Le Marquis de Condorcet."*

Figuera et al., 2005

3.1. Preference aggregation in transport decision-making processes

Dealing with a multiple stakeholders' decision is mainly to bring together different individual preferences into a unique choice able to incorporate and reflect at its best the collective preferences. This is true both when making a single decision among alternatives (at least the "do nothing" decision) or choosing a ranking of alternatives (e.g., to set the priorities of different projects included in a plan) or a ranking of plan objectives. In general, the first case is simple, because the decision-making process is typically based on the majority rule, where the decision is accepted if the majority of the stakeholders are in favour of it. Stakeholders only have to express their opinion about a single project and the collective preference is the majority preference. This simple case can be complicated if stakeholders can communicate and exchange opinions before taking the final decision. The benefit of interaction is to gain a better understanding of the problem and awareness of the consequence of the decision. Interaction among stakeholders can assume different forms and can be supported by several techniques used in practice, such as the citizen juries, consensus conferences, focus groups, Delphi practices (see section 1.4); in any case it is demonstrated that

[19] This chapter is based on paper II: "Modelling multi-stakeholder preference ranking for sustainable policies".

interaction and deliberation can change stakeholders' mind about public policy problems (Quick et al., 2015).

Transport planning is much more complex than taking a single decision on a single project, decisions are multiple and they are generally taken after a process of preference ranking. If the decision is among more than two alternatives, stakeholders have to make their list of preferences (which can be alternatives of a project, objectives etc.) based on the comparisons among alternatives/objectives or between couples of them and to derive a collective preference order.

To this aim, some insights and references will be given on concepts and problems arising when a ranking of preferences is needed as a result of a multi-actor decision-making process. Before introducing them, it is necessary to refer to the theory behind them, i.e. the social choice theory.

3.2. Fundamentals of social choice theory and its relation with deliberative transport planning

"Social choice theory is the study of collective decision processes and procedures. It is not a single theory, but a cluster of models and results concerning the aggregation of individual inputs (e.g., votes, preferences, judgments, welfare) into collective outputs (e.g., collective decisions, preferences, judgments, welfare). […] *Pioneered in the 18th century by Nicolas de Condorcet and Jean-Charles de Borda and in the 19th century by Charles Dodgson (also known as Lewis Carroll), social choice theory took off in the 20th century with the works of Kenneth Arrow, Amartya Sen, and Duncan Black. Its influence extends across economics, political science, philosophy, mathematics, and recently computer science and biology"* (List, 2013).

The origin of voting or preference aggregation methods is often attributed to Condorcet and Borda, having introduced the former the pairwise comparisons method or pairwise majority rule (PMR), the latter the scoring method or Borda count (explained in the next section, 3.3).

In order to define the concept of preference aggregation rule, some premises are necessary (List, 2013):

- suppose to have N ($N = 1, \dots, n$; $n \geq 2$) individuals and X ($X = x, y, z \dots$) alternatives to be compared (e.g., policies, objectives).

- Each individual i has a preference ordering R_i over these alternatives.
- A combination of preference orderings across the individuals, $< R_1, R_2, \dots, R_n >$ is called a profile.

A preference aggregation rule is a function F that assigns to each profile $< R_1, R_2, \dots, R_n >$ a social preference relation $R = F(R_1, R_2, \dots, R_n)$.

Preference aggregation rules derive social preference relations from individual preference orderings. On the other hand, social choice rules aim at finding one or several winning alternatives. A social choice rule is a function f that assigns to each profile a social choice set $f(R_1, R_2, \dots, R_n) \subseteq X$. It may derive from a preference aggregation rule, by defining the social choice set that contains each alternative that wins with every other alternative in X.

In 1951, Arrow formulated a general theorem, which is applicable to a class of possible aggregation methods that he called "social welfare functions". The so called "impossibility theorem" states that no method satisfies at the same time five axioms identified by Arrow (1951), i.e. a preference aggregation rule F should satisfy (List, 2013):

1) *Universal domain*: the domain of F is the set of all logically possible profiles of complete and transitive individual preference orderings.
2) *Ordering*: for any profile $< R_1, R_2, \dots, R_n >$ in the domain of F, the social preference relation R is complete and transitive, i.e. if x is preferred to y and y to z, then x is preferred to z.
3) *Weak Pareto principle*: for any profile $< R_1, R_2, \dots, R_n >$ in the domain of F, if for all $i \in N$ x is preferred to y, then collectively x should be preferred to y.
4) *Independence of irrelevant alternatives (IIA)*: for any two profiles $< R_1, R_2, \dots, R_n >$ and $< R_1^*, R_2^*, \dots, R_n^* >$ in the domain of F and any $x, y \in X$, if for all $i \in N$ R_i's ranking between x and y coincides with R_i^*'s ranking between x and y, then x is preferred to y for R if and only if x is preferred to y for R^*. In other words, the relative ranking of x and y in the output of the aggregation procedure is independent of the voters' preferences for z.
5) *Non-dictatorship*: there does not exist an individual $i \in N$ such that, for all $< R_1, R_2, \dots, R_n >$ in the domain of F and all $x, y \in X$, if i prefers x to y this implies that collectively x is preferred to y, i.e.

if a single voter i prefers x to y, but all the voters disagree, then y should be ranked higher than x.

To overcome the impossibility theorem, it is suggested to relax at least one of the five conditions (List, 2013). The impossibility theorem is applicable to the aggregation of other kinds of ordering different from preference orderings, such as "*multiple criteria that a single decision maker may use to generate an all-things-considered orderings of several decision options, and conflicting value rankings to be reconciled*" (List, 2013).

It has also been extended by Sager to the context of deliberative transport planning: "*empirical social research has found that planning and decision processes are vulnerable to deficiencies similar to those that social choice theory says are hard to avoid. This indicates that the procedural problems are not theoretical chimeras which seem real only because of the heroic simplifications inherent in the social choice framework. The empirical studies give easily understood, rich and vivid accounts making it easy for planners to recognise the procedural difficulties. What the social choice literature does, is give sharper conclusions that are more general as they are not deduced from particular cases.*" (Sager, 2005).

By analogy with Arrow's theorem, Sager (2002) formulated the "impossibility theorem for dialogic decision-making":

"No dialogic decision procedure can combine non-dominance [i.e. non dictatorship]*, the Pareto principle, unrestricted scope, and IIA when arbitrary planning decisions due to decision cycles are unacceptable."*

In particular, he argued that dialogue and amalgamation of individual rankings cannot ensure consistent planning recommendations and simultaneously prepare for political decision-making in a democratic manner, in particular when there are "intangible" consequences. The four adapted axioms are summarized in Table 9. To know more about this theory, the reader can refer to Sager (1999; 2002; 2005).

Table 9. Requirements for making dialogic decisions on plans with intangible consequences (Sager, 2002).

Axioms	Description
Unrestricted scope	*The dialogic decision procedure should allow for the possibility that a new and valid argument might be able to process any (logically) coherent set of argument relations comprising any number of planning alternatives*
Pareto principle	*When planning alternative X is of higher quality than alternative Y with reference to every argument without exception, the dialogic decision procedure must rank X above Y*
Non-dominance (Non-dictatorship)	*Arguments must be non-dominant* [...]. *An acceptable dialogic decision procedure should be a collective choice procedure, not merely rubber-stamping one-person rule or one-argument fanaticism*
Independence of Irrelevant Alternatives (IIA)	*The dialogic decision procedure should yield an ordering of a given set of planning alternatives depending only on the ranking of those alternatives against each of the arguments*

Based on these premises, the problem of selecting the appropriate aggregation procedure of a participatory decision-making process in transport planning is not trivial and should not be underestimated.

The following section will enter into the details of two abovementioned aggregation procedures that satisfy most of the requirements of a social choice rule and that can be used in a group decision-making process, i.e. the pairwise majority rule (PMR) and the Borda rule.

3.3. Two aggregation methods: the Pairwise Majority Rule (PMR) and the Borda rule

The pairwise majority rule (PMR) and the Borda rule are two widely used and well-known methods for deriving collective preference orders from individual preferences. Even if they are both good in satisfying most of the requirements of Arrow's theorem, they are substantially different in the way aggregation is done and they can lead to different results, i.e.:

- with the "Borda Rule" the ranking of alternatives is obtained on the basis of the sum of different scores assigned to reflect each individual preference order of alternatives, while
- with PMR the ranking is obtained by computing how many times each alternative in a pair is preferred to the other one. In

particular, the pairwise preferences of each individual list are coded as components of a binary vector assuming the values of +1 and -1[20]. 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 $n*(n-1)/2$. For example, for the alternatives A, B, C and D (n = 4), there are six pairs ($4*3/2 = 6$): AB, AC, AD, BC, BD, CD.

To compare the two methods, let's consider a simple example[21]. Suppose that a group of 17 stakeholders is involved in a participatory decision-making process about mobility management strategies to be adopted in a University context. Stakeholders express their opinions about the main critical issues regarding mobility, i.e.:

A. low reliability, punctuality and speed of public transport systems
B. lack of coordination between urban and suburban public transport systems
C. high levels of road congestion to access the city
D. lack of infrastructures and facilities for non-motorized mobility

The preferences of the stakeholders can be summarized in Table 10 according to the position the alternatives have in the individual rankings.

Table 10. Results of stakeholder preferences about critical mobility issues.

Criticality	1st choice	2nd choice	3rd choice	4th choice
A	11	2	4	0
B	2	4	4	7
C	3	7	4	3
D	1	4	5	7

Applying the Borda Rule we assign a score to each alternative related to the position it occupies in the rankings (decreasing values from 4 to 1 from the 1st choice to the last one):

Alternative **Scores** (1st choice=4; 2nd choice=3; 3rd choice=2; 4th choice=1)

A 11*4 + 2*3 + 4*2 + 0*1 = 58

B 2*4 + 4*3 + 4*2 + 7*1 = 35

[20] As an example, for the couple AB, if A is preferred to B then AB = +1, vice versa AB = -1.
[21] This example is based on case study 3 that will be described in section 6.3.

C 3*4 + 7*3 + 4*2 + 3*1 = 44

D 1*4 + 4*3 + 5*2 + 7*1 = 33

With the Borda rule the final collective preferences order will be: A>C>B>D.

On the other hand, applying the PMR to the same individual rankings each of them is turned into a binary vector of pairwise preferences and the majority rule is applied. Results are summarized in Table 11.

Table 11. Results of PMR applied to stakeholder (sh) preferences about critical mobility issues.

sh	A B	A C	A D	BC	BD	C D	sh	A B	A C	A D	BC	BD	C D
I	+1	+1	+1	+1	-1	-1	X	-1	+1	+1	+1	+1	+1
II	+1	+1	+1	-1	-1	+1	XI	-1	-1	+1	+1	+1	+1
III	+1	+1	+1	-1	+1	+1	XII	+1	+1	+1	+1	-1	-1
IV	+1	+1	+1	-1	-1	+1	XIII	+1	+1	+1	-1	-1	-1
V	+1	+1	+1	+1	+1	+1	XIV	+1	+1	+1	+1	+1	-1
VI	+1	+1	+1	-1	-1	+1	XV	-1	-1	+1	-1	+1	+1
VII	+1	+1	+1	-1	-1	+1	XVI	-1	-1	+1	-1	+1	+1
VIII	+1	-1	+1	-1	+1	+1	XVII	+1	-1	-1	-1	-1	-1
IX	+1	+1	+1	-1	-1	-1	***PMR result***	**+1**	**+1**	**+1**	**-1**	**-1**	**+1**

With the PMR the final collective preferences list will be A>C>D>B.

This example shows that the two methods can lead to different results, therefore one could ask what is the best one. In general, the PMR is mostly used because, in the largest domain, it satisfies all the requirements of a social choice rule (Raffaelli and Marsili, 2005), while the Borda rule can violate the axiom of independence of irrelevant alternatives (IIA). In this respect, Dasgupta and Maskin (2004) demonstrated that, if the Borda rule had been used during the U.S. election of 2000 and French election of 2002, this would have given space to *"the risk of tactical and opportunistic voting"* (Giansanti, 2007), because the choice between the two most voted candidates might have been influenced by the preferences obtained by the less voted candidate. On the contrary, using the PMR, the neutrality criterion is respected: "*We believe that when more than two choices present themselves, voters* *should submit a ranking of candidates and that majority rule - as we have discussed it - should determine the winner. Such a method would not be perfect; no method is. But as the majority dominance theorem shows, it would come closer to an accurate representation of the voters' wishes than any other system does."* (Dasgupta and Maskin, 2004). Nevertheless, the aggregation of single preference lists by the PMR does not exclude the possibility of intransitive collective lists as result, thus violating the "ordering" axiom. In the next section the intransitivity paradox or "Condorcet paradox" will be described.

3.4. The "Condorcet paradox" and the collective decision deadlock

The "Condorcet paradox" was studied for the first time in 1785 by the Marquis de Condorcet (1785) who demonstrated that, for $n > 2$, the collective social preference order can be intransitive even if the individual preference orders are transitive. The final consequence is the impossibility of taking a consistent decision. Consider the previous example with four alternatives ($n = 4$) and only five stakeholders ($N = 5$). If we apply the PMR to the 5 preference orders, the final result will be a cycle, i.e. A>B>C>D>A (Table 12).

Table 12. Condorcet cycle resulted from aggregation of stakeholder (sh) preference orders by PMR.

sh	Preference order	AB	AC	AD	BC	BD	CD
1	A>B>C>D	+1	+1	+1	+1	+1	+1
2	D>A>B>C	+1	+1	-1	+1	-1	-1
3	B>C>D>A	-1	-1	-1	+1	+1	+1
4	D>A>C>B	+1	+1	-1	-1	-1	-1
5	B>A>C>D	-1	+1	+1	+1	+1	+1
PMR result		**+1**	**+1**	**-1**	**+1**	**+1**	**+1**
Collective list		**A>B>C>D>A**					

The example shows how the result of aggregating 5 individual transitive lists by the PMR is an intransitive collective list, falling into the "Condorcet paradox" or "Condorcet cycle".

The "Condorcet paradox" is one of the main paradoxes that may afflict voting procedures. A review of some of them was done by Felsenthal (2010). Table 13 shows a comparison between the two aggregation methods above described (Borda rule and the PMR).

Table 13. Pros and cons of aggregation methods.

	Aggregation Method	
	Borda rule	**Pairwise majority rule (PMR)**
Pros	Guarantee of a transitive decision	More accurate decisions reflecting the stakeholders' opinions
Cons	Possibility that the "independence of irrelevant alternative" criterion (IIA) is violated	Possibility that the "ordering" axiom is violated, i.e. probability of an intransitive decision or "Condorcet paradox"

It is easy to demonstrate that the probability of "Condorcet paradox" increases with the number of alternatives: if n alternatives are given, then $n!$ possible transitive orders exist, $n * (n-1)/2$ is the number of pairs and $2^{n*(n-1)/2}$ are the possible - transitive and intransitive - binary vectors. Therefore, the probability to have a transitive order is $P(n) = \frac{n!}{2^{n*(n-1)/2}}$ that rapidly decreases with n and goes to 0 when $n \to \infty$ (Figure 12a). A helpful way to visualize the increasing asymmetry between the number of transitive and intransitive lists when n increases is shown in Figure 12b, representing a simplified pictorial view of the "collective preference space": the black cells in the grid indicate the $n!$ transitivity "islands" randomly distributed over the much larger intransitivity "sea", represented by the white cells (for $n = 6$, only $n! = 720$ transitive lists out of 32748 possible lists exist).

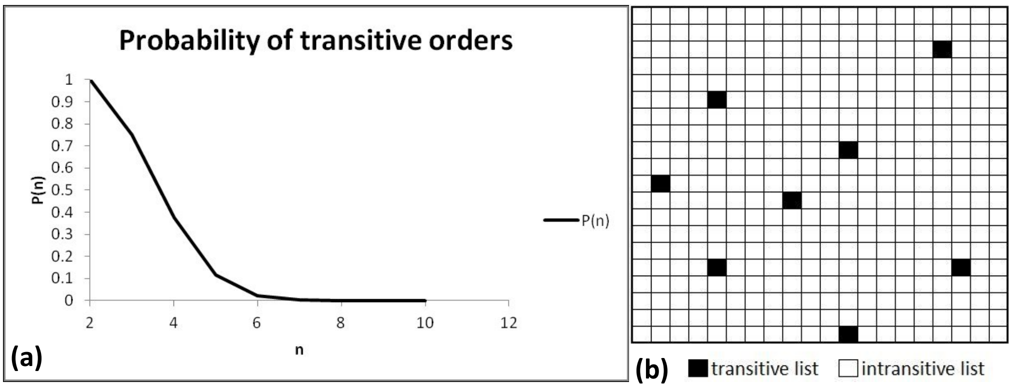


Figure 12 – (a) Probability P(n) of transitive orders as a function of the number of alternatives n. (b) Collective preference space: the few transitive lists are represented as black "islands" within the "sea" of intransitive lists.

It has been demonstrated that the occurrence of the paradox increases also with the number of voters, i.e. in *"a large population of non-interacting voters"* (Raffaelli and Marsili, 2005). 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 (Kelly et al., 2004, Cascetta and Pagliara, 2013), even in the form of the “remote” and anonymous interaction of the Delphi method (Dalkey and Helmer, 1963). Thanks to ICT and to social networks, new forms of e-participation are nowadays emerging, enabling more and more people to easily interact and participate. Nevertheless, the group decision-making based on the decision-support methods (described in section 2.2) usually provide averaged collective decisions, which can be very far from each individual preference, while they could benefit from interaction.

For instance, Raffaelli and Marsili (2005) demonstrate that, the larger the number of alternatives, the easier is to have a collective transitive order in an interacting population; apart from the “unconstrained case”, i.e. when voters are not bound to choose individual transitive order. Columbu et al. (2008) also show the effectiveness of interaction by evaluating the probability of collective transitive orders as a function of an interaction range and find out an optimal distance (namely a Kemeny distance) among voters able to reduce the probability of “Condorcet paradox”.

These models present two main drawbacks:

- they do not explicitly represent the real structure of the relationships among actors;
- they do not adequately consider the degree of consensus of the single actor against the final collective decision.

In order to overcome these limits and contextualize the problem in the field of collective decisions in transport planning, an agent-based model will be used to reproduce the interaction among stakeholders linked together in more realistic networks with different topologies (see section 5.3). This model will allow to both circumvent the “Condorcet paradox” and find a shared transitive collective decision, i.e. a final collective list with a high similarity with the individual ones. Next chapter will introduce the approach of agent-based modelling to reproduce the participation processes in terms of opinion dynamics in networks of stakeholders.

4. AGENT-BASED MODELLING OF OPINION DYNAMICS ON STAKEHOLDER NETWORKS

"How do the interactions between social agents create order out of an initial disordered situation? Order is a translation in the language of physics of what is denoted in social sciences as consensus, agreement, uniformity, while disorder stands for fragmentation or disagreement."

Castellano et al., 2009

4.1. Multi-agent systems (MAS) and agent-based modelling (ABM) to reproduce the complexity of transport systems and decisions

Before going into the details of what (i) an agent, (ii) a multi-agent system and (iii) agent-based modelling and simulations are, a basic assumption can help to understand their usefulness in participatory transport planning: "*to model complex phenomena that involve human or institutional behaviour it is helpful to represent them as multi-agent systems (MAS) and use an Agent-Based Modelling (ABM) approach."* (Voinov and Bousquet, 2010).

The complexity of participatory transport planning has been largely discussed in the previous chapters. Not only decisions are complex because transport problems are "wicked" problems that require the evaluation of plans/projects considering multiple criteria and points of view; participation of multiple actors in the decision-making process adds further complexity being a social phenomenon with emerging dynamics, such as consensus building.

Agent-based models are widely used to represent emergent real-world phenomena. Their use range from modelling the stock market and supply chains, to predicting the spread of epidemics, from modelling the urban sprawling to traffic jams or the immune human system (Benhamza et al., 2012).

i. What is an agent?

An agent is defined as an autonomous entity capable of acting under certain behavioural rules ("*something that acts*"; Odell, 2007). Wooldridge (2002) defines it as "*a computer system that is situated in* *some environment, and that is capable of autonomous action in this environment in order to meet its design* objectives" (Figure 13a).

Another definition is that of Russel and Norvig (1995): "*An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors*" (Figure 13b).

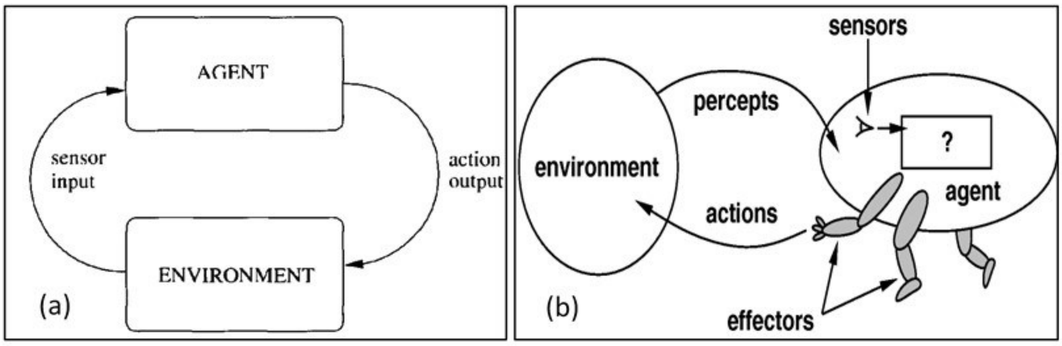


Figure 13 – Intelligent agent interaction with the environment according to (a) Wooldridge (2002) and (b) Russel and Norvig (1995).

There are three basic properties of an agent (Odell, 2007):

- it is **autonomous**, in the sense that is capable of acting without direct external intervention. It has some degree of control over its internal state and actions based on its own experiences;
- it is **interactive**, because it communicates with the environment and other agents;
- it is **adaptive**, because it is capable of responding to other agents and/or its environment; an agent can modify its behaviour based on its experience.

Agents are capable of reactive, proactive and social behaviour (Wooldridge, 2002):

- **reactive** means they can perceive and respond to changes in their environment;
- **proactive** means they can take independent initiatives to achieve their goals;
- **social** means they can interact with other agents to satisfy their objectives.

They are called intelligent if they learn by experience from the environment and adapt to it in the sense that they are provided with "rules to change the rules" (Casti, 1997).

Agents are provided with simple behaviours linked to local information, but when many agents are simulated as a group, behaviours often emerge that were not explicitly programmed into the agents; these are known as emergent phenomena (Landsowne, 2006).

A systematic review of the concept of artificial agents can be found in Burgin and Dodig-Crnkovic (2009).

ii. What is a multi-agent system?

According to Sun (2006), *"a multi-agent system (i.e., a society of agents) is a community of autonomous entities each of which perceives, decides, and acts on its own, in accordance with its own interest, but may also cooperate with others to achieve common goals and objectives".*

Voinov and Bousquet (2010) state that *"MAS* [Multi-Agent Systems] *describe the observed world in terms of actors (agents) that are characterized by certain rules (behaviour) that depend on the state of the environment, the state of the agent and its spatial location. Each agent is represented as an independent computerised entity capable of acting locally in response to stimuli or to communicate with other agents".*

Therefore, a MAS comprises groups of intelligent autonomous and interacting agents. They are used to understand and build "artificial social systems" (Wooldridge, 2002), thus they found applications in different domains.

iii. What is agent-based modelling and simulation?

Agent-based modelling and simulation (ABMS) is basically a computer technique simulating a system whose main components are the agents; therefore, it can be used to simulate a multi-agent system. Self-organization is a typical pattern of these models, because systems are modelled from the "ground up", agent-by-agent and interaction-by-interaction (Macal and North, 2010). A subtle difference exists between agent-based modelling and simulation: while a model can be simply designed to do optimization or search without investigating a dynamic process, simulation includes the modelling of a dynamic and time-dependent process (Macal and North, 2010). In the following, we will refer indistinctly to agent-based modelling and simulations, more in general with the acronym ABM, thus implicitly comprising the component of dynamics.

The structure of an ABM consists of (Macal and North, 2010):

- a set of **agents**, with certain properties and behaviours;
- a set of **relationships** and **methods of interaction**, with a topology that defines how and with whom agents interact;
- the agents' **environment**, where agents interact with each other and with the environment itself.

Some relevant differences can be pointed out between traditional simulation and agent-based simulation approaches:

1) the fundamentals of modelling:
    - in traditional simulation we implement a model according to a centralized theory and analyse the behaviour of the system under different input parameters and scenarios;
    - in agent-based simulation we do not have a pre-set model, we only provide agents with a few rules of behaviour and through the simulation we search for emerging patterns. In this sense, agent-based simulation is more useful to find out new models than simulating existing ones.

2) The level of analysis:
    - in the traditional approach models can be disaggregated and detailed (e.g., behavioural discrete choice models), but they presume limited options, a rational behaviour and maximizing goals;
    - in the agent-based approach intelligent agents are microscopic and interactive, thus it can be thought as the natural evolution of behaviour models.

3) The structure of the model:
    - traditional simulation uses a top-down approach, where the analyst builds a model of the system, that is a simplified abstraction of the real world, relationships among the components of the systems are presumed, a lot of data are needed for calibration of model parameters. Then through the run of several simulations, data are collected to make statistical inferences and try to identify optimal behaviours.
    - Agent simulation uses a ground-up approach, where the main components of the systems are autonomous agents,

data from real world are collected to provide agents with few simple rules on how to behave in their environment using local information. Then, through the run of several simulations, data are collected to understand if a plausible patterns of the system emerge and if general laws of a collective "intelligence" are exhibited.

Table 14 summarizes the main differences between the two modelling approaches.

Table 14. Main differences between traditional and agent-based modelling approaches.

	Modelling approach	
	Traditional	**Agent-based**
Fundamentals of modelling	Centralized theory to build the model; behaviour of the system analysed as a results of different input parameters and scenarios	No pre-set model, few rules of behaviour assigned to the agent; through the simulation we search for emerging models. More useful to find out new models than simulating existing ones
Level of analysis	Aggregated or disaggregated detailed models (e.g., behavioural discrete choice), but with limited options, a rational behaviour and maximizing goals	Intelligent agents are microscopic and interactive, they can be thought as the natural evolution of behaviour models.
Structure of the model	Top-down approach, a lot of data are needed for calibration of model parameters. Through the run of several simulations, data are collected to make statistical inferences and trying to identify optimal behaviours	ground-up approach, data from real world are collected to provide agents with few simple rules. Through the run of several simulations, data are collected to understand if a plausible patterns of the system emerge and if general laws of a collective "intelligence" are exhibited.

ABM has been widely used to reproduce transport problems and interaction among transport stakeholders. For some references, the reader can refer to the papers in the special issues of Transportation Research C on Agents in Traffic and Transportation edited by Bazzan, Klügl and Ossowski (Bazzan et al., 2005; Klügl et al., 2010).

The software MATSim (Multi-Agent Transport Simulation), implemented and sustained by Nagel and Axhausen (Raney et al., 2003; Nagel, 2004), is broadly used for large-scale agent-based transport simulations, allowing demand-modelling, traffic flow simulation and re-planning. A list of the related most important papers can be found in the webpage of MATSim[22].

ABM is also used for multi-stakeholder involvement and analysis in transport problems. Henesey (2006) in his PhD thesis reproduces port container terminal management using MAS and ABM, simulating stakeholders' relations for the analysis of operational policies for sustainable port and terminal management. Anand (2015) in his PhD thesis provides an "ontology" and an overall framework on how to build and validate an ABM for multi-stakeholder analysis of city logistics solutions. The problem of urban freight transport or city logistics has been widely investigated via ABM in the last years (Taniguchi and Tamagawa, 2005; Roorda et al., 2010; Van Duin et al., 2012). These models usually take into account stakeholders' operational behaviour and interaction in response to specific policies.

In this research, the behaviour of stakeholders called to express their opinion about new policies in a participatory decision-making process and the emergent phenomena derived from it are investigated, via ABMs and opinion dynamics models. Next subsection will introduce the software used for ABM, while section 4.2 will introduce and explain the rationale behind opinion dynamics models.

4.1.1. ABM with NetLogo

NetLogo is a multi-agent programmable modelling environment, developed on Java platform by Uri Wilensky in 1999 at the Center for Connected Learning and Computer-Based Modeling (CCL) of the Northwestern University. It is used by ten thousands of students, teachers and researchers worldwide and it can be downloaded for free[23]. Netlogo offers a suitable environment for the development of physical, biological or social systems because it can reproduce most of the characteristics of complex systems, following the time evolution and the significant parameters real-time. It is totally programmable with a simplified language derived from Logo syntax and code examples from the Models Library.

[22] http://matsim.org/publications
[23] http://www.ccl.northwestern.edu/netlogo

It consists of a graphic interface and a code section. The graphic interface is composed of a square or rectangular grid named **World**, where it is possible to define two fundamental objects:

- **Patches**, i.e. the square grid cells, characterized by fixed integer coordinates;
- **Turtles**, i.e. the agents which can move in the grid and that are characterized by variable coordinates in floating point.

Over the Patches and Turtles level there is the **Observer**, namely the programmer. The world can be modified in terms of coordinates system and topology. The graphic interface is interactive since it can be enriched with several elements, such as: **Button**, which recalls a procedure or executes an instruction; **Slider**, which enables to manually change the value of global variables; **Switch** and **Chooser**, that allow to choose respectively from the two options true or false or from different values from a drop-down menu; **Monitor**, to follow the evolution of a certain global variable or other measures; **Plot**, which shows real-time graphs and histograms.

The code consists of routines and subroutines which can be recalled inside other codes or by means of a button; **Setup** and **Go** are two important buttons: the first one declares the variables, the grid and the plots and gives the initial value to the variables; the last one starts the simulation. There are three variables in NetLogo: global, local and own variables. The last one are typical of NetLogo and they serve the purpose to define own attributes of the different agent categories.

NetLogo can be used to model a traffic network (Figure 14a) by assigning simple rules to the car-agents and monitoring sensitive parameters, such as the number of stopped cars, average speed and waiting time of the cars. It can also be used to create a complex network according to specific rules, e.g. following the logic of preferential attachment, where new nodes that are added to the network are linked to nodes that already have many connections (i.e. preferential attachment). Also in this case it is possible to monitor network variables, such as the degree distribution related to the number of links of the nodes (Figure 14b).

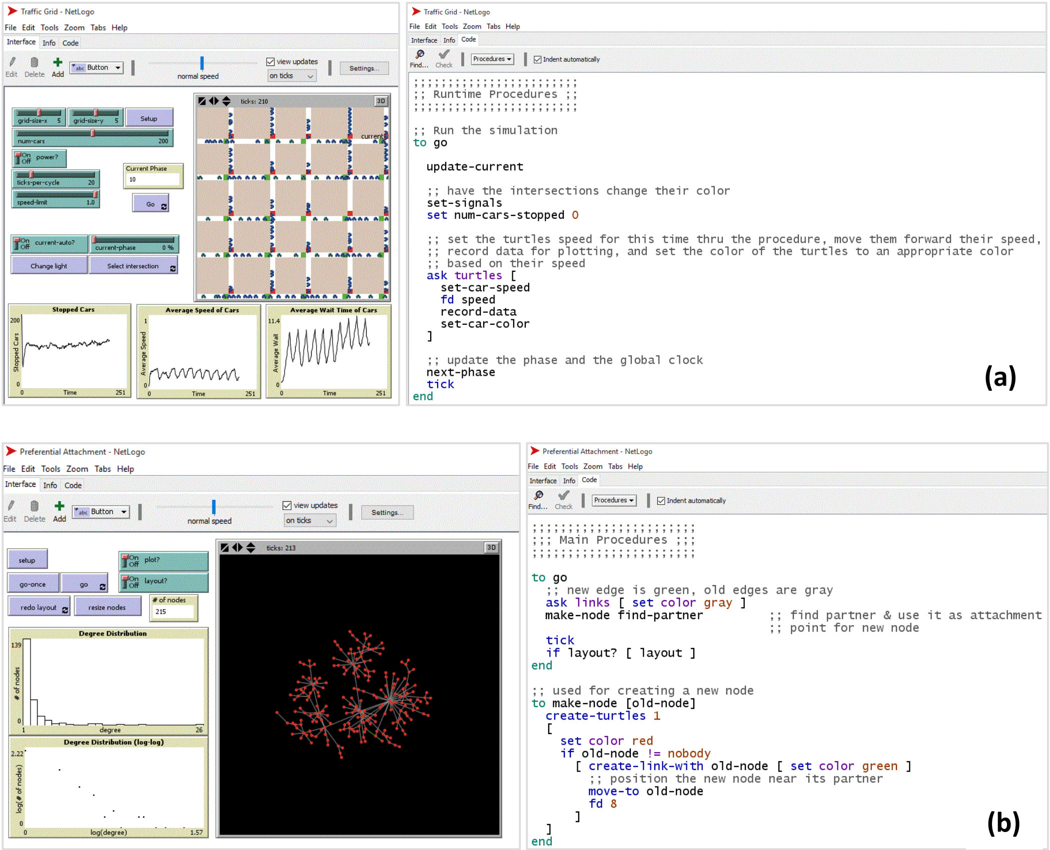


Figure 14 – Examples from NetLogo Models Library: (a) interface of the social science model "traffic grid", with the detail of the "go" procedure; (b) interface of the network model "preferential attachment", with the detail of the "go" procedure.

In the context of participatory decision-making processes, NetLogo can be used to reproduce interaction among stakeholders that are willing to change their opinion to build consensus and find a shared decision. It is possible to create a network of stakeholders (i.e. agents or turtles) connected by links with their neighbours (i.e. the directly linked agents) and ask them to do something (command **Ask**), for instance to have an opinion (from a discrete or a continuous interval) and to change the opinion at the next step according to their neighbours' ones.

The interaction process in a network of stakeholders can be reproduced by means of opinion dynamics models. Next section will introduce some of the concepts and the rationale behind them.

4.2. Opinion dynamics models to reproduce social interaction

In recent years, physicists have started exploring phenomena outside the boundaries of traditional physics, finding regularities and similarities with physics systems. In this context, social dynamics and, in particular, the emerging collective phenomena that derives from social interaction are widely investigated, giving birth to a new branch of physics, i.e. the statistical physics of social dynamics. A basic question of social dynamics is: "*How do the interactions between social agents create order out of an initial disordered situation?*" (Castellano et al., 2009).

Statistical physicists working on opinion dynamics aim at defining the opinion states of a population, and the elementary processes that determine transitions between such states. The behaviour of social agents is clearly simplified with respect to reality, but it can be useful to understand the conditions under which a social interaction can lead to consensus or emerging collective phenomena. One of the main drawbacks of these models is that in general they are not fed with real empirical data.

A comprehensive review of the state of the art of statistical physics of social dynamics and opinion dynamics models can be found in Castellano et al. (2009). In what follows, a succinct literature review of some well-known models will be presented (Table 15).

One of the most widely known is the Hegselmann and Krause (HK) compromise model (2002), where agents form their actual opinion by taking an average opinion based on their neighbours' ones. This leads to a dynamical process which should flow into a consensus among all agents. The HK model is based on the concept of bounded confidence (BC) meaning that an agent can change its opinion only according to the neighbours within its confidence bound (a parameter ε).

Another typical model is that of Sznajd (Sznajd Weron and Sznaid, 2000) where agents are in a two-dimensional grid and their opinions are represented through different colours. Only couples of neighbours with the same opinion can influence the other neighbours. This model was used to predict the Brazilian election results (Bernandes et al., 2001) and it resulted in good agreement with reality.

Another model that tries to describe the real agent behaviour is the so called "Opinion Changing Rate" (OCR) model (Pluchino et al., 2005), which considers the individual inclination to change (OCR), that can affect the opinion dynamics, and it is similar to the characteristic frequency of an oscillator. The authors treat consensus formation as a kind of synchronization, using a modified version of the Kuramoto model of coupled oscillators.

The majority rule (MR) model by Galam (2002) considers all the agents at time *t* endowed with binary opinions (+1, 1) and they can communicate with each other. At each interaction, a group of agents is selected at random (discussion group): as a consequence of the interaction, all agents take the majority opinion inside the group. The MR model has been extended to multi-state opinions and plurality rule (Chen and Redner, 2005) with a number of opinion states s and size of the interaction groups G.

Table 15. Review of some opinion dynamics models.

Model	Reference	Approach
HK compromise model	Hegselmann and Krause (2002)	Agents form their actual opinion by taking an **average opinion** based on their neighbours' ones and according to a "**confidence bound**"
Sznajd model	Sznajd Weron and Sznajd (2000)	Only **couples** of neighbours with the same opinion can influence the other neighbours
Opinion changing rate (OCR) model	Pluchino et al. (2005)	It considers the individual inclination to change (OCR) and consensus formation is treated as a kind of **synchronization**, using a modified version of the Kuramoto model of coupled oscillators
Majority rule (MR) model	Galam (2002)	At each interaction, a group of agents is selected at **random** (discussion group): as a consequence of the interaction, all agents take **the majority opinion** inside the group
Extended majority rule (MR) model	Chen and Redner (2005)	The MR model has been extended to **multi-state opinions** and plurality rule with a number of opinion states s and size of the interaction groups G

In general, the opinion dynamics models consist of algorithms that can be analytically or numerically solved and the dynamics is usually simulated by means of Monte Carlo algorithms. Besides, computer simulations play an important role in the study of social dynamics and one of the most successful methodologies used is ABM. The idea is to construct the computational devices (known as agents with some properties) and then simulate them in parallel to model the real phenomena (Castellano et al., 2009).

ABMs are widely used in simulating complex systems enabling to reproduce the actions of single agents characterized by particular properties and internal complexity; thus the opinion dynamics can be simulated by means of ABM. Pluchino et al. (2006), in their work on compromise and synchronization in opinion dynamics, explained the apparent simplified agent behaviour and the role of agent-based simulations:

"Of course in many cases the individual cognitive behavior is oversimplified, as for example in opinion dynamics models where human opinions are reduced to integer or real numbers. [...] *the aim of agent-based simulations is to provide information on averages over many people, and not on the fate of a specific person. In this sense, despite of their simplicity, these models seem to work very well."*

There are several reasons why ABM has been chosen to simulate the opinion dynamics on stakeholder networks, i.e.:

- the relative easiness to represent a network of nodes (agents) linked together with ties;
- the possibility to ask the agents (endowed with own properties) to have an opinion and act according to simple behavioural laws;
- the power of visualization, that can help the analysis;
- the opportunity to change the global variables, which makes generalization possible;
- the surfacing of collective patterns which are not predictable from the simple initial rules and that emerge from simulations.

Based on these considerations, in this research ABM and opinion dynamics models are used to investigate social interaction in stakeholder networks and reproduce typical participatory decision-making processes in transport planning. Next chapter will show the basis of the methodology and will enter into the details of the three implemented models.

5. METHODOLOGY

"On the one hand the efficiency of the participatory process depends on social relations between the stakeholders, their ability to communicate and exchange information and knowledge, and the skills and methods that can assist them in doing that. On the other hand there is a clear need for technical, analytical and modelling tools and software that can be used in this process."

Voinov and Bousquet, 2010

5.1. Agent-based Modelling of Opinion Dynamics on Stakeholder Networks

The participatory decision-making process in transport planning has been modelled at different levels according to the degree of involvement in the planning process and the purpose of the model. Therefore, ABM of opinion dynamics on stakeholder networks has been used:

I. to investigate consensus building on a single plan/project/policy that requires stakeholders' approval (or disapproval); in the framework of participatory transport planning it can be placed at the "consultation" phase, as a preventive analysis of stakeholder involvement in the decision-making process (section 5.2).

II. to reproduce group decision-making processes with reference to a set of plans/projects/policies, or a ranking of objectives/criteria, thus investigating the probability of decision deadlock due to the "Condorcet paradox" and the conditions that lead to a shared collective ranking; in the framework of transport planning it can be placed at the "participation" phase, when stakeholder involvement should guide the decision-maker towards the final decision (section 5.3).

III. to reproduce an overall participation process through a multilayer network, with a representation of different decision levels interconnected with each other and the possibility of cyclical top-down/bottom-up input and feedback that allows a full inclusion of stakeholders in the decision-making process; in the framework of transport planning it can be seen as an advanced, more transparent and inclusive form of participation (section 5.4).

Table 16 summarizes the main concepts of the methodology with reference to the three above described ABM.

Table 16. ABM of opinion dynamics on stakeholder networks to reproduce participatory decision-making process in transport planning.

ABM of Opinion Dynamics on Stakeholder Networks	Structure of the network	Aim of the model	Level of involvement	Reference papers[24]
I model	Single layer	Consensus formation on a single decision	Consultation	III, IV
II model	Single layer	Collective preference ranking of alternatives	Participation	II, VI,VII,VIII
III model	Multilayer	Multilevel participation process in decision-making	Inclusive participation	V

Next sections will enter into the details of the three implemented models.

5.2. Agent-based model of consensus formation phenomena about a single decision (I model)[25]

In the proposed model stakeholders are agents in a social network composed of nodes (i.e. the agents) and links (i.e. the relationships among them). They can interact with the neighbours (i.e. the directly linked nodes) and they can change their opinion according to an opinion dynamics model.

The implemented opinion dynamics model is inspired to the majority rule (MR) model (Galam, 2002), where all the agents at time *t* are endowed with binary opinions (+1, -1) and they can communicate with each other. At each interaction, a group of agents is selected at random (discussion group): as a consequence of the interaction, all agents take the majority opinion inside the group. This assumption can appear quite simple but, on the other hand, the MR model is the result of an extended interaction which is influenced by topological complexity and by the initial distributions of opinion. Therefore, it allows to simulate a

[24] The list of papers can be found at p 15.
[25] This section is based on paper III: “Modelling stakeholder participation in transport planning”, and paper IV: “Agent-based modelling of Stakeholder Interaction in Transport Decisions”.

community with distributed opinions that can change through frequent opportunities of interaction. The MR model has been extended to multi-state opinions and plurality rule (Chen and Redner, 2005) with a number of opinion states s and size of the interaction groups G.

Our model can be considered a multi-state opinion model with $s = 3$, where agents are endowed with one opinion among approval, disapproval or neutral, denoted by +1, -1 and 0 respectively. The neutral opinion is considered less significant and "contagious" than the two others, so the latter were assigned with a double weight. It is also a bounded confidence model, because of the definition of a confidence bound which limits the way a node can change its opinion: a node with +1 cannot directly change its opinion in -1 (and vice versa), but it must pass through the opinion 0 before. Considering the neutral state as a transition opinion is reasonable because it represents a phase of indecision. The nodes which assume the neutral state can change their opinion at the next step, so opinion changing is not conditioned by a specific time but it depends from the neighbours' opinions.

The algorithm of the model can be described in two main steps: setup of the initial conditions and opinion dynamics (see Figure 15).

<u>SETUP (t=0)</u>. The social network of stakeholders is created, according to a fixed topology. In particular, we distinguish between "strong ties" and "weak ties", a standard description in community structure analysis for indicating, respectively, links between nodes belonging to the same group and links between nodes belonging to different groups (Granovetter, 1973). The "degree" is the total number of links (strong + weak) of a given node and "z-out" is the number of weak links of the same node. Each node (agent) is endowed with two main properties: (i) an influence factor, which is an integer number in the range [0,10] reflecting the social importance of the node; (ii) an "influenceabiliy", which is a random real number in the range [0,1] representing the probability that a node directly changes its opinion without considering the confidence bound. In other words, if this parameter has a value close to 1, the probability to directly change its opinion without passing through the neutral stance is high; vice versa when the value is around 0. Finally, at $t = 0$, an opinion is assigned to all the nodes by setting a "positive initial group", i.e. a group of nodes that are initially in favour of the proposal.

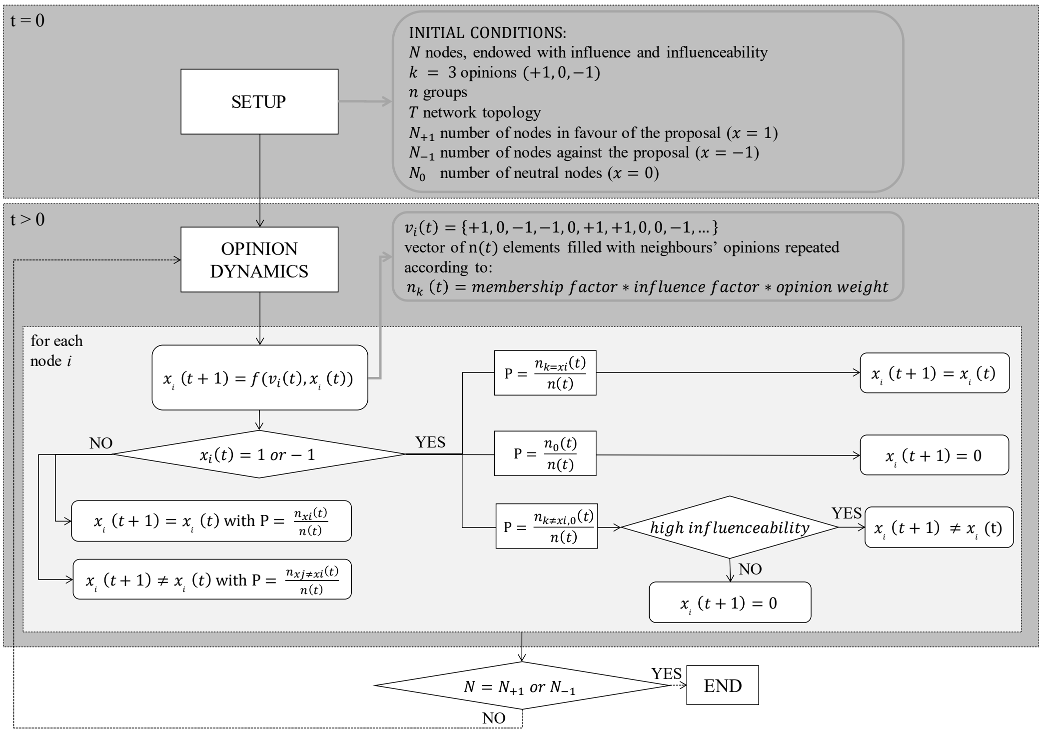


Figure 15 – Main routines of the I agent-based model.

<u>OPINION DYNAMICS (t>0)</u>. At each step of the simulation, each agent can change its opinion based on its neighbours' ones. The implemented algorithm consists of the creation, for each node, of a vector whose components are the weighted opinions of all the neighbours. Let $x_i\ (t)$ be the opinion of the node i at time t; the opinion at time t + 1 will be:

$$x_i\ (t+1) = f(v_i(t), x_i\ (t))$$

where $v_i(t)$ is the vector of the neighbours' opinions, which are repeated, for each neighbour, a number of time $n_k\ (t)$ related to the *opinion weight*, the *influence factor* and according to a *membership factor*, considering that there are more possibilities to interact within the same group:

$$n_k\ (t) = \ membership\ factor * influence\ factor * opinion\ weight$$

with k = -1, +1, 0.

At each time, an element of the vector will be randomly chosen, therefore the most frequent opinion will be the most likely to be selected.

A numerical example can help the comprehension of the algorithm. Consider the network represented in Figure 16 with 11 nodes divided into two clusters. Being node 1 linked with 8 members of its own cluster (strong ties) and with 2 members of another cluster (weak ties), the degree is 10 while z-out is 2. In order to fill the neighbours' opinion vector of node $i = 1$, it is necessary to:

- repeat the opinion of a given neighbour as many times as its influence ($influence\ factor = 10, 8, 6, 4$);
- repeat the opinions of all the neighbours in the same group of node 1 for five times, according to the $membership\ factor$ ($membership\ factor = 5$);
- weigh the different opinions: +1 and -1 are more significant than 0, so they will be considered twice ($opinion\ weight = 2$).

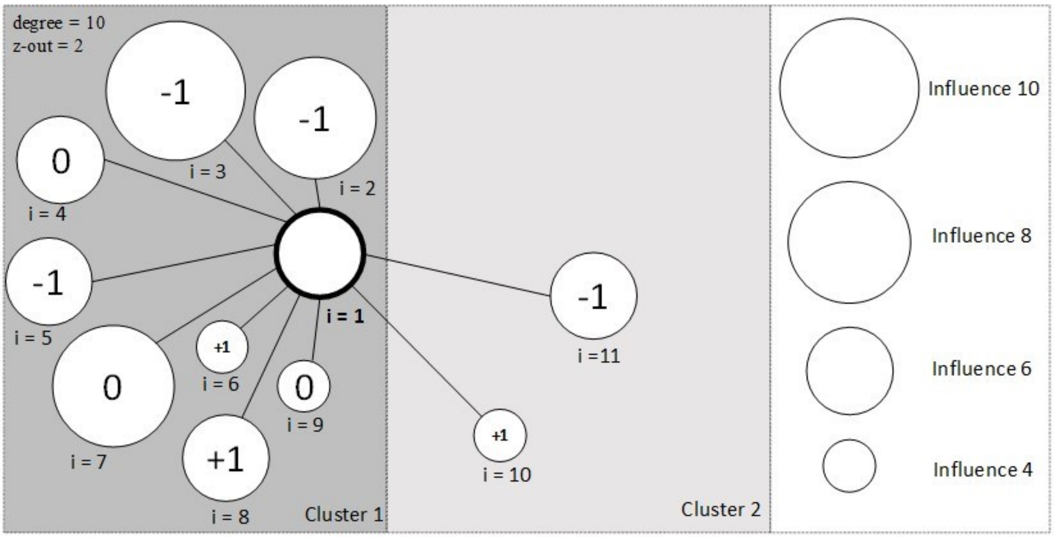


Figure 16 – Network example (degree 10, z-out 2).

The number of times an opinion is repeated is then calculated:

$$n_{-1}(t) = 2 * (5 * 8 + 5 * 10 + 5 * 6 + 6) = 252$$

$$n_{+1}(t) = 2 * (5 * 4 + 5 * 6 + 4) = 108 \quad \rightarrow n\,(t) = 450$$

$$n_0(t) = 5 * 6 + 5 * 8 + 5 * 4 = 90$$

Therefore, the resulting vector $v_i(t)$, with $n(t) = 450$ elements, has the following aspect:

$$v_i(t) = (\overbrace{-1,-1,\dots,-1}^{\text{252 el.}},\overbrace{+1,+1,\dots,+1}^{\text{108 el.}},\overbrace{0,0,\dots,0}^{\text{90 el.}})$$

At this point we can finally calculate the opinion $x_i\,(t+1)$at time $t+1$ by the following matrix, which sets the probabilities P of assuming one among the three possible opinions as a function of $v_i(t)$ $v_i(t)$ and $x_i\ (t)x_i(t)$:$v_i(t)$and$x_i(t)$:

x(t) \ x(t+1)	+1	0	-1
+1	$\frac{108}{450} = 0.24$	$\frac{90}{450} = 0.20$	0 / 0.56
0	$\frac{108}{450} = 0.24$	$\frac{90}{450} = 0.20$	$\frac{252}{450} = 0.56$
-1	0 / 0.24	$\frac{90}{450} = 0.20$	$\frac{252}{450} = 0.56$

Figure 17 – Opinion changing probability matrix.

As already said, the activation of the confidence bound depends on the node $influenceability$; this is why there is a double probability to directly change the opinion from +1 to -1 and vice versa: actually, we will choose the case $P \neq 0$ with probability equal to the $influenceability$ and $P = 0$ with probability $(1 - influenceability)$.

For instance, if node 1 has $x_1\ (t) = 1$:

$$x_1\ (t) = 1 \begin{cases} x_1\ (t+1) = 1 \ \text{ with } \ P = 24\ \% \\ x_1\ (t+1) = 0 \ \text{ with } \ P = 20\ \% \\ x_1\ (t+1) = -1 \ \text{ with} \begin{cases} P = 56\ \% \text{ if } influenceability \text{ is high} \\ P = 0\ \% \text{ if } influenceability \text{ is low} \end{cases} \end{cases}$$

In order to reproduce potential external influences to the opinions, it is assumed that the dynamics can be modified by means of a Changing-Mind-Rate (CMR), a factor that represents the probability that a given node would randomly change its opinion at a given time.

The dynamics can be followed in time by plotting three curves, each representing a different opinion against time. In Figure 18a we show a single typical event in which, starting from a given distribution of opinions among the agents and after a struggle among the three opinions, the simulation ends with all agents converging towards the same opinion. In Figure 18b we report the frequency distribution of the final surviving opinions cumulated over 10 events with the same parameter setting, but different extraction of the random variables: we observe that the main opinions (approval and disapproval) are the only one that survives while the neutral stance is only a transition opinion.

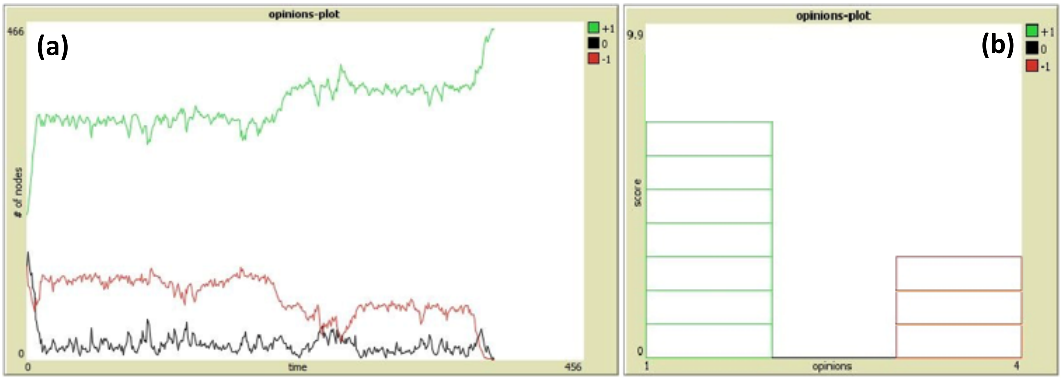


Figure 18 – Plot of opinions over time for a single event (a) and distribution of frequency for ten events (b).

This ABM was used to investigate the stakeholder consultation process with reference to a specific case study: the decision-making process about parking pricing policies inside a University campus, where the number of stakeholders was known (all the professors divided into academic categories and departments), while the networks and the opinions were idealized (see case study 1, section 6.1).

5.3. Agent-based model of collective preference ranking processes and the "Condorcet paradox" (II model)[26]

In the previous ABM an opinion dynamics model is used 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 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

[26] This section is based on paper II: "Modelling multi-stakeholder preference ranking for sustainable policies" and paper VII: "Simulating opinion dynamics on stakeholders' networks through agent-based modeling for collective transport decisions".

opinions has to be found, whilst avoiding the "Condorcet paradox" (see section 3.4, p 90).

The model consists of the following routines:

1) <u>SETUP (t=0)</u>. N stakeholders $S(i)$ $(i = 1, \dots, N)$ are represented as nodes of an undirected network, according to a selected topology with fixed connectivity. 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 the directly connected nodes (first neighbours) in the network. Each preference list is transformed into a binary vector , and the collective binary vector (through PMR) is calculated (see section 3.3, p 87); 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 the initial condition assumed at $t = 0$.

2) <u>MAX OVERLAP TEST (t=0)</u>. As already said, we are interested in finding a final decision, represented by a collective list, which not only has to be transitive, but should also reflect quite appreciably the individual preferences. This latter requirement can be verified through the so called "overlap", that is a measure of similarity (or closeness) between any two lists. If n is the number of alternatives and $m = n * (n-1)/2$ is the number of the possible pairwise couples (i.e. the number of components of each binary vector), the overlap is defined as:

$$O(i,j) = \frac{1}{m}\sum_{k=1}^{m} V_k(i) \cdot V_k(j)$$

where $V_k(i)$ and $V_k(j)$ 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 $O(i,j) \in [-1,1]$; if $\boldsymbol{V}(i) = \boldsymbol{V}(j)$, then $O(i,j) = 1$; if all the homologous components $V_k(i)$ and $V_k(j)$ have opposite signs, then $O(i,j) = -1$; if $\boldsymbol{V}(i)$ and $\boldsymbol{V}(j)$ are uncorrelated, then $O(i,j) = 0$. As an example, the similarity between two lists of $n = 3$ alternatives can be represented by the alignment between the two related binary vectors of $m = 3$ components in the m-dimensional space and the overlap coincides with the scalar product between the same vectors; in Figure 19 the two vectors are partially aligned and the overlap is 0.33.

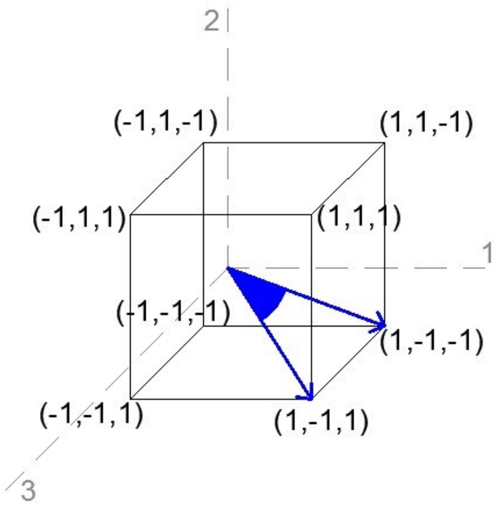


Figure 19 – Geometric interpretation of the overlap, as the scalar product between two binary vectors in the m-dimensional space (case of $n = 3$ alternatives, $m = 3$ components of the 8 possible binary vectors).

The same formula can be used to calculate the overlap between any individual vector $\boldsymbol{V}(i)$ and the collective vector $\boldsymbol{V}(c)$ ($O(i,c) = \frac{1}{m}\sum_{k=1}^{m} V_k(i) \cdot V_k(c)$). For example, it can be used at the beginning of a simulation (i.e. at $t = 0$) to evaluate the similarity between each individual list and the corresponding collective intransitive list, represented by $\boldsymbol{V}^{t=0}(c_{intr})$; it is quite intuitive that, since the initial individual lists are randomly selected, the average overlap, calculated as $\bar{O}^{t=0}(i, c_{intr}) = \frac{1}{N}\sum_{i=1}^{N} O^{t=0}(i, c_{intr})$, assumes values close to zero.

Using the concept of overlap, if the main goal was only escaping from the Condorcet cycle, we could simply select, among all the possible transitive lists, that one whose binary vector $\boldsymbol{V}^{t=0}(c_{tr}^{*})$ has the maximum overlap with $\boldsymbol{V}^{t=0}(c_{intr})$, i.e.:

$$O^{t=0}(c_{tr}^{*}, c_{intr}) = \frac{1}{m}\sum_{k=1}^{m} V_k^{t=0}(c_{tr}^{*}) \cdot V_k^{t=0}(c_{intr}) = \max\{O^{t=0}(c_{tr}, c_{intr})\}$$

Assuming that closeness between two cells in the collective preference space is a rough measure of their overlap, this selection just corresponds (see Figure 20) to find the closest "transitive island" (grey cell) to the intransitive initial list (bold white cell). Nevertheless, it is quite probable that the average overlap $\bar{O}^{t=0}(i, c_{tr}^{*}) = \frac{1}{N}\sum_{i=1}^{N} O^{t=0}(i, c_{tr}^{*})$ between the selected transitive list and all the individual lists (proportional to the colour intensity of grey cells in the collective preference space) will be close to zero, like $\bar{O}^{t=0}(i, c_{intr})$. Actually, this is exactly what happens, as it will be shown later through the simulations. In other words, the final collective list found by such a "max overlap test" does not fulfil the requirement of appreciably reflecting the individual preferences.

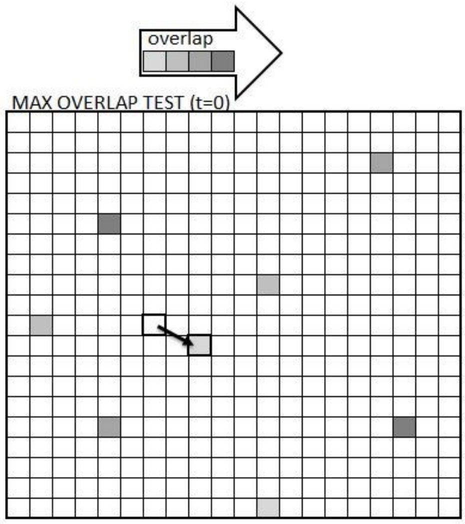


Figure 20 – Representation of the max overlap test in the collective preference space.

3) <u>RANDOM TEST (t>0)</u>. From the previous step it appears that, in order to get a transitive collective list with a higher average overlap with the individual lists, it is necessary a searching strategy able to find a darker grey island of transitivity in the collective preference space, starting from the initial cell of intransitivity. One could wonder if a random searching strategy could be suitable to this aim. This implies the following dynamical algorithm: starting from the initial intransitive collective list, at each step $t > 0$ each stakeholder $S(i)$ randomly changes his preference list and the corresponding collective preference list is derived, as explained in step 1. The process ends when a transitive collective list is obtained, generally after a small number of steps. In the collective preference space, this corresponds to a "random path" in the sea of the intransitive lists, until a transitive island is found (see Figure 21). However, due to the randomness of this procedure, the corresponding average overlap $\bar{O}^{t=0}(i, c_{tr})$ results to be again very low. As simulations will confirm, even if the algorithm is further run - finding other randomly selected islands - there would not be an increase in the average overlap.

This means that the “random test” fails too, therefore it is necessary to find a more suitable searching strategy, able to reflect the individual preferences.

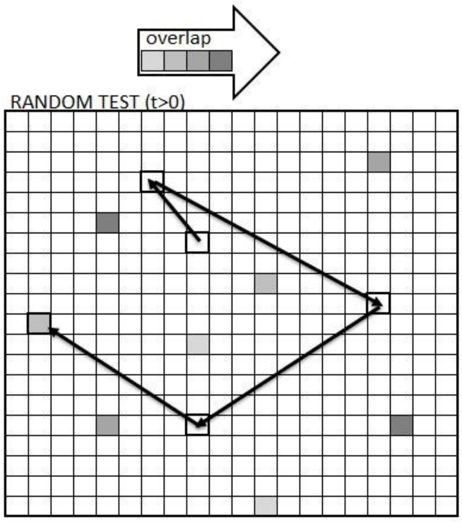


Figure 21 – Representation of the random test in the collective preference space.

4) OPINION DYNAMICS (t>0). As already said, interaction among stakeholders is a key of success for a transparent and shared decision-making process. In the simulations, an opinion dynamics model is used to reproduce the opinion changing process in the network of connected and interacting people. In particular, at each step $t > 0$, each stakeholder $S(i)$ interacts only with his $N(i)$ first neighbours $\{S(j)\}_{j=1,\dots,N(i)}$ in the network. Due to the interaction, $S(i)$ has a certain probability of changing opinion, depending on both the influence $I(j)$ of his neighbours and the similarity with their lists. More precisely, we assume that $S(i)$ will change his list with the one of a given neighbour $S(k)$ with a probability $P(i,k) = \frac{I(k)}{\sum_{j=1}^{N(i)} I(j)}$, but only if the overlap $O(i,k) > 0$; otherwise, $S(i)$ will maintain his list. After all the stakeholders updated their lists at time t, a new PMR - and its corresponding collective preference list - is calculated: if the latter is transitive, the new average overlap $\bar{O}^t(i, c_{tr})$ is computed, recorded and plotted as function of time; on the other hand, if during the process a Condorcet cycle occurs, the solution is discharged. In both the cases the algorithm goes on, in order to find more and more shared transitive solutions. This procedure can be visualized again in the collective preference space, where an iterative and progressive path among transitivity islands, through adjacent intransitivity cells, is followed (Figure 23). The striking point

is that, at variance with what happens in the case of the random strategy, in general this path leads to transitive islands with higher overlap, until the "darkest" grey island is reached, i.e. the one with the maximum achievable overlap. In fact, as it clearly appears plotting the average overlap versus time (see Figure 22), the first transitive lists found usually show a low overlap, but, when the interaction is repeated, $\bar{O}^t(i, c_{tr})$ presents a growing – even if not monotonous – trend, until it reaches a stationary state, corresponding to its maximum value (Figure 22). The final list is therefore assumed as the transitive "most shared" collective solution, appreciably reflecting the individual preferences of all the stakeholders.

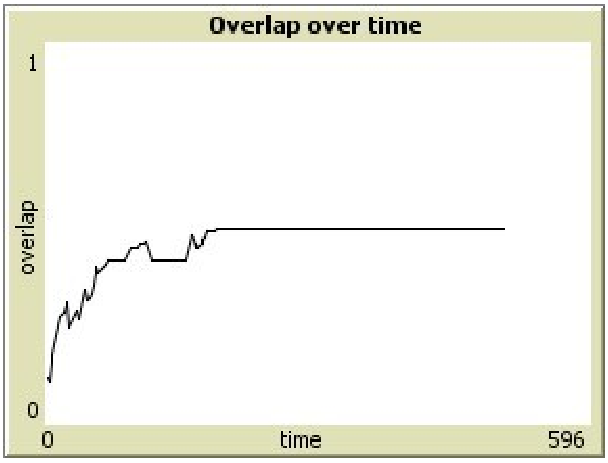


Figure 22 – Plot of average overlap over time.

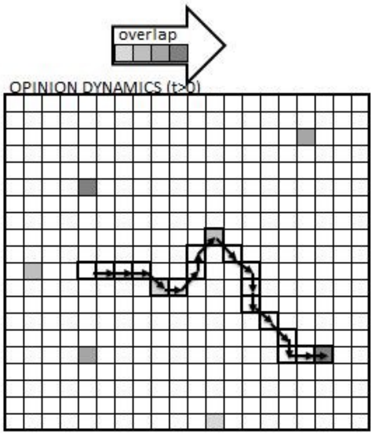


Figure 23 – Representation of the interaction dynamics in the collective preference space.

The main routines of the model are summarized in Figure 24. This ABM was used for different purposes: from one side, ideal complex networks, that showed similarities with typical stakeholder networks, were considered to test the model (see case study 2, section 6.2); from the other side, two case studies based on real participation experiences were used to make an effort of validation of the model (see case studies 3 and 4, section 6.3 and 6.4).

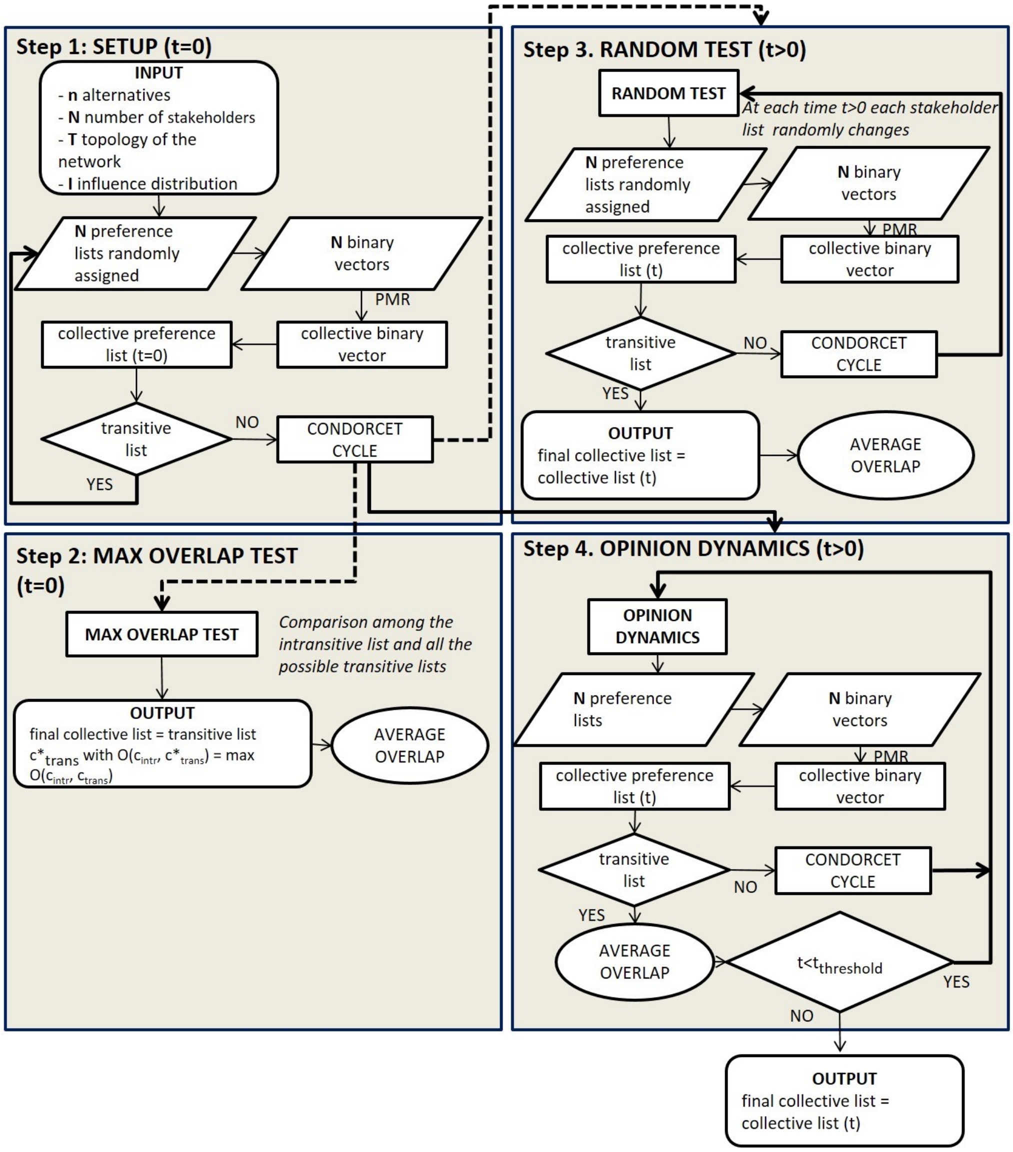


Figure 24 – Description of the main routines of the II agent-based model.

5.4. Agent-based model of stakeholder involvement in policy-making processes with the multilayer approach (III model)[27]

The III ABM aims at simulating the stakeholder-driven decision-making process with respect to policy change using a multilayer network, where each layer represents a different level of description and details of the process. As in the previous cases, the model links stakeholders in social networks, where the nodes represent the agents and the links are the

[27] This section is based on paper V: "Agent-based modeling of stakeholder involvement for urban freight transport policy-making".

relationships among them. The interaction process is simulated by means of an opinion dynamics model, reproducing the opinion flows through the network of relationships. It is assumed that stakeholders decide to cooperate so to find a shared decision with respect to policy measures priorities through a cycle of meetings with other actors belonging to the same categories. Stakeholders have an opinion represented by the priority order they assign to a list of policy measures. This opinion reflects their aim to maximize the utility assigned to each set of policy measures. They are available to modify their opinion as much as they interact with other actors with similar opinions. Their willingness to change is increased by repeated cycles of interactions through the multilayer network.

Multilayer networks constitute more realistic graphs with multiple interconnected levels, which generalize the single-level networks, allowing for a more realistic and effective representation of complex phenomena (Boccaletti et al., 2014). In the case of socio-economic systems, such as decision-making processes, a particular type of multilayer network should be used, the so called "multiplex" network, where each node belongs to all the layers but the relationships among them can change within the layers.

The policy-making problem involving heterogeneous stakeholders is represented as a multiplex network with three layers whose structure is reported in Figure 25:

- the bottom layer is the "interaction" level, represented by all the stakeholders linked in "small-world" networks with the other members of the same category. The "small-world" network is a typical social network characterized by high levels of communication efficiency thanks to its structure of regular network "rewired" with some long-range links (Watts and Strogatz, 1998); it has been chosen to represent the communication within the stakeholder categories due to its similarity with real social networks;

- the middle layer is the "negotiation" level, where an agent of each category acts as the spokesperson and is directly linked with all the other members of the same category. The topology is a "star" network, with a hub directly linked with all the other nodes; the "star" network represents quite well the meetings of trade unions and associations where the members communicate their preferences to a delegate;

- the top layer is the "decision" level, where the spokespeople of the three categories are linked with each other and interact supporting the opinion of their constituency. The topology is a "fully connected" network, representing a focus groups where each delegate is in charge of representing the interests of his category in front of other delegates and they all discuss to find a shared decision.

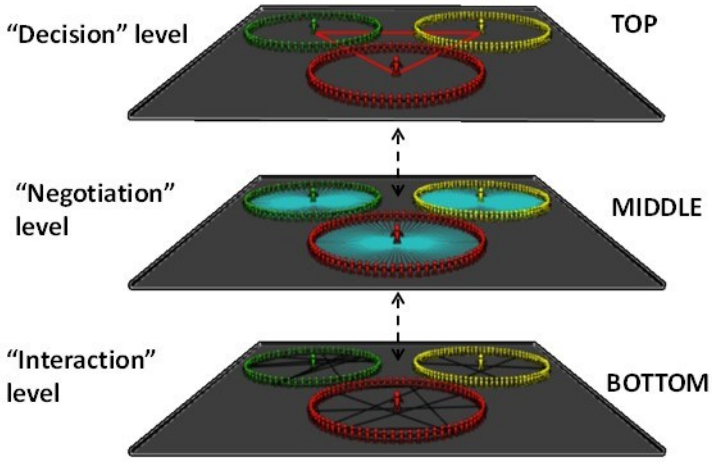


Figure 25 – Multiplex network of stakeholders (with three categories).

The interrelationship between the layers is guaranteed by the presence of all nodes in the three layers. The structure of the network allows at the same time bottom-up and top-down feedbacks.

The model consists of several routines and it can be described in two main steps: setup of the initial conditions and opinion dynamics process.

SETUP (t=0). The stakeholder-agents are created and each agent i is endowed with individual utility functions U^i, characterized by certain attributes x_n with the related parameters β_n. Other agents are created as spokespeople for each category c and they are endowed with an integer parameter I_c representing the influence of their category. The agents are linked in the three layers according to the topologies described above (small-world networks in the bottom layer, stars in the middle layer and a fully connected network in the top layer). Each simulation reproduces the decision-making process between two alternatives: *status quo* (SQ) and a given policy change (PC), characterized by different combinations of attribute levels. It is assumed that the agents, being involved in a participatory decision-making process, while interacting will show a certain availability to change their opinion in order to find a shared solution.

At time $t = 0$ the generic agent i can associate utility values to the two alternatives according to its utility function; subsequently, it will choose the policy which maximizes its utility and it is endowed with a certain willingness to change "wtc" (wtc^i), calculated as the difference between the utility associated with the two alternatives: *status quo* (U_{sq}^i) and policy change (U_{pc}^i):

$$wtc^i = 1 - \frac{|U_{pc}^i - U_{sq}^i|}{|\Delta U_{max}|} \in [0,1]$$

where ΔU_{max} represents the maximum difference of utility between the two alternatives. The higher the utility difference between the two alternatives, the less the agent would be willing to change its opinion. Suppose that one has the possibility to choose between the perceived best policy and the perceived worst one (high utility difference): the preferred policy will be strongly supported and the willingness to change will be very low. On the contrary, if one could choose between two policies, which are quite the same in terms of perceived utility, then it will be easier to change idea and switch the choice from the first best to the second best (low utility difference and high wtc).

<u>OPINION DYNAMICS (t>0).</u> Once the initial conditions are set up, the simulation of the dynamic interaction can start. It goes forward through the interplay between two distinct opinion dynamics (OD) processes, which act in sequence realizing a cyclic global process: a bottom-up OD, in which the information flows from the bottom layer to the top one; and a top-down OD, in which the information follows the inverse path, from the top to the bottom layer.

The bottom-up opinion dynamics is based on a majority rule (Galam, 2002): once all the agents at the bottom layer have chosen the preferred policy, the generic spokesperson of the category c assumes, at the middle layer, the policy of the majority of its group and it is also endowed with a certain wtc. The spokespeople represent the will of each of their groups, therefore they will be more willing to negotiate with the others at the top level, and eventually to change opinion, if their group is "divided" between the two policies (meaning that there is not a clear majority) or if they are, on average, very willing to change. Therefore, their wtc will depend both on the average wtc of their group ($\overline{wtc_c}$) and on the number of nodes supporting the non-preferred policy ($\%minority$):

$$wtc_c^{sp} = \frac{|\%minority \ + \ \overline{wtc}_c|}{2} \ \in \ [0,1]$$

The top-down opinion dynamics is based on an incremental algorithm with thresholds that determine the opinion change. At each time step, the interaction between any two connected agents i and j occurs as follows: agent i receives a given "pressure" from agent j in terms of increase of its wtc ($+\Delta wtc$) if the opinion of j is different from that of i; vice versa, i will strengthen her opinion by reducing its wtc ($-\Delta wtc$). In the next time step, the preferences of the agents are updated: if the new wtc of agent i overcomes a threshold ($wtc^i \geq 1$), then it will change opinion; otherwise, it will maintain the same opinion of the previous step (Figure 26).

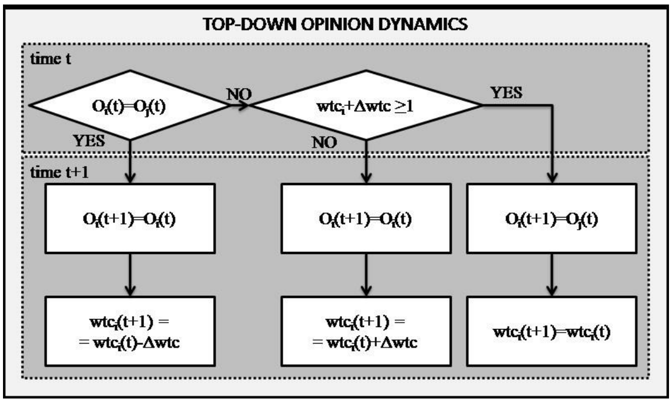


Figure 26 – Algorithm of the opinion dynamics model between any two agents *i* and *j* ($O_i(t)$ = opinion of agent *i* at time *t*).

This "pressure" mechanism acts in each one of the three layers, while the information goes from the top to the bottom:

1. at the top layer the spokespeople interact with each other by exerting a pressure that is related to the influence of the category they represent; for this reason, in the top layer, we multiply the pressure Δwtc ($\approx 10^{-1}$) by I_c. Based on the received pressures, the spokespeople will maintain or change their opinions;

2. at the middle layer all the agents receive a pressure from the spokespeople and, according to it, they update their opinions;

3. at the bottom layer the agents of each category interact with their neighbours (i.e. the directly linked nodes) and, eventually, update their opinions; in both the middle and the bottom layer we consider

a smaller value for the pressure, i.e. $\Delta wtc \approx 10^{-2}$, reflecting the difference in the type of interaction with respect to the top layer.

After the top-down process, the agents communicate the updated majority preference established at the bottom layer to the spokespeople, so that the bottom-up dynamics can be repeated again. This bottom-up/top-down process goes on until a stationary state is reached, i.e. when no one is no longer willing to change opinion to any further extent: this can either mean that a total consensus is reached or that two categories (out of three) are polarized towards the same policy. The cyclic mechanism implemented in the agent-based model reproduces quite well a participatory policy-making approach where consensus building is the result not only of the negotiation among spokespeople, but also of subsequent interactions with the groups they represent and opinion exchange flows inside the same groups. Figure 27 summarizes the main routines of the agent-based model with the detail of the top-down/bottom-up mechanisms based on the opinion dynamics (OD) mechanisms above described:

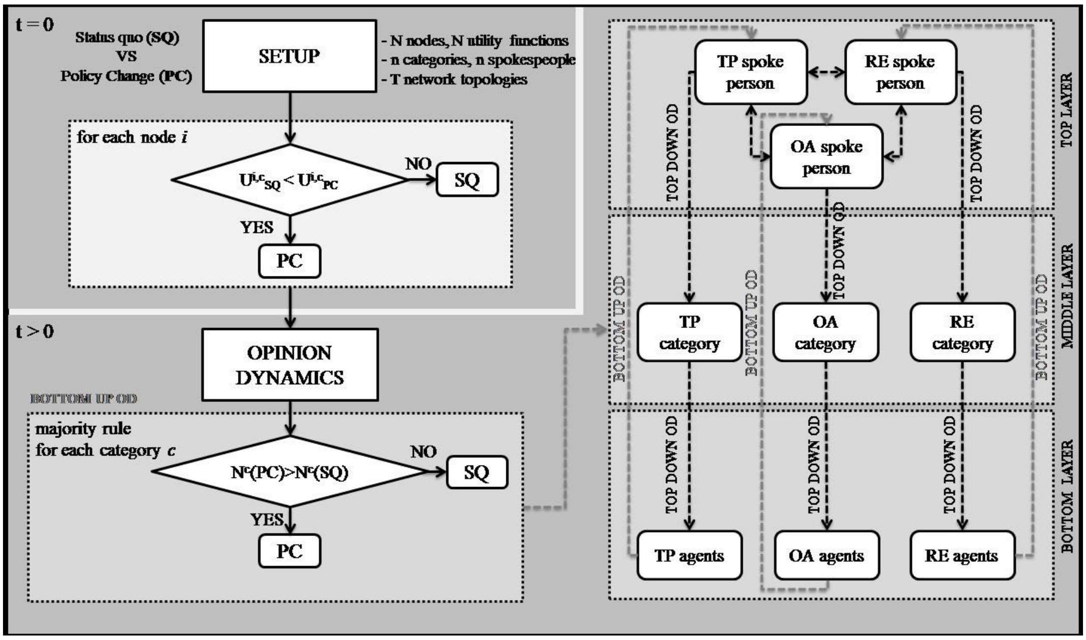


Figure 27 – Description of the main routines of the III agent-based model. (TP, RE, OA refer to the case study of section 6.5 where there are three stakeholder categories: transport providers (TP), retailers (RE), own-account providers (OA)).

This model was used to reproduce a cyclical inclusive participation process with reference to a specific case study: the policy-making process about urban freight transport. The model was fed with empirical data from an econometric model, thus the number of stakeholders and their utility functions were known, while the networks used and the opinion dynamics were idealized (see case study 5, section 6.5).

5.5. Towards models' validation: building participation experiments with the help of group decision-support methods (GDSMs)

In general, a model requires real-world data to be accurate and empirically sound. As an example, a typical transport demand model requires specification, calibration and validation to be effective (Cascetta, 1998), i.e.:

- the specification of a demand model can be defined as the complete identification of its mathematical structure, i.e. the definition of its functional form and of the explanatory variables (attributes) used.
- Calibrating the model requires the estimation of the vectors of attributes from the choices made by a sample of users.
- In the validation phase the reasonableness and the significance of estimated coefficients are verified, as well as the model's capability to reproduce the choices made by a sample of users. In addition, the assumptions underlying the functional form assumed by the model are tested. All of these activities can be completed with appropriate tests of hypotheses for a sample of users.

While these procedures are well coded for traditional mathematical models, such as transport demand models, this is not true for ABM, where the whole process in general is referred to as validation, or "empirical validation" (Fagiolo et al., 2007):

"The expression empirical validation (of an ABM) typically means the procedure through which the modeller assesses the extent to which the model's outputs approximate reality, typically described by one or more 'stylized facts' drawn from empirical research. More generally, however, to 'empirically validate' a given ABM can involve the appraisal of how 'realistic' the set of model assumptions are (e.g. the behavioural rules employed by the agents in the model), or the evaluation of the impact of alternative market designs and/or policy measures."

Based on this premise, the problem of how to validate an ABM is still controversial and a challenging task that needs appropriate validation techniques (Windrum et al., 2007; Moss, 2008; Darvishi and Ahmadi, 2014). Validation is required at multiple levels, starting from the static architecture of the model to the dynamic behaviour of the agents that can lead to unexpected and unpredictable results. Three factors are crucial in determining the performance of an empirical ABM: agent heterogeneity, model structure and the input data (Buchmann et al., 2016). Given the different approaches in developing ABMs, there are fundamental differences in the way empirical validation is conducted, also related to the questions that one wants to answer with the model. A useful way to know how to tackle model validation is to understand the intrinsic features of the model (Windrum et al., 2007): (i) the nature of object under study (e.g., quantitative or qualitative analysis, single or multiple variables), (ii) the goal of analysis (e.g., descriptive or predictive), (iii) the modelling assumptions (e.g., size of the space of parameters, treatment of time, types and dynamics of decision rules and of interaction structures), and (iv) the method of sensitivity analysis (e.g., sensitivity to micro/macro parameters, to initial conditions). In general, model validation aims at reducing the number of variables of the system via empirical evidence. Klügl (2008) defines a validation process combining specific "face validation techniques" (i.e. with experts' involvement) with statistical methods (sensitivity analysis, calibration of parameters and statistical validation) and states that the main problem is the missing availability of empirical data. Following this approach, some authors argue that econometric validation techniques can be used in empirical social simulations (Windrum et al., 2007), while others claim the importance of engaging stakeholders in the modelling and validation process in the so called approach of "companion modelling" (Bousquet et al., 1999). An analysis of these two alternative approaches to empirical validation of ABM was done by Moss (2008), underlining the main differences between them: while the first approach (referred to as "the economist's view") aims at validating the model by comparing the results of simulations with empirical data, the second approach (i.e. that of companion modelling) considers the validation procedure starting from the building of the model, with the help of participating stakeholders. The companion modelling can be considered a combination of agent-based models and role-playing games, aimed at raising the "*awareness of the stakeholders (including scientists) of the variety of* *points of view and their consequences in terms of actions*" (Voinov and Bousquet, 2010).

In this respect, an interesting approach for validation was done by Anand (2015). He used a participatory simulation gaming framework to validate his ABM of city logistics, by involving students in role game where they played the role of shopkeepers. The method was meant to collect information about their underlying beliefs and the actions taken in specific situations using a "Belief-Desire-Intention" architecture (Rao and Georgeff, 1995). Another approach is followed by Henesey (2006) in the validation of his ABM of port container terminal management (SimPort). This approach is considered a "verification" process, i.e. a method for ensuring that the data of the real system has been transferred to a computer model with sufficient accuracy and it consists of "discussion with domain experts" (Henesey, 2006) via qualitative interviews and quantitative questionnaires. The experts argued that the model was accurate to describe what they would expect for a real container terminal.

Given the complexity of the task, some authors substitute the word "validation" with "authentication", because *"the term validation is no longer adequate, as many interactions are beyond such an experimental approach. Authentication seems a better approach, as it requires forensic abilities and witnessing".* (Becu et al., 2003).

Besides, an additional challenge derives from opinion dynamics model validation:

"*Whilst evidence-based models are naturally validated, I am not aware of any attempts at specific validations of opinion dynamics models. If we take seriously the issues raised by Windrum et al. and explored here, then an appropriate step for opinion dynamics modellers and others far from the evidence-driven end of the evidence-theory spectrum would be to identify appropriate principles for the validation of their models. As far as I am aware, this has not yet happened.*" (Moss, 2008).

Castellano et al. (2009) in their review on opinion dynamics models confirm that "*the contribution of physicists in establishing social dynamics as a sound discipline grounded on empirical evidence has been so far insufficient"* and they pose the attention on empirical analysis via now available large datasets:

"*One of the main contributions of the physical approach to opinion dynamics should be to focus on the quantitative aspects of the phenomenon of consensus formation, besides addressing the mere qualitative question of when and how people agree/disagree. What is needed is then a quantitative phenomenology of opinion dynamics, to define the phenomenon in a more objective way, posing severe constraints on models. Sociological investigations have been so far strongly limited by the impossibility of studying processes involving large groups of individuals. However, the current availability of large datasets and of computers able to handle them makes for the first time such empirical analysis possible.*"

The empirical data suggested by the authors refer to elections, such as the Brazilian elections whose results were compared with those obtained by the model of Sznajd (2000).

In our case, where ABMs of opinion dynamics on stakeholder networks are implemented to reproduce participatory decision-making processes in transport planning, model validation is even more difficult. This is because of the complexity of decisions that need to be analysed by considering multiple criteria and multiple points of view, and where a collective decision has to be made, with all the problems connected with it (see social choice theory, chapter 3).

A comprehensive validation process should be aimed at understanding if the models:

i. properly consider the role each agent plays in the decision-making process and its characteristics (e.g., belief and goals, influence and influenceability);
ii. truthfully represent the relationships among stakeholders;
iii. realistically reproduce the interaction process that can occur in real participation experiences;
iv. give results of collective emergent phenomena that are in agreement with reality.

Further complexity is added by the absence of a predetermined procedure to conduct participatory decision-making processes given the heterogeneity of techniques that can be used and the specificity of each situation. The three models have been tested with reference to different participatory decision-making contexts that will be described in the next chapter. Two participation experiments were conducted with the help of

Group Decision-Support Methods (GDSMs). They were carried out both to validate the ABM and to test the efficacy of GDSMs in guiding a participatory decision-making process towards a shared and consistent decision (Case study 3 and case study 4). In both the experiments the method chosen to elicit stakeholder preferences was the Multi-Actor Analytic Hierarchy Process (MA-AHP) described in subsection 2.2.1. It is clear that this choice is subjective and that other MCDM/A methods could be suitable to this purpose. Nevertheless, there are several reasons for this choice, e.g.:

- AHP is a consolidated technique to elicit stakeholder preferences and it has been widely used to study transport problems (see subsection 2.2.1 for some examples);
- the structuring of the problem in a hierarchy allows an easy understanding of the problem by stakeholders;
- the pairwise comparisons between couple of alternatives are more accurate in eliciting stakeholder preferences (rather than directly comparing all the alternatives together);
- AHP can be easily extended to group decision-making processes (MA-AHP).

The two experiments were designed to (i) elicit stakeholder preferences and (ii) see how the interaction among them could change their initial opinions.

AHP was used to elicit preferences from the pairwise comparisons. Interaction was carried out in two different ways: in the first experiment it was a one-step of direct interaction all-with-all; in the second experiment a Delphi procedure was followed, with one step of anonymous interaction among the actors that were linked with the facilitator. In both cases it was possible to reproduce the network of communication in the ABM.

Next chapter will enter into the details of the applications of the ABMs, referred to as "case studies".

6. CASE STUDIES

"All models are wrong, but some are useful"

Box and Draper, 1987

The three models have been tested with reference to different participatory decision-making contexts. Some of the applications are purely theoretical, other are grounded on empirical data and/or experiences from real participation processes. For the sake of simplicity, all these applications will be referred to as "case studies", even if they have more or less a theoretical component and an empirical one, with reference to data acquisitions and model applications. In particular:

- The first model was used to investigate the stakeholder consultation process with reference to a specific case study: the decision-making process about parking pricing policies inside a University campus, where the number of stakeholders was known (all the professors divided into academic categories and departments), while the networks and the opinions were idealized. In this sense, the application of the model can be considered a <u>theoretical case study</u>;
- the second model was used for different purposes: from one side, ideal complex networks, that showed similarities with typical stakeholder networks, were considered to test the model; from the other side, two case studies were used to make an effort of validation of the model:
  - the first case study was a participation experiment with University students where a two-round interactive AHP was used to elicit their preferences about mobility management strategies to be adopted in their University and to see how interaction among them could change their opinions. The results of the experiment were compared with the result of an agent-based simulation where a network with exactly the same number of nodes and the same topology was considered;
  - the second case study was a combined Delphi-AHP experiment with experts and stakeholders that analysed and expressed their opinions about cycling mobility strategies in an urban context. The Delphi structure allowed an anonymous interaction among the actors that

led to a convergence of opinions. The data from the experiment fed the model, that was conveniently modified to reproduce the same experiment, with a similar opinion dynamics mechanism, representing a step towards model's validation.

In this sense, the applications of the model are of three levels: purely theoretical or ideal case study, theoretical case study compared to empirical data from a real case study, theoretical case study built with empirical data from a real case study;

- the third model was used to reproduce a cyclical inclusive participation process with reference to a specific case study: the policy-making process about urban freight transport. The model was fed with empirical data from an econometric model, thus the number of stakeholders and their utility functions were known, while the networks used and the opinion dynamics were idealized. In this sense, the application of the model can be considered a theoretical case study built with sophisticated data.

The methodology has been applied in five case studies, which characteristics are summarized in Table 17 and Table 18.

Table 17. Case studies description.

Case study	Model	Type of application	Data	Model assumptions
1	I	theoretical case study	number and type of stakeholders	topology, opinions, opinion dynamics
2	II	ideal case study	no empirical data	number and type of stakeholders, topology, opinions, opinion dynamics
3	II	theoretical case study compared to empirical data from a real case study	number and type of stakeholders, topology	opinions, opinion dynamics
4	II	theoretical case study built with empirical data from a real case study	number and type of stakeholders, topology, opinions (individual preference rankings), opinion dynamics	No strong model assumption: simplified opinion dynamics with respect to reality
5	III	theoretical case study built with sophisticated data	number and type of stakeholders, opinions (individual utility functions)	topologies, opinion dynamics

Table 18. Empirical data used to feed the models in the different case studies (sh= stakeholders).

Case study	Number of sh	Type of sh	Topology of the network	Opinions of sh	Opinion dynamics
1	✓	✓	-	-	-
2	-	-	-	-	-
3	✓	✓	✓	-	-
4	✓	✓	✓	✓	✓
5	✓	✓	-	✓	-

6.1. Case study 1. Stakeholder participation in policy-making about parking pricing[28]

The I ABM described in section 5.2 was tested representing a simple, real situation of a decision-making process regarding transport issues, i.e. the decision-making process about parking pricing that involved a well-known situation of a restricted homogeneous community of people with the same interest, i.e. easy access to the workplace.

This study was conducted at University of Catania, one of the oldest (1434) and largest in Italy with approximately 53,000 students and 2,500 staff. It is located in the city of Catania with 300,000 residents, in the southeast of Italy. About a quarter of students and personnel commute every day in the main campus, located up on a green hill in the north of the city. It is one of the biggest open spaces in Catania, a 70 ha area experienced by students, teaching staff and employees. It contains a number of sites spread over the area, including lecture rooms, offices, student residences, parking lots and few utilities. Though it was designed as pedestrian campus, its location far away from the city centre and the lack of transit accessibility have encouraged a high rate of car travels and a consequent high pressure on campus governance to build parking lots in the last decades (Figure 28). Nevertheless, parking spaces are overcrowded during peak hours and the continuous search for available spaces degrades both the accessibility and the liveability of the campus. Indeed, campuses must balance competing needs for parking supply, sustainability goals and budget constraints (Riggs, 2014). Nowadays more attention is paid by the University to sustainability; a

[28] This section is based on paper III: “Modelling stakeholder participation in transport planning” and paper IV: “Agent-based modelling of Stakeholder Interaction in Transport Decisions”.

Mobility Management Office (MOMACT) was established and a University Travel Plan was issued in 2009 (MOMACT, 2009) to promote sustainable mobility of the university community, mainly through awareness campaigns and transport demand management measures. The campus, likened to a small town, was thought as an ideal place to experiment actions for influencing travel behaviour. A critical challenge for transport decision-makers is to identify effective strategies for rebalancing the modal split between private car and public transport. Adopting economic measures, such as imposing fares to access parking spaces (Inturri and Ignaccolo, 2011), establishes the right distinction between those road users with the greatest need of access and parking in more attractive urban areas and those who have less (Hensher and King, 2001). Danaf et al. (2014) found that increasing parking fees and decreasing bus travel time through the provision of shuttle services or taxi sharing could be promising strategies for mode switching from car to public transport for campus students of the American University of Beirut.

Based on these premises, MOMACT proposed a parking pricing scheme of the campus according with the following actions (Figure 29):

- Building a Park-and-Ride facility at a distance of 1.5 km from the campus
- Linking the P&R to the campus by a free shuttle bus line
- Adopting a parking pricing scheme:
    - free parking and transit ride from P&R facility to the campus;
    - parking pricing inside the campus.

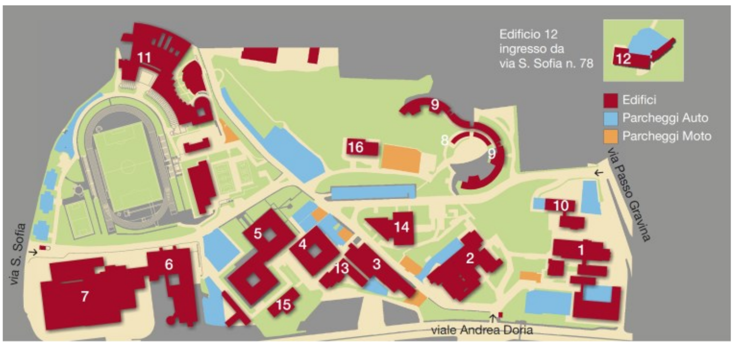


Figure 28 – Campus: Building (red) and parking (blue and orange).

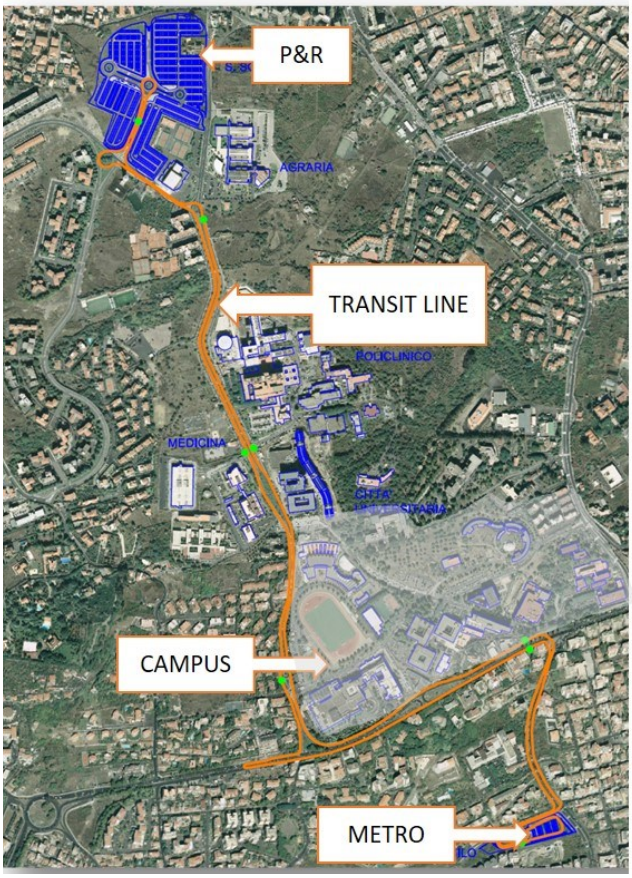


Figure 29 – Case study area: campus, P&R and transit line.

One important precondition for the successful implementation of transport pricing strategies is public acceptability, which is generally low (Schade and Schlag, 2003). May (2015) argues that involving stakeholders in Sustainable Urban Mobility Planning from the initial stages of determining objectives to the final process of implementation and evaluation will enhance the acceptability of final decisions. Attard and Ison (2015) illustrate the effects of stakeholder constraints on the effectiveness of parking policy. Reis and Macario outline an approach in which public transport stakeholders' business models are integrated to enhance public policy benefits (Reis and Macario, 2015).

The decision-making process regarding transport planning is characterized by a high level of complexity and it is not simple to be described with a model. In particular, the case study is about the idea of adopting parking pricing inside the University Campus. The topic involves all the University staff, including full professors, associate professors and assistant professors, while students are excluded because they cannot access those parking spaces. In this respect, student consultation showed that a better management of the parking spaces (where they can access) is one of main priorities for them (Le Pira et al., 2015a).

Some observations carried out during several meetings on these issues, though not systematic and statistically significant, were useful for the construction of the model. The network was created according to relationships derived by roles and by department organization (institutional relationships). Thanks to the knowledge of all the elements it was possible to build the network and simulate the opinion dynamics which should lead to a consensus/dissent (see Table 19). The "institutional" stakeholder network was reproduced by dividing all the departments' members into the three academic categories (assigning the role of head of department to one of the full professors), and then creating the links among them; in particular, heads of department are linked with all the members of their departments (Figure 30).

Table 19. Details of departments' structure.

DEPARTMENTS	FULL PROFESSORS	ASSOCIATE PROFESSORS	ASSISTANT PROFESSORS	TOT
Architecture	10	22	15	47
Physics and Astronomy	27	27	24	78
Civil and Environmental Engineering	14	17	10	41
Electric, Electronic and Informatics Engineering	21	20	13	54
Industrial Engineering	16	9	17	42
Maths and Informatics	23	27	30	80
Chemical Sciences	28	14	18	60
Pharmacy	14	20	22	56
TOT	153	156	149	458

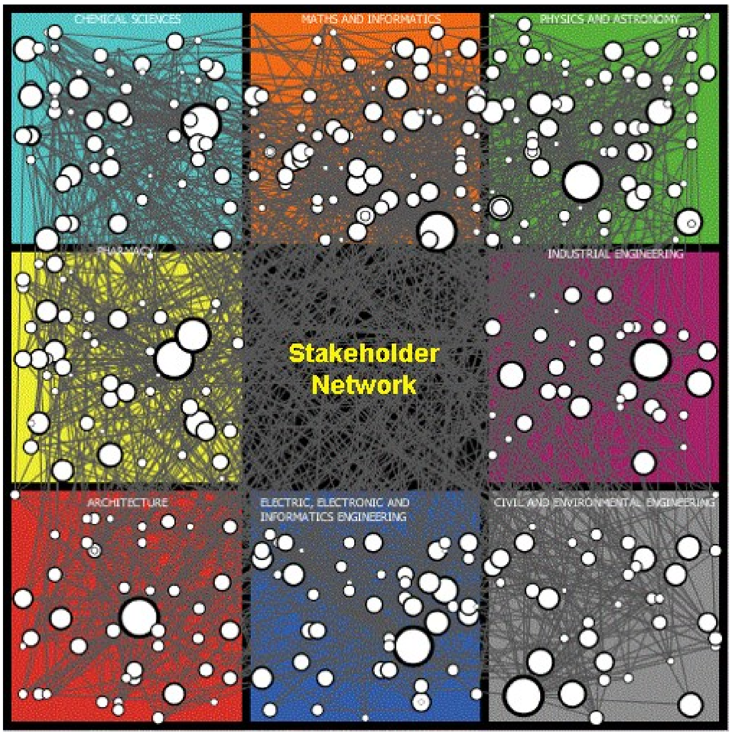


Figure 30 – Representation of the stakeholder network in NetLogo.

6.1.1. Simulations performed

Simulations were performed by exploring the parameter space with different setting choices in order to have a records of multiple interaction processes among stakeholders and derive some general considerations from them.

Three main elements can be modified in the model: (1) the topology (i.e. the average degree, average z-out), (2) the initial conditions (i.e. the positive initial group) and (3) the opinion dynamics (i.e. the Changing-Mind-Rate CMR) (Table 20).

Two different topologies were considered to simulate stakeholder interaction on low-connected networks, with average degree 10 (i.e. on average each node is connected with other 10 nodes) and high-connected networks, with average degree 20 (i.e. on average each node is connected with other 20 nodes). These assumptions seem quite realistic considering that on average departments are composed of about 57 people, and each of them could likely communicate with 10-20 colleagues of the same department. The simulations were performed by varying the number of weak ties to reproduce communication with members of other departments, i.e. with a parameter z-out ranging, on average, from 1 to

5 for degree 10 and from 5 to 10 for degree 20 (both degree and z-out are extracted from normal distributions). The higher connectivity inside the same department reflects the higher frequency of occasional discussion, i.e. official department meetings, sharing of the same working spaces.

The rationale behind the choices made is to see how the level and the type of connections among stakeholders can affect the convergence of opinions. Different initial positive groups, i.e. nodes in favour of the given proposal, were considered to understand the impact on the final result of the interaction process, i.e.: nodes with the same role (heads of departments, full professors, associate professors, assistant professors), nodes belonging to the same department and number of departments (1 department, 2, 3 or 4 departments), number of random positive nodes (from 0 to 400), random +1, 0, -1 nodes. In this respect, the influence of each node is chosen at random following a normal distribution with standard deviation equal to 2 and an average decreasing with the role (i.e. 10 for heads of department, 8 for full professors, 6 for associate professors and 4 for assistant professors).

A series of simulations was made by assuming a certain probability of random changes of opinion (CMR = 0.5%) in order to understand the impact of external influences. Several runs have been performed, since the outcomes of different simulations with the same initial conditions (i.e. multiple events) can be different.

Table 20. Parameter values used for the simulations.

Model setup	Parameter	Low-connected networks	High-connected networks
Topology	av. degree (normal distribution)	10	20
	z-out (normal distribution)	1, 2, 3, 4, 5	5, 6, 7, 8, 9, 10
Initial positive group	Nodes with the same role	heads of departments, full professors, associate professors, assistant professors	heads of departments, full professors, associate professors, assistant professors
	Number of +1 departments	1, 2, 3, 4	1, 2, 3, 4
	Number of random positive nodes	0, 50, 100, 150, 200, 250, 300, 350, 400	0, 50, 100, 150, 200, 250, 300, 350, 400
	+1,0,-1 nodes	Random assignment	Random assignment
Opinion dynamics	CMR (probability)	0	0.5%

6.1.2. Simulation results

Considering E events for each simulation, we are interested into the following results: the number of events ended with a complete consensus (all the opinions equal to +1) or complete dissent (all the opinions equal to -1) and the average time for reaching consensus or dissent. In order to convert the final outcome of the events into a unique parameter we calculated an acceptance rate W, as the weighted average of the final network state, i.e. the net frequency of the events which end with +1:

$$W = \frac{E_{+1} - E_{-1}}{E}$$

where E_{+1} is the number of events ended with consensus (k = +1), E_{-1} with dissent (k = -1) and E is the total number of events. W is included in the interval [-1, +1], where the extreme values -1 and +1 represent, respectively, 100% of events ended with dissent or consensus. Notice that this parameter does not indicate the rate of agents which have the opinion +1 at a certain step of the simulation, but it only measures the average tendency of the final state of the system towards the full consensus or the full dissent.

A time threshold was defined in order to exclude the cases in which the process took too long time ($t > 500$) before reaching consensus (or dissent). Therefore, when time exceeds the threshold without reaching any convergence of opinions, we say that the simulation ended with “no convergence” (“nc”). Figure 31 shows some simulation results in terms of the parameter W above defined.

Acceptance rate W (av. degree = 10, CMR =0%)	low-connected networks					high-connected networks					
	z-out					z-out					
Positive initial group	1	2	3	4	5	5	6	7	8	9	10
heads of department (8 nodes)	**nc**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**
full professors (149 nodes)	**nc**	**nc**	**0.2**	**1**	**0.4**	**0.4**	**0.6**	**1**	**0.8**	**0.2**	**0.8**
associate professors (156 nodes)	**nc**	**nc**	**-0.6**	**0**	**-0.8**	**0.2**	**0.2**	**0.2**	**-0.4**	**-0.8**	**0**
assistant professors (149 nodes)	**nc**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**	**-1**
random nodes	**nc**	**nc**	**0.4**	**-0.2**	**0.4**	**-0.2**	**0.2**	**0.2**	**0**	**0**	**0**
1 department	**nc**	**nc**	**0.2**	**0.4**	**0.6**	**0.6**	**0.8**	**0.6**	**0.2**	**1**	**0.6**
2 departments	**nc**	**nc**	**0.4**	**0.2**	**0.6**	**1**	**1**	**1**	**1**	**1**	**0.8**
3 departments	**nc**	**nc**	**1**	**1**	**1**	**1**	**1**	**1**	**0.8**	**1**	**1**
4 departments	**nc**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Figure 31 – Acceptance rate (W) with initially positive groups (av. degree = 10, CMR = 0.0%).

By considering different initial groups, it is clear that a too small number of weak ties critically slows down the information exchange; actually, when a node has on average 10 links, it is evident that we need more than 2 weak ties in order to reach convergence of opinions. Furthermore, the parameter W is minimum when the positive initial nodes are heads of departments (a minority, but very much influent) or assistant professors (more numerous, but less influent), that is to say that it is very difficult to reach consensus when only one of these groups is originally positive about the given topic (in our case the parking pricing). On the other hand, higher W values are achieved with entire positive departments.

If we study the behaviour of the parameter $\boldsymbol{W}$ versus an increasing number of randomly chosen initially positive nodes (ranging from 0 to 400), there is a transition from dissent ($\boldsymbol{W = -1}$) to consensus ($\boldsymbol{W = +1}$) in correspondence of around 150 positive nodes (Figure 32a). Indeed, all the events end with dissent up to 50, then there is a transition phase with some events ended with dissent and some others with consensus (from 50 to 250 nodes) and where the lines for different z-out can intersect, whilst all the events end with consensus when there are more than 250 (randomly chosen) initially positive nodes.

For what concerns the average time to reach the final decision, it is possible to plot it as a function of the number of random positive nodes and for several values of z-out (Figure 32b). It results that the convergence time presents a peak exactly in correspondence of the transition from total dissent to total consensus. Such a peak is much more pronounced for smaller values of the average z-out, i.e. when the small number of weak ties does not allow the positive opinions to spread over the entire network.

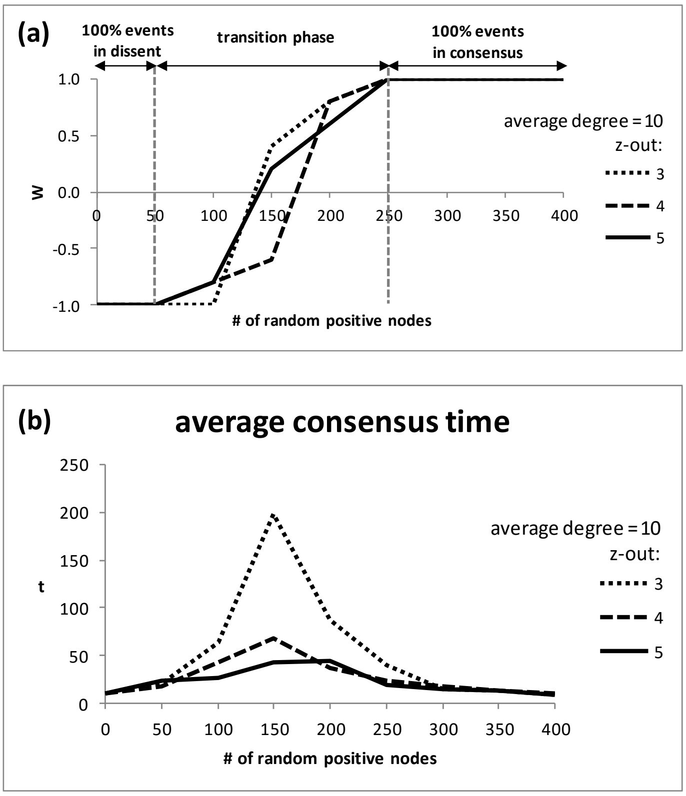


Figure 32 – (a) Acceptance rate *W* and (b) average convergence time as a function of the number of random positive nodes on varying z-out (av. degree = 10, CMR = 0.0%).

It is interesting to make a comparison between and an analogous result found in the context of the OCR model (Pluchino et al., 2004). In the latter, authors found a second-order phase transitions from an incoherent phase to a synchronized one, separated by a region of partial synchronization (Figure 33), which looks very similar to the transition found in our simulations (as can be appreciated by comparing Figure 32a with Figure 33). It is important to notice that in the presented model there are not states of "partial synchronization" as in the OCR model. The analogy with it is only in the transition phase, because the passage from total dissent to total consensus, where not all the events end with the same result, reminds the "partially synchronized phase" of the OCR model.

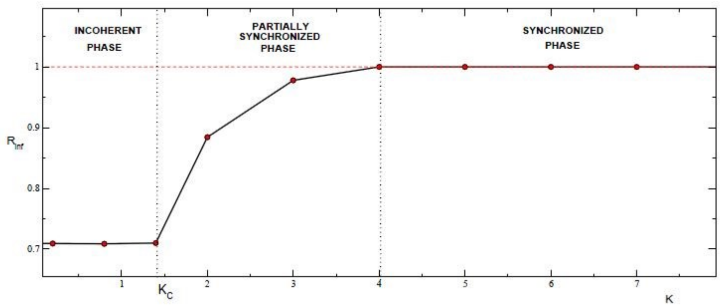


Figure 33 – Asymptotic order parameter as a function of the coupling K in the OCR model (Pluchino et al., 2004).

It is also interesting to notice another similarity with the continuum opinion dynamics of HK compromise model (Fortunato et al., 2005). The authors discovered that the convergence time to reach consensus, as a function of the confidence bound, follows the same trend represented in Figure 32b. Actually, the convergence time shows a divergence in correspondence of the consensus transition and, more in general, whenever the opinion clusters of a given configuration merge into a smaller number of clusters (Figure 34). In our case, the peak occurs when the number of random positive nodes is between 150 and 200 nodes (out of 458): this means that there is more struggle for reaching a compromise when almost half of all the nodes are initially positive, while consensus/dissent is achieved in a smaller time when the initial number of positive nodes is small (dissent) or big (consensus).

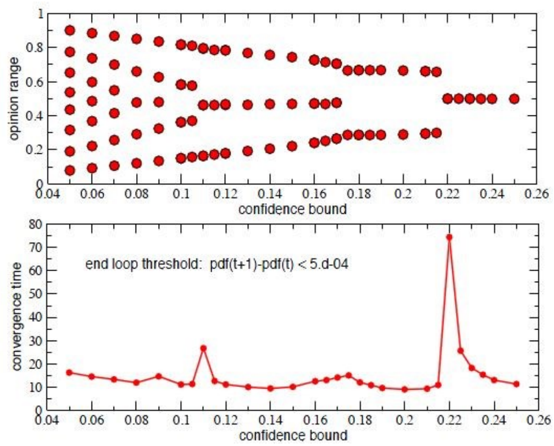


Figure 34 – (Top) Final configuration of the system as a function of the confidence bound ε. The circles indicate the positions of the surviving clusters in opinion space. (Bottom) Variation of the convergence times with ε. (Fortunato et al., 2005).

If we consider high connected networks (average degree = 20) the results are similar. The greater number of links improves the communication among nodes, so a convergence of opinions is always reached, even when the number of weak ties is small. If we consider the presence of external influences, represented by non-zero values of the CMR indicator (CMR = 0.5%) in general it produces an increase in convergence time, but does not significantly affect the transition from dissent to consensus, which occurs between 150 and 200 initially positive (randomly chosen) nodes (Figure 35). The external influences represent "rumours" which modify the dynamics and slow down the process. Indeed, people will be changing their mind at some steps (related to the CMR) at random, without following the original opinion dynamics rules. This is the reason why the convergence process slows down.

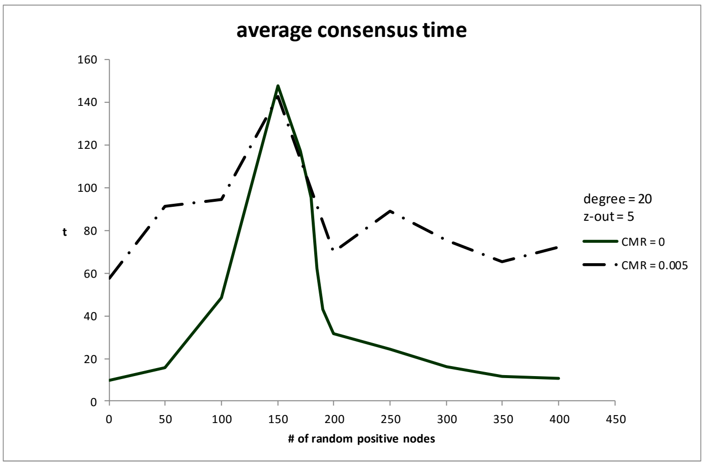


Figure 35 – Average convergence time on varying CMR (average degree = 20, z-out = 5).

6.1.3. Policy implications

Some policy implications can be derived from simulation results. It is evident that parking management strategies involving an increase in the parking fee are difficult to be accepted. Nevertheless, knowing in advance what could be the possible outcome of an interaction process can be helpful to plan an effective participation process. It is worthy of notice that the interest is not in the final result derived from interaction (i.e. approval or disapproval of the parking management strategy); on the contrary, it is useful to see how the process of convergence of opinions can change according to different setting and how it can be favoured. In this respect, many links help the communication exchange and speed up the process of taking a shared decision. This suggests the importance of planning a series of meetings that sees the participation of members of the same department (i.e. departmental meetings) and especially of members belonging to different departments (i.e. interdepartmental meetings), since a short number of "weak ties" critically slows down the opinion convergence process. Besides, entire departments in favour of the proposal can influence the final outcome of the interaction process; this can give some suggestions on how to program the participation process, e.g. by making at the beginning departmental meetings in order to favour the convergence of opinions inside the same group and eventually making interdepartmental meetings to foster further opinion exchange.

Given the hierarchical structure of departments, with different roles associated to the academic position, one would think that more "important" people could substantially affect the final result by influencing the others. Simulation results show that this is not obvious, e.g. it is not sufficient to speak with heads of department to reach the overall consensus even if they are all in favour of the proposal and they can easily influence all the members of the same departments; on the contrary, a large number of in-favour influential nodes is necessary (e.g., full professors). This confirms that a participation process should involve all the interested parties to be successful and not only the spokespeople or the most influential people.

Independently on the influence of stakeholders, it is demonstrated that a good majority in favour of the proposal would likely leads to a total consensus in a short time, while unpredictable results can occur when there are more divergent opinions and it usually takes more time. This suggests that a good knowledge of the initial opinions of stakeholders can be helpful to have an idea on how much time a participation process would take to reach a shared decision.

Based on these quite general considerations, some specific suggestions can be formulated in the context of a University campus where a decision has to be made about optimizing the parking supply through pricing measures. Actually, interaction among professors can be favoured, not only by increasing the number of interdepartmental or departmental official meetings, but also through targeted outreach on sustainability issues, or encouraging the use of alternative modes of commuting to University. The attitude to change opinion, included in the model, becomes realistic if all possible information gaps of professors are filled with: (i) the general objectives of the decision, (ii) the impact of alternative measures on the environment and (iii) the knowledge of alternative transport options available to them (discounted public transport, carpooling, bicycle facilities, etc.). Both information and interaction are therefore critical to carry out an effective decision-making process and increase the probability that a decision will be implemented and accepted.

Finally, some key points emerge:

- stakeholder analysis is fundamental to reproduce the existing network of relationships among the multiple actors that, to different extents, can influence and are influenced the final decision;
- having a preliminary knowledge of the distribution of opinions among stakeholders can be helpful to arrange the participation process;
- diffuse and repeated interaction (and information) opportunities contribute in smoothing strongly diverging opinions and achieving a shared decision in a short time.

6.1.4. Discussions and conclusions

The I ABM was applied in a very simple case study, both to test the model and to capture the intrinsic essence of the complex phenomena of social interaction. The decision-making process regarding the introduction of a parking charge inside a University Campus, where a restricted and homogeneous community of people (professors) with the same interest, made quite reasonable the simple opinion dynamics model implemented.

The model can be used for an *ex-ante* analysis aimed at understanding the conditions that would likely lead to consensus building, suggesting some policy implications and recommendations on how to design stakeholder involvement. It can be placed in the framework of transport planning for a preventive analysis of stakeholder involvement in the decision-making process prior to the phases of consultation and participation in the final decision. It allows to set up the priority for information and it helps to understand how to improve the linkages among stakeholders in order to facilitate the involvement process.

6.2. Case study 2. Ideal stakeholder networks to reproduce the preference ranking process avoiding the "Condorcet paradox"[29]

The II ABM described in section 5.3 was set up to reproduce interaction in stakeholder 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 has to be found. The aim of this model is twofold:

- to avoid decision deadlock due to the "Condorcet paradox";
- to find a collective transitive list that satisfies stakeholders to a high degree.

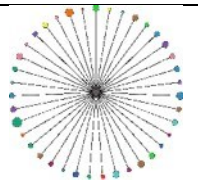
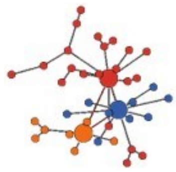
The ABM was first tested with reference to stylized stakeholder networks. Simulations aimed at investigating how the collective decision-making process could be affected by the features of the participation process. In this respect, several simulations were performed by comparing the different strategies discussed in section 5.3 in order to select a transitive and shared collective decision, in particular when different numbers of stakeholders and different topologies are considered.

6.2.1. Stakeholder networks description

Table 21 gives a short description of the different undirected networks used for the simulations (for a review see Estrada, 2011). Node colours are different opinions at $t = 0$, size is proportional to the node influence. The number of neighbours of a given node, i.e. the so-called "degree" of the node, is indicated with k.

[29] This section is based on paper II: "Modelling multi-stakeholder preference ranking for sustainable policies" and paper VII: "Simulating opinion dynamics on stakeholders' networks through agent-based modeling for collective transport decisions"

Table 21. Networks used for the simulations.

Network	Description	NetLogo interface
Star	One central node (hub) is directly linked with all the other N-1 nodes. Every node has degree 1, except the hub that has N-1.	
Fully connected	It is a totally connected network where each node is connected with all the others. The degree is N-1 for all nodes.	
Scale free Barabasi-Albert (BA) (Barabasi and Albert, 1999)	The network is built sequentially following the preferential attachment criterion: at each step a new node is added to an existing node with a probability proportional to its degree k. This process generates a network with a power law degree distribution, i.e. $P(k) \sim k^{-\gamma}$ with $\gamma = 3$.	
Scale Free Tree with fully connected hubs	The network is built sequentially following a modified preferential attachment criterion where one path only exists for each pair of nodes, i.e. there are not "triangles of nodes" in the network. It can be therefore classified as a tree with some hubs, i.e. a few nodes with a very high degree. We further link all the hubs in a fully connected subgraph. This process generates a network with a power law degree distribution, i.e. $P(k) \sim k^{-\gamma}$ with $\gamma = 2 \div 3$.	
Small world network (Watts and Strogatz, 1998)	Small world networks are "highly clustered, like regular lattices, yet they have short characteristic path lengths, like random graphs". Nodes are linked with their first 4 neighbours in a circle, with a certain probability p 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%). The average degree is 4.	

These prototypical networks are chosen to represent different stakeholder groups and the related interaction processes. The rationale behind the choices made is that all these topologies can likely be found in real participation processes:

(i) the star network is a typical structure of the Delphi practices, where a facilitator is linked with all the actors involved, but they are not linked to each other to avoid the risk of "leadership" (Dalkey and Helmer, 1963);

(ii) the fully connected network can represent quite well the focus group meetings, aimed at analysing a specific topic with the interested stakeholders affected by the decision;

(iii) the scale free BA shows a power law degree distribution with few high-connected nodes and many low-connected nodes and it is a typical structure found in many social networks (Barabasi and Albert 1999);

(iv) the scale free tree with fully connected hubs also shows a power law degree distribution, but the high-connected nodes (i.e. the hubs) are all connected with each other and the subgroups form trees, representing typical hierarchical structures where the information from the nodes converges to the hubs, e.g. those that can be found in citizen councils at different levels (neighbourhood, municipal or regional);

(v) the small-world network is a structure that has been found in real social networks, with high levels of communication efficiency thanks to the structure of regular network "rewired" with some long-range links (Watts and Strogatz. 1998).

Besides, Bakht and El-Diraby (2014) demonstrate, by tracking the discussions in infrastructure discussion networks (IDN) such as Twitter, that the structures of the interacting communities show characteristics of complex networks, in particular small-world behaviour, scale-free degree distribution, and high clustering. This type of engagement with social media methods is also known as "Microparticipation" (Evans-Cowley and Griffin, 2003) and can be very interesting for the study and interpretation of the complex phenomenon of social interaction.

In all the networks considered for simulations, the influence $I(i)$ of node i-th is an integer random variable distributed with a Poisson law with mean 8. A multi-event version of the model was implemented in order to consider several simulation runs with the same structure but different initial conditions. The simulations performed consider $n = 6$ alternatives for each preference list, while various sets of simulations run in correspondence of different number of nodes ranges (ranging from 20 to 120) and of different network topologies. The results of each simulation will be averaged over 100 events, each of them running over 500 time steps, that have been verified to be enough for reaching the overlap stationary state (i.e. no more opinion change).

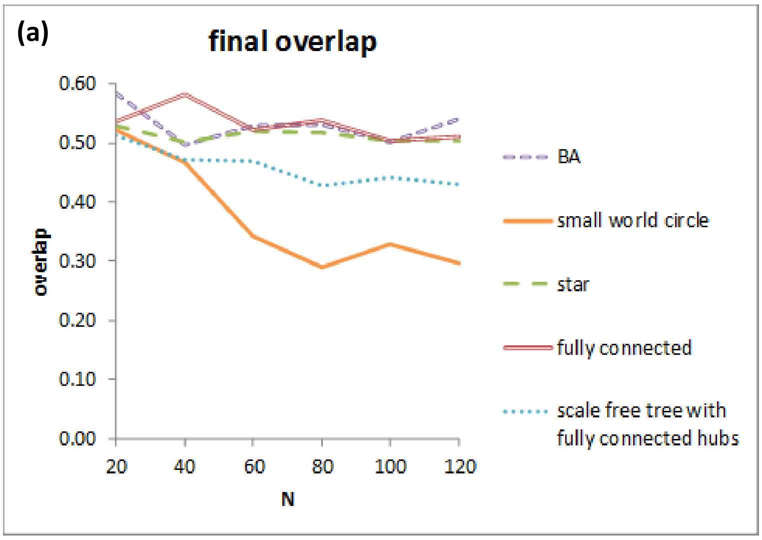
6.2.2. Simulation results

Results are expressed in terms of average final overlap $\bar{O}^t(i, c_{tr})$ after interaction, i.e. a measure of the similarity among the individual lists and the final collective one (see section 5.3), and of a parameter representing the "interaction efficiency" (IE). The latter is calculated dividing the overlap by the number of links n_l in order to include the "communication costs" to be sustained in highly connected networks:

$$IE = \frac{\bar{O}^t(i, c_{tr})}{n_l}$$

In Figure 36a, the final average overlap is plotted as function of the network size N and for all the previously introduced network topologies. As visible, all the scores range from about 0.3 to 0.6, that is a very good result. In particular, they stay quite high (> 0.5) when the size of the networks is small ($N = 20$), regardless of the topology. When the number of stakeholders increases some differences among the different networks do emerge. As expected, the fully connected network performs very well, because each stakeholder influences, and it is influenced, by all the others in the network. The same holds for the star topology, probably because there are, on average, only two degrees of separation between any couple of nodes. On the other hand, the small-world network results to be the topology with the lowest values of final overlap for $N > 50$, and – in the same range – also the performance on the scale free tree with fully connected hubs is not excellent, likely due to the absence of interaction triangles among stakeholders; vice versa the overlap outcome for the scale free BA network remains quite constant at high levels. These results confirm the robustness of the interaction strategy in finding the more shared transitivity solutions in the collective preference space.

In Figure 36b, the final overlap is divided by the number of links for each topology, in order to obtain the interaction efficiency. It clearly appears that, if one includes the "communication costs" in the balance, for small groups of stakeholders ($N = 20$) the fully connected network becomes the less efficient if compared with the other topologies, while the star and the scale free tree network show the highest values of overlap per link. In any case, increasing the number of nodes, differences among the topologies are less and less evident.



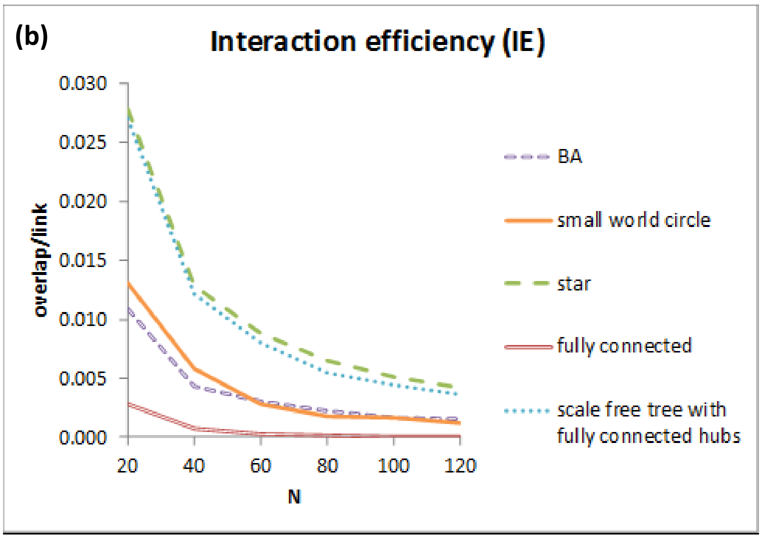


Figure 36 – Plots of the final overlap (a) and of the normalized final overlap, called "interaction efficiency" (b), resulting from the interaction dynamics performed for different topologies and for an increasing number of stakeholders.

In order to better appreciate the results obtained with the interaction strategy, they are compared with the analogous ones obtained considering the other two test strategies (see section 5.3). In Figure 37 and Figure 38 the results of the "random" test (a) and the "max overlap" test (b) are plotted, again as function of the number of stakeholders and for the various topologies. In both cases the final overlap is independent on the topology (since both the tests do not involve any communication among the agents) and, more importantly, it is always quite lower than the one resulting from the interaction process. In particular, with the first test the average overlap ranges from 0.08 to 0.20 while, with the second test, it goes from 0.06 to 0.15.

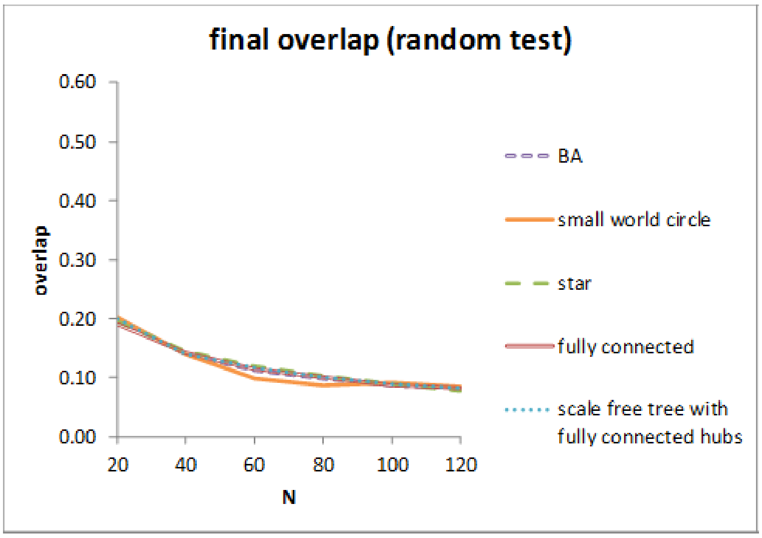


Figure 37 – Plots of the final overlap resulting from the "random test" for different topologies and an increasing number of stakeholders.

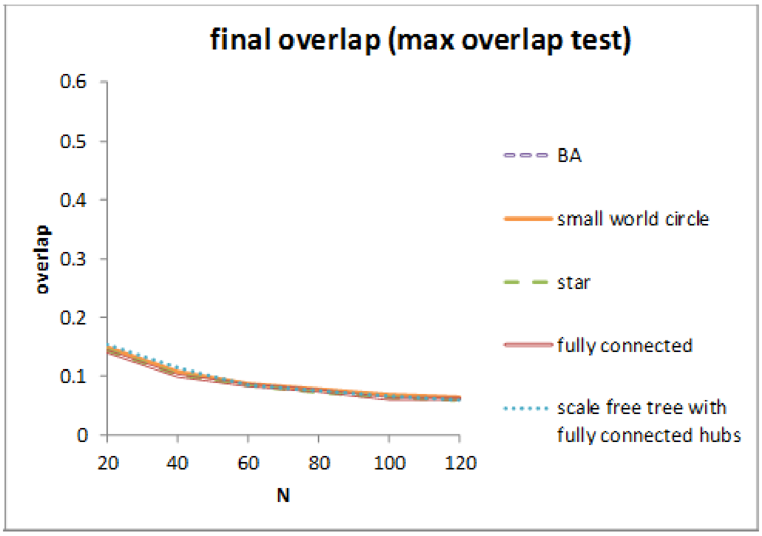


Figure 38 – Plots of the final overlap resulting from the "max overlap test" for different topologies and an increasing number of stakeholders.

6.2.3. Discussion and conclusions

These results confirm that, even if it is possible to imagine other strategies that allow to circumvent the "Condorcet paradox" faster and easier than the interaction one, only the collective solutions that come out from repeated discussions and opinions' exchanges among the stakeholders are able to actually reflect enough the individual preferences, ensuring the "most shared" transitive decision, whatever the topology one decides to adopt for the interaction network. On the other hand, taking into account the topology of interactions, the previous results could also give some insights or suggestions in order to build an efficient participation process. Actually, they can be useful from a practical point of view because the real structures of many participation processes share strong similarities with the analysed interaction networks.

It is evident that a real participation interaction is not easy to control and sometimes it is quite difficult to draw out constructive conclusions from it. Nevertheless, the results of the simulations are not intended as a tool to build real networks or to "guide" the individual opinions, but they demonstrate to what extent the degree of interaction and the type of communication have an influence on the final collective decision. In the author opinion, the optimum for a participatory planning approach can be reached neither with dictatorial single-judge processes, nor with diffuse participatory democracy, but with a halfway interactive process where the topological structure of the interacting stakeholder network can be guided by the simulation results.

For a first step towards validation, the results of conveniently conducted participation experiences (see section 6.3 and section 6.4) are used to test the suitability of the model.

6.3. Case study 3. Stakeholder participation in the ranking process of mobility management strategies[30]

This case study reproduces a participation process through an experiment in which university students acted 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.

According to the participatory planning framework (see Figure 3 at p 37), 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 MCDM/A methods is fundamental to elicit individual preferences that have to be aggregated into a collective decision. 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.

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 - nonrandom - judgments;

[30] This section is based on paper VI: “Analysis of AHP methods and the Pairwise Majority Rule (PMR) for collective preference rankings of sustainable mobility solutions”

- acceptability, i.e. it reflects the individual preferences at a reasonable level (or a good degree of consensus).

In this case study AHP was used to elicit stakeholder preferences and also to aggregate them (1), together with the Borda Rule and the PMR (2); the overlap was used to evaluate the degree of consensus of the collective ranking (3). The agent-based model described in section 5.3 was used to simulate the same participation process (4).

1. AHP to elicit and aggregate stakeholder preferences

AHP is generally used to elicit single decision-maker opinions, but it can be extended to group decision-making (see subsection 2.2.1). 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: 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. In this study, the row geometric mean method (RGMM) is used as prioritization procedure and both AIJ and AIP are used to aggregate the individual rankings.

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. These two 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.

3. Overlap to measure consensus

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 the concept of average overlap described in section 5.3 will be used as a simple indicator of consensus 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.

4. Agent-based model of stakeholder interaction

The II ABM was used to reproduce the participatory group decision-making process. 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.

In this study, the simulation results obtained through the above described model are compared with analogous results derived from the 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.

6.3.1. Case study

The study is based on a public participation experiment where a given number of University 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 above described. 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 2nd 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.

6.3.1.1. 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.

6.3.2. 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) carpooling 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 MCDM/A 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.

6.3.3. 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 22 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.

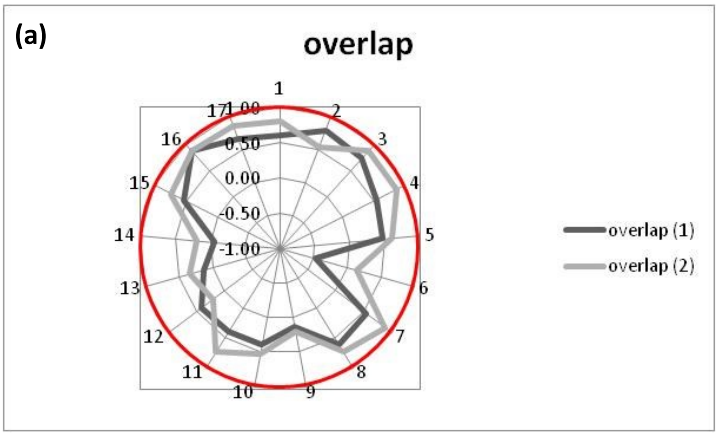
Table 22. Results of collective orders and average overlap before and after interaction using different aggregation methods.

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 Figure 39a, 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 Figure 39a 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 0.10, represented by the red circle in Figure 39b 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 (Figure 39b).



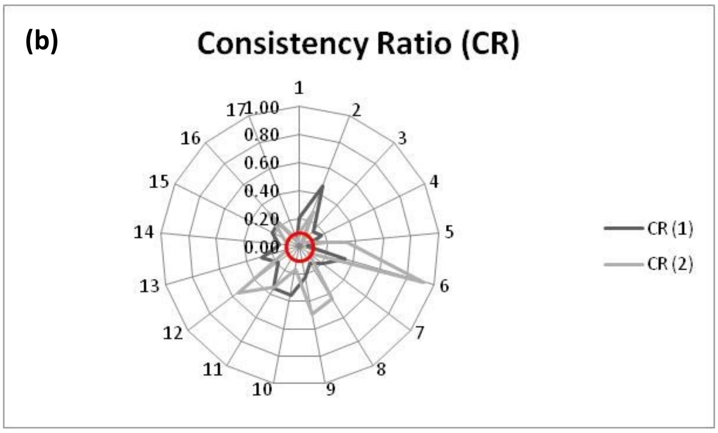


Figure 39 – (a) Overlap and (b) consistency ratio for the 17 students before (1) and after (2) interaction; the red circles represent (a) the maximum reachable overlap (O(i,c)=1) and (b) the limit of consistency (CR≤0.10).

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.

Figure 40 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.

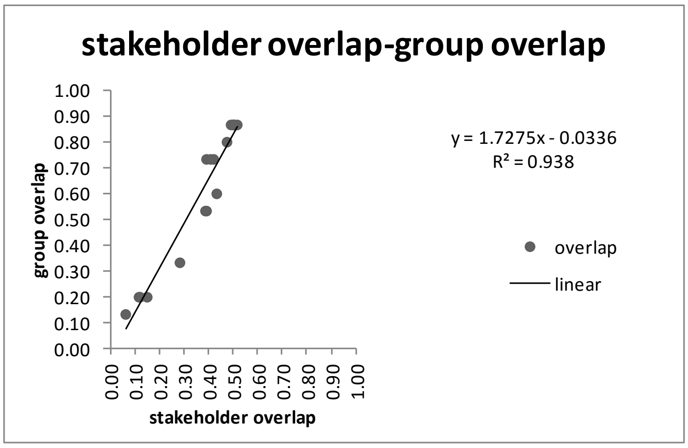


Figure 40 – Linear correlation between stakeholder overlap and group overlap considering resulting from PMR (after interaction).

6.3.4. Results of the agent-based simulations

In order to reproduce the same experiment with the II ABM, 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 Figure 41a: 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., 2015b). The same simulations are therefore repeated for this kind of network and, as shown in Figure 41b, while the average overlap remains the same, the average ratio overlap/links is sensitively higher than before.

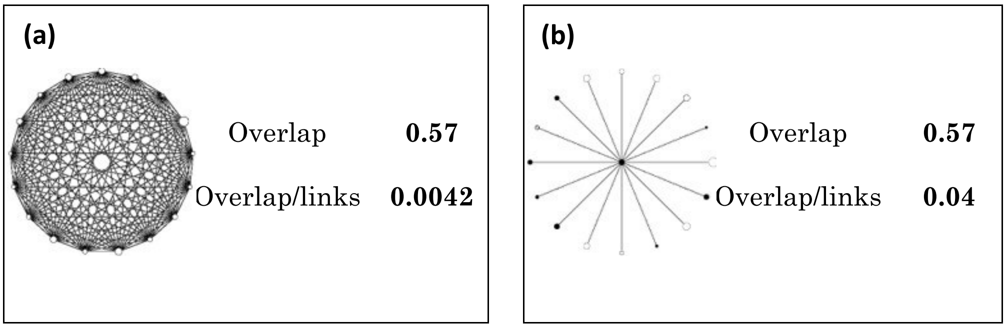


Figure 41 – Results of the simulations: (a) fully connected network; (b) star network.

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.

6.3.5. Discussion and conclusions

In this section we presented the results of a public participation experiment with students and of an agent-based simulation that reproduced it. The aim was to analyse different aggregation procedures starting from the elicitation of the individual preferences with the well-known MCDM/A 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 behaviour 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.

6.4. Case study 4. Combined experts and stakeholder involvement for priority setting of strategies to promote cycling mobility[31]

The study deals with a participation process that involved several phases, with different stakeholders involved and processes adopted. In particular, this case study focuses on the phase of involvement of experts and stakeholders in a combined AHP-Delphi procedure.

Data collected from this experiment are used to derive group preference rankings by different aggregation procedures and to evaluate to what extent interaction contributes to achieve a more shared decision.

AHP was used to to structure the problem, elicit stakeholder preferences and aggregate them (1), together with PMR (2); the Delphi method was used to build consensus (3) and the overlap was used to evaluate the degree of consensus of the collective ranking (4). The agent-based model described in section 5.3 was used to simulate the same participation process (5).

1. <u>AHP to elicit and aggregate stakeholder preferences</u>

AHP was here used to structure the problem in a hierarchy together with the experts and then to elicit their preferences in terms of pairwise comparisons. The row geometric mean method (RGMM) is used as prioritization procedure and both AIJ and AIP are used to aggregate the individual rankings.

2. <u>PMR to aggregate stakeholder preferences</u>

In this case the "Pairwise Majority Rule" (PMR) will be used to aggregate the individual rankings derived from AHP and the results will be compared with those derived from the traditional AHP techniques.

3. <u>Delphi method to build consensus</u>

The Delphi method (Dalkey and Helmer, 1963) is a procedure that is generally used to make experts' opinions converge on shared solutions (see section 1.4). It is addressed to a panel of experts and it is based on some solid assumptions (Pacinelli, 2008), i.e.:

[31] This section is based on paper VIII: "Modelling consensus building in Delphi practices for participated transport planning".

- iterative structure, meaning that participants are called to express their opinions in more rounds;
- anonymity, to avoid bias due to leadership and reciprocal influence of the participants;
- asynchronous communication, with the possibility for the members of the panel to interact remotely and in different times.

At each round of anonymous interaction the members of the panel are asked to align their opinions according to a range where the 50% of the opinions stands (between the first and the third quartiles). The iterations are aimed at mitigating strong positions and finding a collective decision which is shared from the panel. In principle, it has been used to elicit experts' opinions about the future, with the aim to find "real" values, but it can also be used to explore consensus building in a group.

Being a practice for the convergence of opinions, it can be combined with other methods aimed at eliciting individual preferences. An interesting approach is the one that combines Delphi practices with multi-criteria decision-making methods, such as AHP (Tavana et al., 1993; Vidal et al., 2011) or ANP (Analytic Network Process). García-Melón et al. (2012) combined the Delphi procedure with ANP to involve stakeholders in a participatory and consensus-building process about sustainable tourism strategies and conclude that, according to the stakeholders involved, this procedure enhanced participation and transparency.

In this study, a Delphi procedure is combined with the AHP method, to elicit preferences of experts and stakeholders about sustainable transport strategies and to see if the anonymous interaction could lead to a convergence of opinions. In this respect, there are multiple ways to measure consensus derived from Delphi, some based on qualitative analysis and others on descriptive statistics (von der Gracht, 2012). With AHP, from the judgments in terms of pairwise comparisons, vectors of preferences on multiple elements are derived. In this case, to measure consensus, we propose the overlap measure as a simple indicator of similarity between two vectors of preferences.

4. Overlap to measure consensus

The concept of average overlap described in section 5.3 will be used to measure to what extent stakeholder anonymous interaction due to

Delphi method may affect the degree of achieved consensus towards the final decision.

5. Agent-based modelling of Delphi anonymous interaction

The II ABM described is here used to reproduce the participatory group decision-making process based on Delphi anonymous interaction.

In this study, the model is adapted by changing the opinion dynamics in order to reproduce a participation process with the Delphi method. In particular, the network considered is a star, where each node is directly linked only with a "hub" that represents the facilitator of the process, in order to guarantee the condition of anonymity. At each step of the simulation, the facilitator proposes the collective list to the agents that can decide to change their list according to the similarity with it (i.e. the overlap). Simulation outcomes can give some suggestions about how to manage a Delphi-based participation process and to predict the possible results of interaction.

6.4.1. Case study

The study is based on a participation experiment where a given number of transport experts and stakeholders were involved to identify policy measures to promote cycling mobility in the city of Catania (Italy).

They were asked to: (i) structure the problem and build the AHP hierarchy, (ii) answer the pairwise comparisons of elements for each level of the hierarchy, (iii) reformulate their judgments after (anonymously) knowing the results of the others. The AHP method was applied - before and after interaction - to derive a priority ranking of alternatives for each actor. The aggregation of the priority vectors was done by using the methods derived from AHP and the Pairwise Majority Rule. The Delphi method was carried out in two steps of iteration. The panel was composed of seven participants in total: five experts from the University of Catania, with different background (experts on safety issues, land use planning, transport planning), one stakeholder belonging to an association of cyclists and one person that can be considered as a "sophisticated stakeholder" (Mau-Crimmins et al., 2005), being employed in the municipal transport company and being a transport expert.

After a short description of the state of art of cycling mobility in Catania with the structuring of the problem made by the panel, the experiment will be described and the results discussed.

6.4.1.1. Cycling mobility in Catania

In the last years cycling mobility has been receiving more attention from policy-makers as a sustainable and efficient mode of transport in urban areas. Many cities are adapting to welcome facilities and infrastructures for cyclists, but still lots have to be done, in particular in car-addicted cities.

Catania is a medium-sized city (300,000 inhabitants) located in the eastern part of Sicily, Italy. The city is part of a greater Metropolitan Area (750,000 inhabitants), which includes the main municipality and 26 surrounding urban centres, some of which constitute a whole urban fabric with Catania. The main city contains most of the working activities, mixed with residential areas. Even if several attraction polarities (hospitals, main schools, shopping centres) are spread over the whole territory, the transport demand pattern is mostly radial. Motorized modal split is about 85% private transport and 15% public transport, while the amount of travelled kilometres by bicycle is negligible (even if increasing). 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 for the transport system of Catania.

Based on these premises, the panel of experts and stakeholders met in a brainstorming session to analyse the problem of promoting cycling mobility in Catania, structuring it into a four-levels hierarchy (Figure 42). They agreed that four different criteria were necessary to evaluate the alternative measures, i.e. the criteria representing the three dimensions of sustainability (environmental, social and economic) and a transport criterion. The last one was chosen from the panel as an independent criterion even though in principle the transport dimension is encompassed in the other three sustainability criteria. The reason given from the panel is that, in the peculiar case of Catania, an improvement in the transport system contributes itself to a better quality of life.

Seven indicators were chosen to represent the four criteria and then the alternative measures to promote cycling mobility were identified from the panel:

- building a comprehensive cycling network;
- setting up extended 30 km/h zones;
- making information and education campaigns, to increase public awareness towards pros of cycling mobility;
- funding citizens to buy electric bicycles;
- establishing a city bike sharing service.

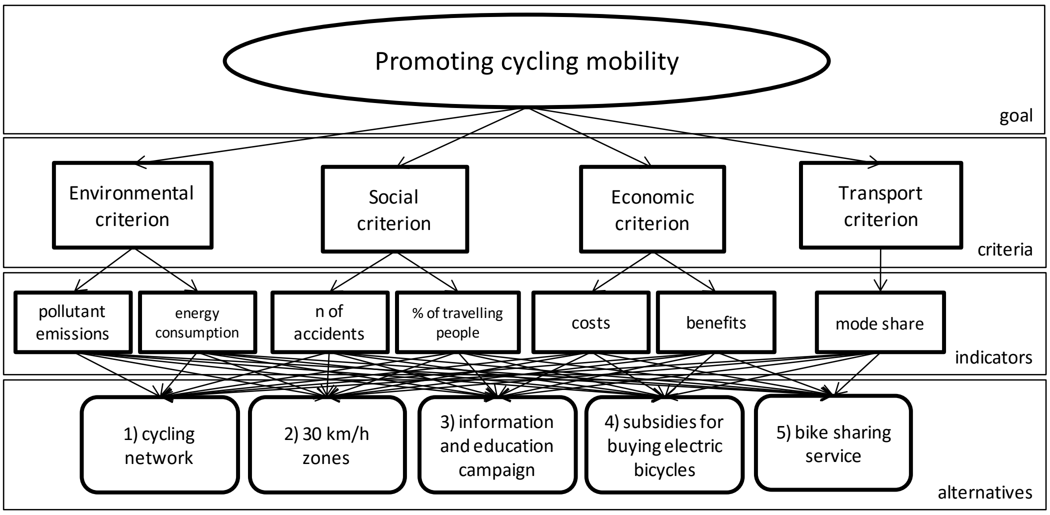


Figure 42 – Hierarchy of the problem "promoting cycling mobility".

6.4.2. The Delphi experiment

The Delphi experiment was conducted in two steps. First, each member of the panel was asked to make judgments in terms of pairwise comparisons between the elements of each level of the hierarchy. Due to the great number of answers they had to give (a total of 79 pairwise comparisons), the facilitator guided them into the whole process paying attention to the consistency of their judgments.

Once all the members filled in the questionnaire, the results derived from AHP were analysed in order to go on with the second step of the Delphi method. In particular, for each pairwise matrix, the local priority vectors were derived, the first quartile (corresponding to the 25% of judgments) and the third quartile (corresponding to the 75% of judgments) were chosen as reference numbers for the members of the panel to "align" their judgments in the second iteration (see example in Table 23).

By doing this, the results of the second round are in terms of priority vectors for each level of the hierarchy. By aggregating them, the new priority vector for the group is derived, representing the alternative ranking of the panel of experts and stakeholders involved.

Table 23. Example of part of the Delphi questionnaire.

DELPHI (II round)	**Criteria comparison**			
	previous judgment	***1st quartile***	***3rd quartile***	**new judgment**
environmental criterion	0.56	*0.14*	*0.54*	**0.50**
social criterion	0.26	*0.20*	*0.32*	**0.28**
economic criterion	0.12	*0.08*	*0.25*	**0.12**
transport criterion	0.06	*0.12*	*0.26*	**0.10**

6.4.3. Results of the experiment

The individual preferences were aggregated with the two methods derived from AHP. In particular, in the first round of judgments both the aggregation of individual judgments (AIJ) and the aggregation of individual priorities (AIP) methods were used, while in the second round only the AIP method was used, because the panel was asked to "align" the opinions starting from priority vectors (and not from pairwise comparisons). The individual rankings were also aggregated with the Pairwise Majority Rule (PMR) to see if it leads to the same results since it is the aggregation rule used in the agent-based model.

Table 24 summarizes the results of the average overlap in the first and second round of iteration with the different aggregation methods and sources of individual preferences to be aggregated (from PWC or from priority vectors).

Table 24. Results of collective rankings and average overlap before and after interaction using different aggregation methods.

Aggregation method	Source of individual preferences	Description	Collective Ranking		Average Overlap	
			I round	II round	I round	II round
AHP-AIJ-gm	PWC	PWC aggregated into a group matrix (AIJ) using the geometric mean (gm); AHP applied	2>1>3>5>4	-	0.74	-
AHP-AIP-gm	Priority vectors	Geometric mean (gm) of the priority vectors derived from AHP for each level (AIP)	2>1>3>5>4	2>1>3>5>4	0.74	0.80
PMR	PWC	PWC transformed in binary vectors (+1 and -1); PMR applied	2>1>3>5>4	2>1>3>5>4	0.74	0.80

The three methods led to the same results (before and after interaction) and the collective ranking resulting from them shows very high values of overlap (0.74 compared with the maximum reachable value of 1). This is due to the fact that the actors involved showed more or less the same level of competence and objectives, even if there are some differences in the individual rankings. After the second round of the Delphi method, there is an increase in the convergence of opinions and this confirms the effectiveness of interaction in the group decision-making process. The opinion changes are expressed in terms of adjustments of the priority vectors derived from AHP (Figure 43): even though there are not big changes in the weights assigned to the alternatives, in the second round the opinions are closer and less dispersed, with the softening of some initial strong positions.

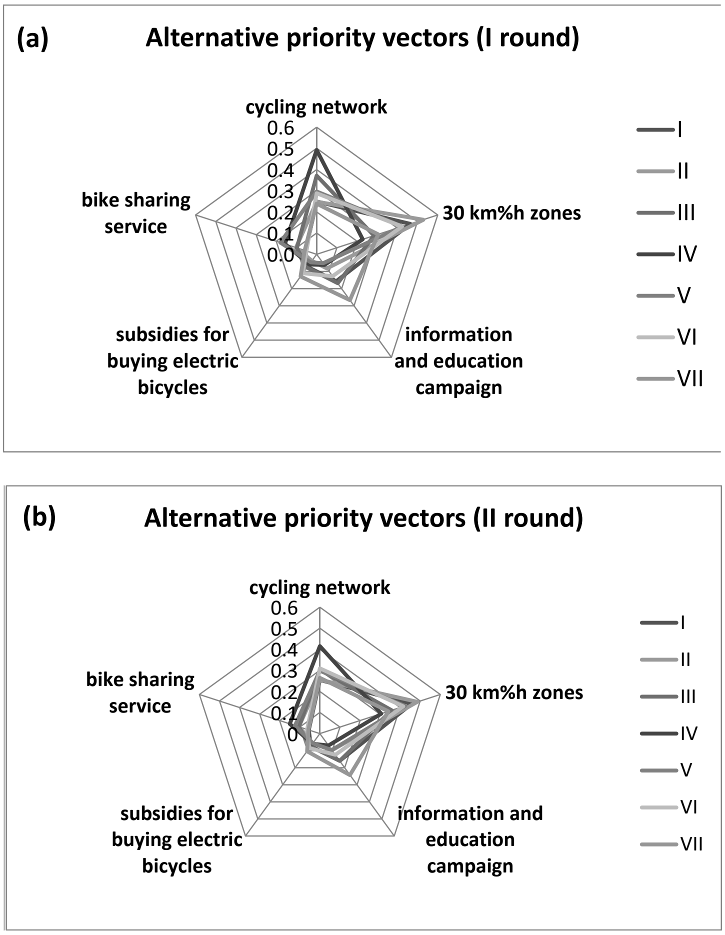


Figure 43 – Alternative priority vectors for the 7 members of the panel in the first round (a) and in the second round (b) of Delphi method.

6.4.4. Results of the agent-based simulations

The same experiment was reproduced with the II ABM. A network with exactly the same number of agents (7 members of the panel + 1 facilitator) is considered. The network is a "star network", where the hub (i.e. the facilitator) is directly linked with all the others. This can represent quite well the anonymous interaction process among the members of the panel, that could not communicate with each other but knew the other (averaged) answers. Actually, the model is simplified because it starts from their actual preference rankings, evaluates a collective preference ranking through PMR and then agents decide to align their ranking to the collective one according to the similarity with it (in terms of overlap). In other words, while in the real experiment the stakeholders were asked to modify their preferences in terms of weights assigned to the elements of the hierarchy of Figure 42, in the model they decide to directly change their preference order on alternatives (or maintain it) based on the similarity (i.e. the overlap) with the collective ranking.

Despite its simplicity, results show that the model is able to capture the essence of the phenomenon of consensus building and they are summarized in Table 25. Several simulations were performed by changing the agents' behaviour in terms of willingness to change their ranking with the collective one. We assume that for each agent the higher the similarity (i.e. the overlap) with the collective ranking the more probable his willingness to change opinion. Therefore, hereafter we will use overlap as a proxy of the willingness to change of the agents[32].

By modifying the willingness to change of the agents, we found some thresholds that made the outcome changes (see Table 25):

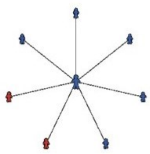
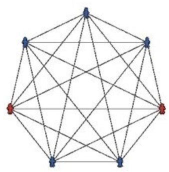
- when it is less than 0.6 a total consensus is reachable (i.e. average overlap = 1);
- when it ranges from 0.6 to 0.8 it is not possible to reach total consensus; in this case the final degree of consensus (i.e. average overlap) is similar to the one obtained with just one step of interaction in the Delphi experiment (0.8 with the Delphi experiment instead of 0.886 with the simulations);
- when it overcomes 0.8 the agents are not willing to change their opinions, therefore they maintain the initial one and the process of consensus building does not start.

The topology of the network was also changed to see how agents' influences can affect the final outcome. All the agents were linked in a fully connected network, the influence was randomly assigned with a Poisson law and the simulations were repeated 100 times to have a statistics of events. Results show (Table 25) that direct interaction of agents with different degrees of influence is not beneficial in terms of consensus buildings, with lower values of final overlap with respect to the star network, where the anonymous interaction is guaranteed, avoiding the risk of leadership. Other simulations were performed by assigning initial random preference rankings to the agents: in this case

[32] Notice that the "willingness to change" (wtc) here used is different from the one explained in section 5.4 (i.e. in the III model) and that will be used in the next section (case study 5), even if the rationale behind them is the same. They both represent an availability to change opinion, but while in this case wtc is approximated to overlap, the one used in the III model is related to the utility associated to the policies (and not the similarity with the others' opinion).

the final degree of consensus is much lower than the one obtained with the data from the experiment, meaning that a homogeneous community of people (in terms of interests and expertise) is much more efficient for the success of a Delphi experience rather than a heterogeneous one. This result suggests that the Delphi method could be more effective in eliciting opinions and finding consensus with an expert group rather than a group of stakeholders with diverging interests. The model also allows monitoring of possible decision deadlock due to "Condorcet paradox" with random initial conditions (i.e. Probability of Cycles "Pcycles" in Table 25): while the star network with few nodes (i.e. 7+1) makes quite improbable to fall into the paradox because the agents are only linked with the facilitator, an intransitive ranking is more likely to occur in a fully connected network where all the agents influence each other.

Table 25. Results of the agent-based simulations in terms of final average overlap (i.e. degree of consensus).

Network		**Initial conditions**			
		Delphi experiment		**Random**	
		wtc* <0.60	wtc= 0.60÷0.80	wtc < 0.60	wtc = 0.60 ÷ 0.80
Star		1	0.886	0.425 (Pcycles = 0%)	0.378 (Pcycles = 0%)
Fully connected		0.89	0.766	0.373 (Pcycles = 15 %)	0.329 (Pcycles = 7%)

*wtc = willingness to change

6.4.5. Discussion and conclusions

Results of the experiment show that the combination of AHP with Delphi method is suitable to support complex group decision-making processes. In this respect, the cooperation of the panel of experts in structuring the problem and sharing criteria, relevant indicators and alternative measures increased the probability to have a good convergence of opinions after only one step of anonymous interaction.

Results of the ABM allow to give some suggestions on how to build an effective participation process based on the Delphi method. In particular, it is proved that the outcomes are appreciably influenced by the willingness to change of the agents, resulting in total or partial consensus after interaction. Besides, the guarantee of anonymity avoids the possibility of leadership due to reciprocal influence that can likely reduce the convergence of opinions. Agent-based simulations also suggest that the Delphi method seems to be more effective in terms of consensus building when a quite homogeneous group of experts is involved.

6.5. Case study 5. Stakeholder involvement for urban freight transport (UFT) policy-making[33]

The III ABM described in section 5.4 was used to reproduce a particular case study, regarding stakeholder involvement in policy-making about urban freight transport (UFT), using the multilayer approach and agent-specific data from an econometric model.

UFT, also known as city logistics, has been defined in several ways. Basically, it is *"the movement of freight vehicles whose primary purpose is to carry goods into, out of and within urban areas."* (EC, 2012). In a larger domain, including the optimization of logistics activities of private companies and the social and economic issues related to it, city logistics has been defined as "*the process for totally optimising the logistics and transport activities by private companies with support of advanced information systems in urban areas considering the traffic environment, the traffic congestion, the traffic safety and the energy savings within the framework of a market economy."* (Taniguchi et al., 2001).

There is a wide literature concerning UFT and how to tackle the problems connected with it, even if there is still the need of a clear ontological demarcation of what UFT research is (Anand et al., 2012). For a first succinct, yet updated, literature review on the topic according to a thematic clustering of articles, the reader can refer to Marcucci and Gatta (2014).

Next subsection will introduce the case study of UFT by describing the peculiarities of policy-making about it.

6.5.1. UFT policy-making

Urban freight transport (UFT) policy-making is a complex task. This is due to heterogeneous, interacting, and often divergent, stakeholders' preferences. An *ex-ante* knowledge of stakeholders' objectives and ensuing behaviour can increase policy-makers' awareness and policy crafting capabilities, thus allowing for better decision-making (Taniguchi and Tamagawa, 2005). Public authorities are increasingly recognizing the importance of a direct involvement of all the interested private actors in the decision-making process, during the definition of

[33] This section is based on paper V: "Agent-based modelling of stakeholder involvement for urban freight transport policy-making".

policy measures (Eriksson et al., 2005; Stathopoulos et al., 2012; Quick, 2014; Quak et al., 2016). Not only it is important to get an active and direct involvement of all the interested parties in the decision-making process, but also one has to find the most shared, and thus supported, policy emerging from a transparent deliberative process.

Muñuzuri et al. (2005) classify measures (or solutions) into four groups: public infrastructure (e.g. transfer points and modal shift), land-use management (e.g. parking and building regulations), access conditions (e.g. spatial and time restrictions) and traffic management (e.g. scope of regulations and information), while Stathopoulos et al. (2012) identify six broad policy classes with the potential to mitigate freight problems: (a) market-based measures, (b) regulatory measures, (c) land use planning, (d) infrastructural measures, (e) new technologies, and (f) management measures.

Taylor (2005) identifies four fundamental stakeholders to be consulted when evaluating urban freight transport policies:

- shippers;
- freight carriers;
- residents;
- planners and regulators.

Shippers generate freight demand with the intent of either making final goods available to end consumers or alternatively to import/export semi-finished goods from/to other industrial partners. Planners/regulators define the overall framework under which transport providers perform the delivery tasks. A dilemma often arises between the conflicting objectives relating to urban freight operators and their customers, on one side, and the community, on the other (Browne and Allen, 1999).

Stakeholder response to policy change is a largely debated topic. Models are widely used to study the problem and evaluate stakeholders' behaviour in response to specific policies (Hensher and Puckett, 2005; Holguin-Veras, 2008; Stathopoulos et al, 2012; Bjerkan et al., 2014; Holguin-Veras et al., 2015; Marcucci et al., 2015; Gatta and Marcucci, 2015; Zhang et al., 2015). Nevertheless, some authors show that only few effective urban freight transport measures are successfully implemented (Quak, 2008; Jones et al., 2009; Wisetjindawat, 2011).

A significant heterogeneity in stakeholders' policy acceptability has been observed (Gatta and Marcucci, 2014). Stakeholders' response to public sector policies reveals the asymmetric power relations among suppliers, carriers and receivers (Holguín-Veras et al., 2015); it was found that receiver-cantered policies are more likely to produce successful behavioural changes with respect to carrier-cantered ones.

Public successfully implemented regulations are only possible if they are practically feasible for private stakeholders and help them pursuing their distinctive objectives. From a modelling standpoint, individual interests and the ensuing behavioural changes that a modification of the *status quo* would most likely induce, must be included in the framework used when dealing with policies influencing the overall city logistics framework. Modelling should allow the exploration of the various interconnected decision-making processes and patterns characterizing the different stakeholders in relation to regulations and policy measures tested. Gatta and Marcucci (2014) demonstrate how an agent-specific knowledge of the effects each policy component produces can increase the decision makers' awareness thus helping taking better decisions. In the last few years, researchers have started exploring city logistics problems using agent-based approaches exploiting their renowned capability of capturing both the individual stakeholders' dynamic behaviour as well as their interconnections (Anand et al., 2012). ABMs and discrete choice models (DCMs) seem a promising combination to model heterogeneous stakeholder dynamic involvement in UFT policy-making.

6.5.2. ABMs and DCMs for stakeholder involvement in UFT policy-making

ABMs can reproduce a distributed decision-making process as the outcome of a set of autonomous entities interacting in a common environment. They allow in the planning process to realistically address stakeholders' desires, beliefs and preferences (Anand, 2015).

ABMs have been used to simulate the effects of alternative city logistics measures considering the behaviour and the interactions among several stakeholders (Taniguchi and Tamagawa, 2005; Roorda et al., 2010; Van Duin et al., 2012) Davidsson et al. (2005) provide an extensive analysis of existing agent-based research approaches to transport logistics; they find ABM to be very suitable for this domain while acknowledging that their use at the strategic decision-making level seems under-researched.

Most of the literature examined so far focuses on evaluating policy measures' impacts assuming a decision unilaterally made by a public authority that impacts on stakeholders' behaviour and, subsequently, triggering their reactions (Traditional Planning). It is unknown to the author any ABM attempt to simulate stakeholders' interaction in a city logistics context with the intent of finding a shared decision with respect to alternative policy measures (Participatory Planning).

From a policy-maker perspective, considering inter-agent heterogeneity is fundamental to evaluate the impact of each policy component on specific agent behaviour, thus increasing their awareness and knowledge of the likely impact each policy component used might have and, thus, helping taking better decisions. Besides, a participatory approach in the decision-making process about policy change should consider the dynamic behaviour of interacting stakeholders aimed to stimulate an opinion change towards a shared decision. In this respect, a combination of agent-specific DCMs with ABMs seems promising because:

- DCMs are the typical instrument used to investigate stakeholders' preference heterogeneity in order to forecast their individual choice behaviour (see subsection 1.3.3);
- ABMs can be used to reproduce the opinion dynamics process where stakeholders interact and modify their choices to find a shared solution.

Based on these premises, an agent-specific and dynamic approach is here used, by combining an econometric and an agent-based model to explore stakeholder-based decision-making processes with respect to UFT policy changes.

The agent-based model described in 5.4 is fed with detailed agent-specific data accounting for personal heterogeneity in preferences on the base of sound micro-economic theory. According to the data used, the stakeholder categories considered in the multilayer network model are three: retailers, transport providers and own-account transport operators. They are linked with the members of the same category at the bottom layer ("interaction level"), while at the middle layer they communicate with their spokespeople ("negotiation level"). The top layer is the "decision level" where the three spokespeople interact with each other (see Figure 25 p 121).

Next subsection will present the data used.

6.5.3. Agent-specific data for policy change[34]

Data refers to a research study in the city of Rome aimed at improving the efficiency of the urban freight distribution system (Marcucci et al., 2013a). The area investigated refers to the freight limited traffic zone characterized by an access fee and time windows restrictions (Marcucci et al., 2011a).

Acknowledging that effective policy interventions are better promoted when local authorities are aware of stakeholders' preferences and their contrasting objectives, a behaviourally consistent UFT policy evaluation is fundamental (Marcucci et al., 2012). Separate and joint stakeholder meetings are the basis for understanding their concerns about the main problems with respect to urban freight (Stathopoulos et al., 2011). Moreover, they allow for the identification of the most appropriate attributes and levels to be used in the analysis. Relevance, credibility and high level of shared support are the main criteria for attribute selection. In particular, policy alternatives, included in the choice task, are defined on the basis of:

1) number of loading/unloading bays (LUB);
2) probability of finding a loading/unloading bay free (PLUBF);
3) time windows (TW);
4) entrance fee (EF).

The latter has 5 levels while the others 3. The minimum level for LUB and PLUBF coincides with the current situation while EF has a symmetric range of variation with respect to the *status quo*. TW levels are the same in terms of amount of access restriction while differ for their specific distribution over the day. Attributes and levels are specified as follows:

- LUB (400, 800, 1200);
- PLUBF (10%, 20%, 30%);

[34] The author is thankful to Edoardo Marcucci and Valerio Gatta for providing the data and for collaborating to our joint work.

- TW (open from 18:00 to 08:00 and from 14:00 to 16:00; open from 20:00 to 10:00 and from 14:00 to 16:00; open from 04:00 to 20:00);
- EF (200€, 400€, 600€, 800€, 1000€).

The agent-types considered are:

(1) transport providers, representing the supply for urban distribution services;
(2) own-account operators, who themselves organize the required transportation services;
(3) retailers, who hire third parties for this service.

Data acquisition is based on a stakeholder-specific multi-stage efficient experimental design (Marcucci et al., 2013b). This approach, incorporating stakeholder-specific priors guarantees a high quality data acquisition process and it produces benefits in terms of attribute significance and/or reduction in sample size needed (Marcucci et al., 2011b). A total of 229 interviews were gathered. An agent-specific approach is needed not only when acquiring data (Gatta and Marcucci, 2013) but also when estimating discrete choice models. Marcucci and Gatta (2013), focusing on own-account operators, find that TW have a significant impact on their preferences. Transport providers are more interested in LUB than PLUBF (Marcucci et al., 2015) while the opposite is true for retailers (Marcucci and Gatta, 2014). Preference heterogeneity is also relevant within a single agent category. Following Marcucci and Gatta (2012), a sophisticated approach for detecting heterogeneity is applied. Latent class models (Greene and Hensher, 2003) are estimated for each agent category and individual coefficients are obtained. This represents a valuable input for agent-based modelling which simulates interactions but often is not fed with sophisticated agent-specific data accounting for personal heterogeneity in preferences and based on sound micro-economic theory.

6.5.4. Simulations performed

Table 26 summarizes the policy changes to be compared with the *status quo* (SQ). The rationale behind the choices made is the following: different scenarios for improving LTZ accessibility and usability conditions were considered by varying the attributes' levels used in the experimental design, within the range defined by two extreme scenarios, i.e. "the worst case scenario" (WCS), where the entrance fee is maximized vis. a vis. the provision of no other improvements, and "the best case scenario" (BCS), with maximum attribute improvements for the three categories vis. a vis. no increase in the entrance fee.

Given the heterogeneity of the stakeholders involved, different scenarios more in line with one of the three categories are tested. The *a-priori* with respect to what each category likes best is derived from the extensive investigations performed by Marcucci and Gatta (2013; 2014) and Marcucci et al. (2015). In particular, transport providers are more interested in the number of loading/unloading bays (LUB), therefore the "transport-provider-oriented scenario" (TPS) considers the maximum increase in the LUB while keeping the other *status quo* conditions unchanged. Similarly, "retailer-oriented scenario" (RES) is the one where only the probability to find the bays free (PLUBF) is maximized, being the most important point for them. Own-account members are interested only in time windows (TW), therefore "own-account-oriented scenario" (OAS) considers only a change in the time window.

The increase in the entrance fee in these stakeholder-oriented scenarios is limited to 200 € (EF=800 €), since simulations with a higher entrance fee (1000€) end with a total consensus towards *status quo*, suggesting that stakeholders are not willing to pay this higher amount independently of what could be offered in compensation.

Three plausible scenarios are also considered: a "second-best case scenario" (2BCS), where the improvements of the BSC are counterbalanced by an increase in the entrance fee of 200 €; a "third-best case scenario" (3BCS) with an additional increase in the entrance fee with respect to the previous case (EF=1000 €); a "willingness-to-pay-oriented scenario" (WTPS) that derives from considerations about the heterogeneous willingness to pay of the agents is also considered. In a previous study, Marcucci and Gatta (2014) used an agent-specific approach and found that, under certain conditions, each stakeholder would have paid the same amount (166 €) to have an increase in the number of bays (+395), an increase in the probability to find them free (+9.5%) and a different time window (TW3). Starting from these considerations, WTPS is based on an entrance fee of 766 €, 795 LUB, 19.5 % PLUBF, TW3.

Table 26. Policy changes considered for simulations.

Attribute	***SQ***	*WCS*	*BCS*	*TPS*	*RES*	*OAS*	*2BCS*	*3BCS*	*WTPS*
LUB	**400**	400	1200	1200	400	400	1200	1200	795
PLUBF	**10**	10	30	10	30	10	30	30	19.5
TW	**(2)**	(1)	(3)	(2)	(2)	(3)	(3)	(3)	(3)
EF	**600**	1000	600	800	800	800	800	1000	766

6.5.5. Simulation results

Results are expressed in terms of policy ranking based on a dynamic parameter called "global satisfaction". At time t, the global satisfaction $S(t)$ is defined as the product between the degree of consensus $C(t)$ and a (normalized) overall utility $u(t)$, i.e.:

$$S(t) = C(t) * u(t) \quad \in [0,1]$$

where $C(t) = \frac{agents\ of\ majority\ (t)}{total\ number\ of\ agents} \in [0,1]$ is represented by the percentage of agents in favour of the majority policy and $u(t) = \frac{|U(t) - U_{min}|}{|U_{max} - U_{min}|} \in [0,1]$ is the normalized overall utility. $u(t)$ is equal to 1 if all the stakeholders can support their preferred policy and, therefore, their utility would be maximized ($U(t) = U_{max}$); on the other hand, it is equal to 0 if all the stakeholders are willing to accept the least preferred policy and, therefore, their utility would be at its minimum ($U(t) = U_{min}$).

Global satisfaction is an overall parameter that can be interpreted as an acceptability measure of the final result for the three categories.

Given the agent-specific approach adopted, certainly a relative satisfaction would be more appropriate to take into account the heterogeneity of the stakeholders involved. In fact, political acceptability is a big concern for policy-makers and the redistributive effects of policies among groups of citizens should be explicitly included, as citizen-candidate game approaches explicitly assume (see for an example Marcucci et al., 2005).

Nevertheless, at this stage of the research, a global satisfaction parameter alone is assumed sufficient to describe our interactive participatory decision-making process. As visible in Figure 44, due to the interaction and the opinion change, the degree of consensus usually shows an increasing trend, while the overall utility generally decreases. As a consequence, the global satisfaction $S(t)$, being the product of these two quantities, initially increases in time, rapidly reaching a maximum, then slowly decreases. It is therefore possible to monitor and record the maximum value reached, which expresses the optimal combination of consensus and utility during a single simulation run. Then, an average over 10 runs, with different initial conditions, can be performed in order to have more reliable results.

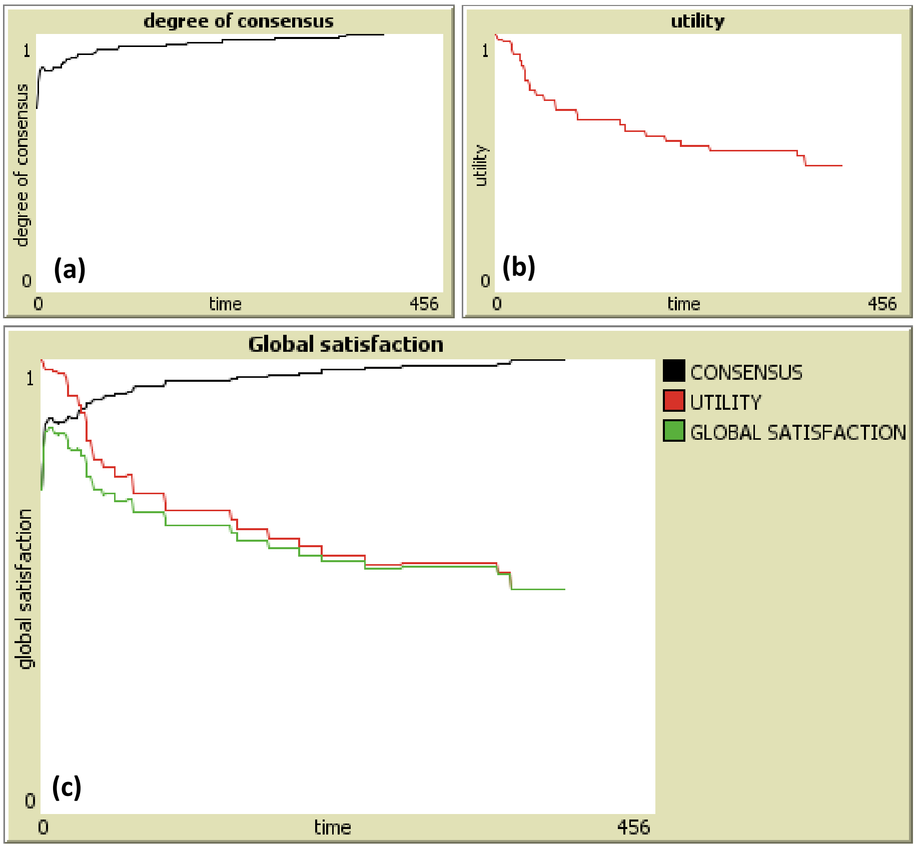


Figure 44 – Plots of degree of consensus (a), overall utility (b) and global satisfaction (c) for own-account-oriented scenario (OAS) (one simulation run).

Apart from the two baseline scenarios, i.e. BCS and WCS, whose results are trivial since they are, from the beginning, respectively totally supported and totally rejected by all the agents, the other policies tested show some interesting results. The interaction process related to stakeholder-oriented policies (TPS, RES, OAS) always ends with the majority in favour of policy change (with respect to the *status quo*) with a partial or total consensus.

It is quite surprising that the policy which favours only own-account agents reaches a higher level of global satisfaction if compared to the others; in fact, TPS and RES are good policies for both transport providers and retailers, while are negative only for own-account agents. This result can be explained by a general *a priori* tendency towards policy change and a lower elasticity of own-account agents to pay more with respect to the other two categories.

2BCS and WTPS perform very well in terms of global satisfaction, being the former a package of measures that globally improves LTZ accessibility with a slight increase in the entrance fee, the latter an optimal combination of measures that generates a balance in the WTP of the different categories.

Results are quite different from 2BCS to 3BCS where the only difference is an additional increase in the entrance fee: when the entrance fee is higher some simulations end with an opinion convergence towards the *status quo*, others towards policy change. In this case it is not possible to make any reliable prediction on the expected final outcome of the overall interaction process. By changing the relative influence of the three stakeholder categories, it is possible to test if and how this impacts on the end result of 3BCS. In particular, own-account agents are the most reluctant to pay an additional fee, therefore simulations end in favour of policy change only if retailers, transport providers or both of them are considered more influential than own-account. In any case, the final global satisfaction is very low (from 0.56 to 0.60).For the other cases, it is possible to provide a global satisfaction policy ranking (Table 27).

Table 27. Policy ranking based on global satisfaction (averaged over ten simulation runs).

Ranking	*PC vs SQ*	*global satisfaction [0,1]*	*time step*	*degree of consensus [0,1]*	*utility [0,1]*
1	2BCS	0.96	62	1	0.96
2	WTPS	0.95	28	1	0.95
3	OAS	0.85	6	0.87	0.98
4	RES	0.70	143	0.78	0.91
5	TPS	0.60	1	0.60	1

As already noticed, 2BCS and WTPS are the best performing in terms of global satisfaction while the stakeholder-oriented policies show lower values. However, it is also interesting to consider the simulation time steps needed to reach the maximum satisfaction values (Figure 45).

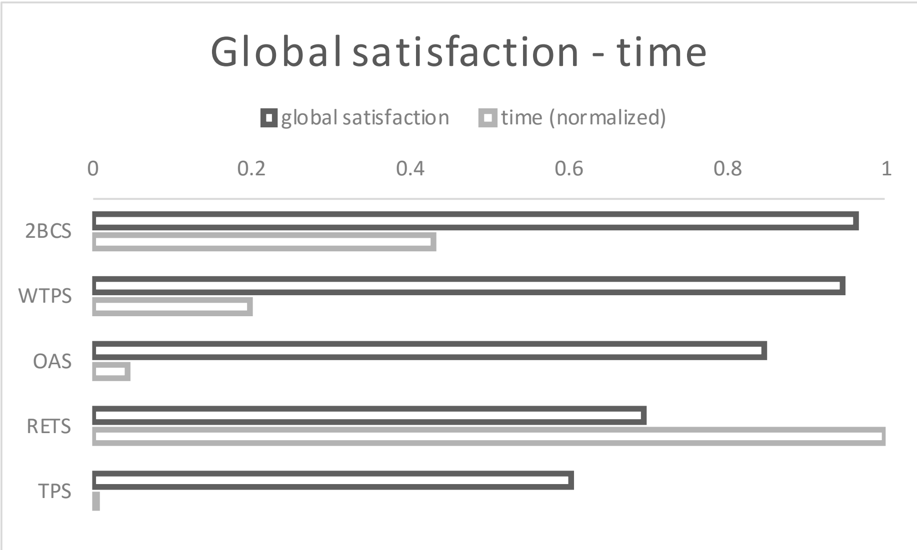
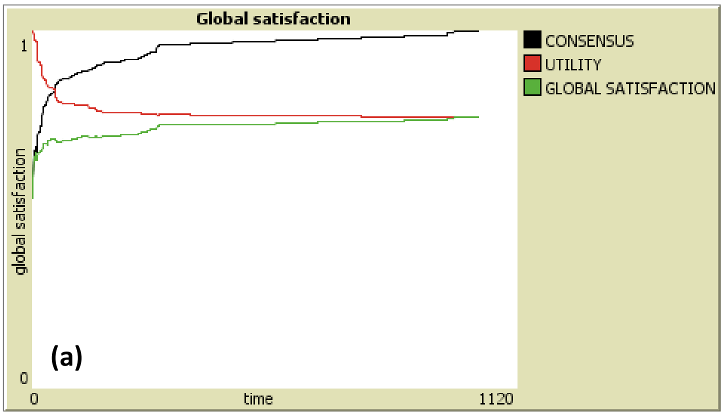


Figure 45 – Maximum global satisfaction per policy change and time needed to reach it (averaged over ten simulation runs).

Simulation time is an important variable because, even if it does not have any precise contextual meaning, it can give an idea of how much time an interaction process would take to be reach a satisfactory level (in terms of trade-off between consensus and utility).

There is a notable difference among the policies with respect to the time needed to reach the maximum global satisfaction. For instance, the TPS policy requires, on average, only one interaction step to reach the maximum global satisfaction and further interaction would lead to a loss of utility that is not compensated by the increase in the degree of consensus.

On the contrary, the RES policy, on average, takes much more time and this is because in some cases the simulation ends with a total consensus, in other cases with a partial one. While in the first case global satisfaction reaches its maximum when all the nodes turn in favor of policy change, in the other case the maximum value is reached after few interaction steps (Figure 46) and further interaction leads to a lower degree of consensus. This result is a bit controversial because it implies that an extended interaction can be either beneficial or negative in terms of global satisfaction, therefore suggesting that one should not exceed with the cycles of meetings because this could lead to a divergence (instead of convergence) of opinions. An excessive number of meetings could lead to group polarization rather than to group agreement.



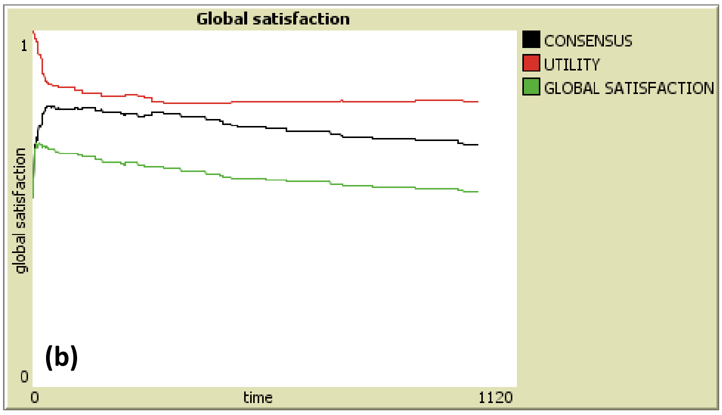


Figure 46 – Plots of degree of consensus, utility and global satisfaction for RES in the case of final total consensus (a) and final partial consensus (b) on policy change (one simulation run).

The OAS policy shows good values of degree of consensus and overall utility, suggesting that it would be more globally accepted with respect to the other two stakeholder-oriented policies.

In any case, if compared with the first two ranked policies in terms of entire interaction processes, they look quite different, showing comparable values of maximum "global satisfaction" and ending the three of them with a total consensus, but with a completely different loss of utility (much bigger for OAS than for 2BCS and WTPS) (Figure 47).

This supports the idea that the first two policies should be preferred to the third one and confirms that simulation time can be used to infer how many interactions steps are needed in real participation processes (e.g., how many meetings) to build consensus while guaranteeing a satisfactory level of stakeholder utility.

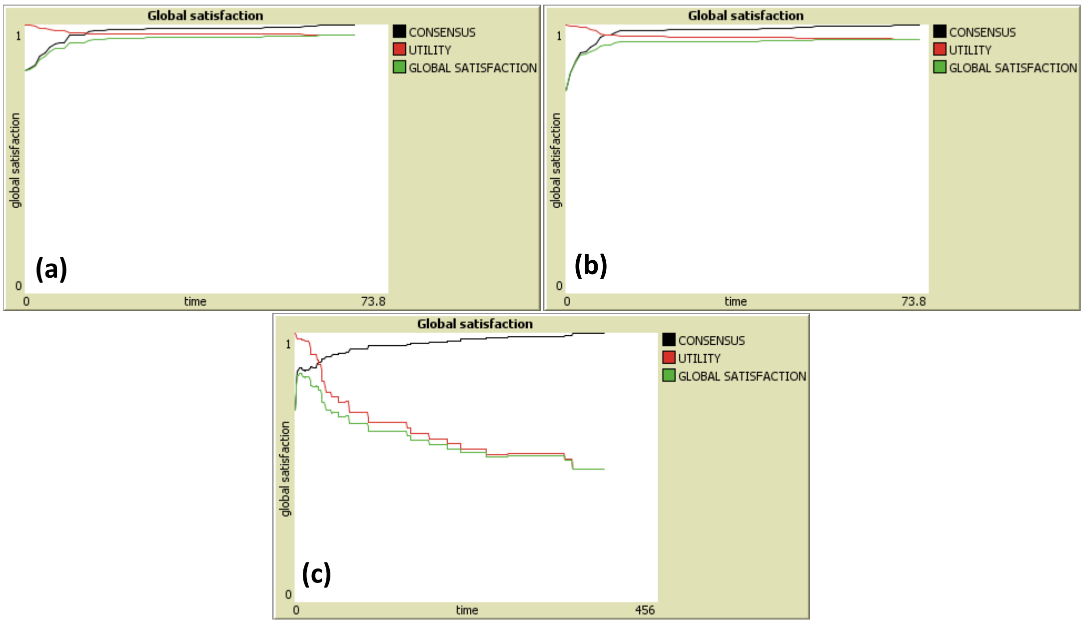


Figure 47 – Plots of degree of consensus, utility and global satisfaction for 2BCS (a), WTPS (b) and OAS (c) (one simulation run).

6.5.6. Policy implications

Simulation results suggest some recommendations and policy implications.

In general, stakeholders accept all the scenarios of LTZ accessibility improvements if this involves only a slight entrance fee increase, even if the improvements are oriented towards one of the three categories. When the entrance fee is further increased, it is nearly impossible to reach a consensus on policy change, confirming that policy-makers should not force restrictive measures (e.g., the entrance fees) if they are not enough counterbalanced by complementary incentives (e.g., number of facilities).

As expected, the best policy in terms of global satisfaction is the one that maximizes at the same time the improvements for the three categories while slightly increasing the entrance fee. If we consider an excessive entrance fee increase even in this “one scenario fits all”, simulations do not provide us with any precise suggestion since the results are not clearly directed towards any policy change. Besides, by considering different influences for the three categories, their heterogeneity is further stressed and results can change. In particular, if retailers or transport providers (or both of them) are considered more influential than own-account, the interaction process would likely lead to policy acceptance. This suggests that in real processes policy-makers should recognize the heterogeneous influences of the categories, which surely have an impact in the final decision.

A package of measures that matches the heterogeneous WTP of the categories is a successful policy, well accepted by stakeholders, thanks to the balance between increase in the entrance fee and improvements for all the stakeholders involved. This confirms that an agent-specific approach is necessary to find an optimal solution accounting for different stakeholders' preferences.

6.5.7. Discussion and Conclusions

This section presented an agent-based approach to model the participatory decision-making process about UFT decisions. Agent-specific utility functions have been used to characterize stakeholders' choices (i.e. retailers, transport providers and own account providers) and an agent-based model has been used to simulate the opinion dynamics process on a multilayer network. The multilayer approach has been chosen since it is an innovative and more realistic way to model the policy-making process.

Results show that interaction among stakeholders is beneficial in achieving convergent opinions and providing a policy ranking based on the maximization of consensus building and the minimization of utility losses. Some policy implications are discussed on the base of the results obtained. The different influence of stakeholder categories is important in affecting decision-making process outcomes and should not be underestimated.

A good policy is the one that provides a package of measures integrating the diverse stakeholders' interests thus suggesting that an agent-specific approach is fundamental to deal with the variety of interests involved in the UFT policy-making process.

6.6. General results and discussion

The methodology has been tested with reference to different case studies. Some of the applications were purely theoretical, other grounded on empirical data and/or experiences from real participation processes, but some general results can be derived from them:

a) when the group decision-making process aims at finding a consensus decision about a **specific policy** (in terms of approval or disapproval of it) simulation results show that a high connectivity helps the communication among stakeholders, and it takes few time to reach the final decision; on the contrary, few links slow down the process and sometimes it requires too much time to reach consensus or dissent. A substantial majority in favour of the proposal would likely lead to consensus, while the outcome is not trivial with more divergent opinions or when the favourable group is composed of influential agents. These results suggested some policy implications on how to conduct a real participation process that should be effective (in reaching a shared decision) and efficient (in short time), by fostering repeated interaction occasions and by appropriately informing stakeholders on the decision to be made.
b) When the group decision-making process aims at finding a **collective list of preferences**, simulation results show that, with a repeated interaction among stakeholders, it is possible not only to escape from inconsistent decisions, but also to reach a good degree of convergence of opinions, numerically assessed in terms of overlap among the lists, whatever the topology considered for the interaction network. On the other hand, taking into account the topology of interactions, the previous results could also give some insights or suggestions in order to build an efficient participation process. In particular:
   - in case study 3 the results of a public participation experiment with students were in agreement with the results of the agent-based simulation that reproduced it. The final results suggest that ABM can be useful, on one hand, to anticipate the behaviour 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. Indeed, other topologies, e.g. a star network (where only one central node is linked with all the others),

resulted to be more efficient than the real stakeholder network (i.e. a fully connected network).

- In case study 4 data from a combined Delphi-AHP experiment were used in the model. Results of the ABM allow to give some suggestions on how to build an effective participation process based on the Delphi method. In particular, it is proved that the outcomes are appreciably influenced by the willingness to change of the agents, resulting in total or partial consensus after interaction. Besides, the guarantee of anonymity avoids the possibility of leadership due to reciprocal influence that can likely reduce the convergence of opinions. Agent-based simulations also suggest that the Delphi method seems to be more effective in terms of consensus building when a quite homogeneous group of experts is involved.

c) When the group decision-making process is represented as a multilayer network with **multiple levels of communication** (interaction, negotiation and decision levels), simulation results show that agent heterogeneity is fundamental to take into account specific stakeholders' interest at the interaction layer (where they communicate with the other stakeholders) and at the negotiation level (where they communicate with their representatives), while considering different stakeholder influences at the decision level is important because it can affect the decision-making process outcome. Besides, data from econometric models are essential to understand the impact of policies consisting of packages of different measures on stakeholders' utility, proving that a combination of ABMs with DCMs is a promising tool to correctly model stakeholder involvement in policy-making.

d) For what concerns the **participation experiments**, built **with the help of decision-support methods** (i.e. AHP) and **participation methods** (i.e. Delphi), they proved that quantitative methods are 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. In particular, a combination of AHP with Delphi method proved to be suitable to support complex group decision-making processes. In this respect, the cooperation of the panel of experts in structuring the problem and sharing criteria, relevant indicators and alternative measures increased the probability to have a good convergence of opinions after only one step of anonymous interaction.

6.7. Further research

By looking at the three ABMs there are some considerations about further research:

In the 1st ABM further research will tend to modify: (i) the opinion dynamics, e.g. by increasing the number of possible opinions or changing the model from a discrete choice model to a continuum one, or including the possibility that the stakeholders could change their mind by policy persuasion or awareness raising; (ii) the stakeholder network, e.g. by seeing how the geographical distance and the organization affinity can influence the topological distance of the nodes, affecting the information exchange.

In the 2nd ABM: further research will tend to consider: (i) more realistic networks with data from real participation processes; (ii) other aggregation methods different from PMR; (iii) a multilayer representation.

In the 3rd ABM: further research is needed to enhance the realism and accuracy of the model. Possible improvements relate to the: (i) explicit consideration of the relationships among the different categories, (ii) simulation of the choice between more than two alternatives, (iii) examination of results in terms of relative satisfaction per each category to take into consideration the political acceptability of policies related to specific groups of agents.

The problem of model validations remains still open. The author is fully aware that a systematic approach is needed, following the wide and yet not like-minded literature about the topic (see section 5.5 for a first understanding).

More empirical data from real participation processes could improve the architecture of the models and increase the realism of the simulation outputs. A participatory gaming approach could be used to better understand the behaviour of real and heterogeneous stakeholders in a participation process.

In conclusion, based on the discussion about model validation done in section 5.5, further research for model validation should tend to improve:

- the architecture of the models, i.e. by properly considering the role each agent plays in the decision-making process and its characteristics (e.g., belief and goals, influence and influenceability) and truthfully representing the relationships among stakeholders. This can be achieved with more empirical data;
- the behaviour of stakeholders, i.e. by realistically reproducing the interaction process that can occur in real participation experiences, e.g. with the companion modelling and participatory gaming approach;
- the realism of the output of the models, in terms of results of collective emergent phenomena that are in agreement with reality. This can be achieved with more empirical data.

Nevertheless, for the purpose of this research, the models demonstrated to be suitable in giving an insight on the complex field of collective decisions and stakeholder involvement in transport planning. They are not intended as operative participative decision-making tools, but as a strategic and preventive mean to plan and guide effective participation processes and to predict the possible results of stakeholder interaction towards a shared decision.

7. TOWARDS PARTICIPATORY DECISION-MAKING PROCESSES IN TRANSPORT PLANNING

"There is no formula for good participation. Unlike cars, which despite different models and updates, operate in more or less the same way with predictable results even in different environments, public participation is not based on a fixed, reliable technology. Instead, public policy problems, the participants, methods for organizing the process and other features of the context interact uniquely in every setting"

Quick and Bryson, 2016

7.1. Lessons learned: consultation, participation and inclusion

Dealing with public participation in the transport planning process can be a very hard task. There is still bewilderment about (a) what role the public and stakeholders should have in the decision-making process, (b) how to deal with multiple diverging interests, (c) to what extent participation is beneficial for the success of the plan.

The attempt made with this research was to investigate the complex world of participated decisions, through agent-based models (ABMs) reproducing the interaction processes among social actors and tailored social experiments built with the help of multi-criteria decision-making (MCDM) methods. Three agent-based models were implemented to mimic different processes. They can be distinguished according to two main aspects: (1) the type of decision-making process and (2) the level of participation of stakeholders. They are summarized in Figure 48.

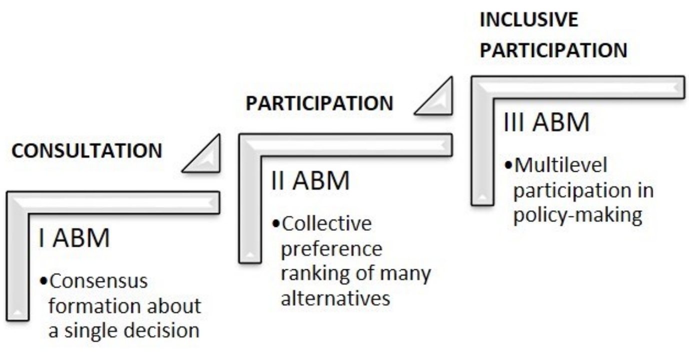


Figure 48 – Scheme of the three agent-based models (ABMs).

The three models represent growing levels of involvement in the decision-making process, from consultation about a single decision (I ABM) to participation in the ranking of many alternatives (II ABM) to an inclusive participation through multilevel involvement in the decision-making process (III ABM). However, this simple distinction is not trivial and may be arguable. Indeed, the underlying differences between the concepts of consultation, inclusion and participation are often stressed by public participation researchers.

According to Bickerstaff et al. (2002) "*consultation is different from participation: modes of 'consultation' – where local authorities receive suggestions and criticisms but can simply reject the ones they think are inappropriate or irrelevant – and 'participation' where there is a certain degree of redistribution of power*" (Bickerstaff et al., 2002). In this respect, the first model simulates a consultation process where the result is approval or disapproval of a given proposal, i.e. a kind of "suggestion or criticism" about the policy for decision-makers; on the contrary, the second and the third models reproduce participation processes where the results are stakeholder-driven rankings of alternatives that decision-makers should take into account when making the final decision (see Figure 3 at p 37).

Quick and Feldman (2011) distinguish inclusion from participation: *"Participation practices entail efforts to increase public input oriented primarily to the content of programs and policies. Inclusion practices entail continuously creating a community involved in coproducing processes, policies, and programs for defining and addressing public issues."* According to the authors, participation is oriented to "increasing input" for decisions, while inclusion in oriented to "making connections" among people, across issues, and over time. Deliberative practices, i.e. those that implies communication and interaction, should be included in inclusive processes to be effective. In this sense, our third model is "inclusive", simulating a repeated multilevel interaction among stakeholders. Clearly the term inclusion for the authors is more general, because it also implies connections across issues, sectors, and engagement efforts (Quick and Feldman, 2011).

Another categorization of "public participation", "active involvement" and "consultation" derives from Directive 2000/60/EC, which establishes a framework for Community action in the field of water policy and encourages the involvement of all interested parties in the form of “information supply” and “consultation”. While these two levels of involvement are to be ensured, the “active involvement” should only be encouraged (EC, 2003). Although the directive does not require “active involvement”, in the related Guidance on Public Participation (EC, 2003) it is considered as a prominent part in the framework of “public participation”, enclosing “consultation” that, in turns, encloses “information supply” (Figure 49).

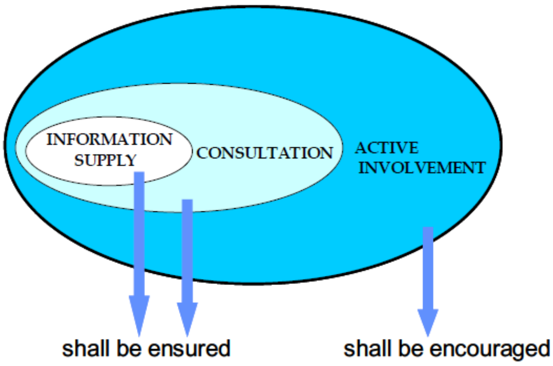


Figure 49 – Framework of public participation in relation to the Water Framework Directive (EC, 2003).

Also the way stakeholder consultations are conducted can produce more or less benefits for the decision-making process, as suggested by CIVITAS (2011): surveys and one-on-one meetings produce less benefits than a multi-stakeholder consultation which, in addition to the others, gives the opportunity for participants with divergent opinions to learn from one another, but which is surely more expensive (Figure 50).

Comparative benefits of various stakeholder consultations			
Benefits	Survey	One-on-one meetings	Multi-stakeholder consultation
A range of inputs	✓	✓	✓
Increased stakeholder satisfaction with end result	✓	✓	✓
Opportunity for real dialogue		✓	✓
Opportunity to build consensus			✓
Opportunity to build ownership of the plan and its goals		✓	✓
Opportunity for participants with divergent opinions to learn from one another			✓
Efficient use of time	✓		✓
Inexpensive (if travel is not required)	✓		

Comparison of the benefits of three types of stakeholder consultation (Logan 2004)

Figure 50 – Comparative benefits of various stakeholder consultations (CIVITAS, 2011).

To sum up, one could say that consultation is less effective than active involvement, i.e. direct participation that, in turns, is less effective than inclusion, which implies a continuous involvement over time and across issues. Figure 51 summaries what can be called the "Matryoshka" of public engagement.

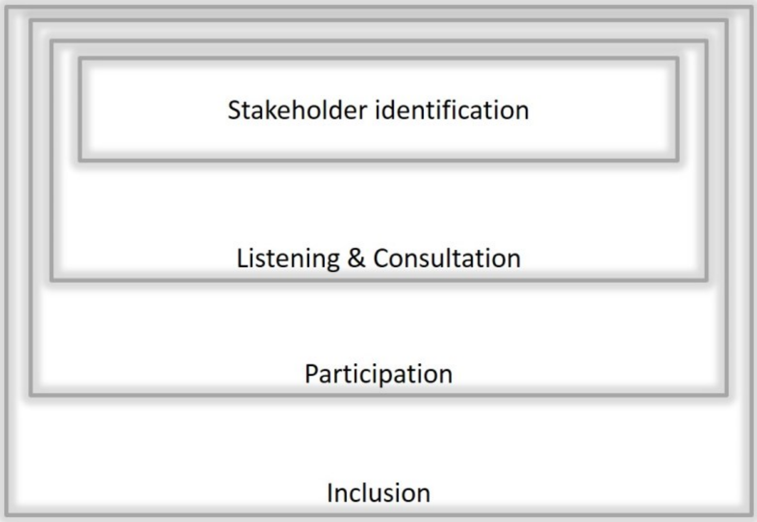


Figure 51 – The "Matryoshka" of public engagement.

Next section will enter into the details of the participatory transport planning process, by placing public engagement all along the planning process.

7.2. Placing public engagement in the transport planning process

Transport planning is typically characterized by sequential phases and it is a cyclical process, with the possibility of returning to previous steps. Chapter 1 of this thesis presented the different approaches to decision-making that have been adopted over time, from a "strongly rational" model to a "cognitive rationality" model, i.e. from a single decision-maker static approach to a multi-actor dynamic approach. In this new framework, public engagement is an integral part of the planning process (see Figure 2 and Figure 3 in section 1.2). Nevertheless, given the diversity of the phases that characterize a planning process and the diversity of involvement levels (from consultation to inclusion), public engagement need to be properly put in the framework of transport planning.

To this purpose, it is necessary to analyse the overall decision-making process in transport planning step by step based on the framework of Cascetta et al. (2015) and Le Pira et al. (2015a):

1. Decision-making context identification and present situation analysis. It consists of a preliminary, exploratory phase of the context where the decisions will be made. It implies a **first identification** of the relevant **stakeholders** that will be involved in the planning process.
2. Identification of objectives, constraints and project typologies and alternative systems projects (plans) formulation. This phase encompasses several steps and it is a typically hierarchical process. On the basis of the goal(s) of the plan, the **stakeholders** to be involved have to be **clearly identified**. The decision-making hierarchy consists of the decomposition of the problem into levels, from the definition of the goal, objectives, criteria and plan alternatives. In these levels, stakeholder and citizen involvement has to be part of the decision-making process, in the form of **listening and consultation** about the objectives and criteria and in the form of **participation** for the definition of plan alternatives. Listening and consultation can consist of citizen surveys and one-on-one meetings with stakeholders, to elicit their preferences about objectives and criteria. Participation can involve multi-stakeholder interactive meetings whose results influence the selection of the plan alternatives.
3. Project simulation and technical assessment/alternative solutions comparison (evaluation) and interventions choice. This phases parallel, from one side, project simulations and technical evaluations of alternatives (made by planners), from the other, **continuous inclusion of stakeholders** in group decision-making processes that "make connections" among people, across issues, and over time (Quick and Feldman, 2011). At this stage, reiterated involvement of stakeholders is fundamental to make opinions converge towards shared decisions.

Figure 52 shows the framework of the participatory transport planning process.

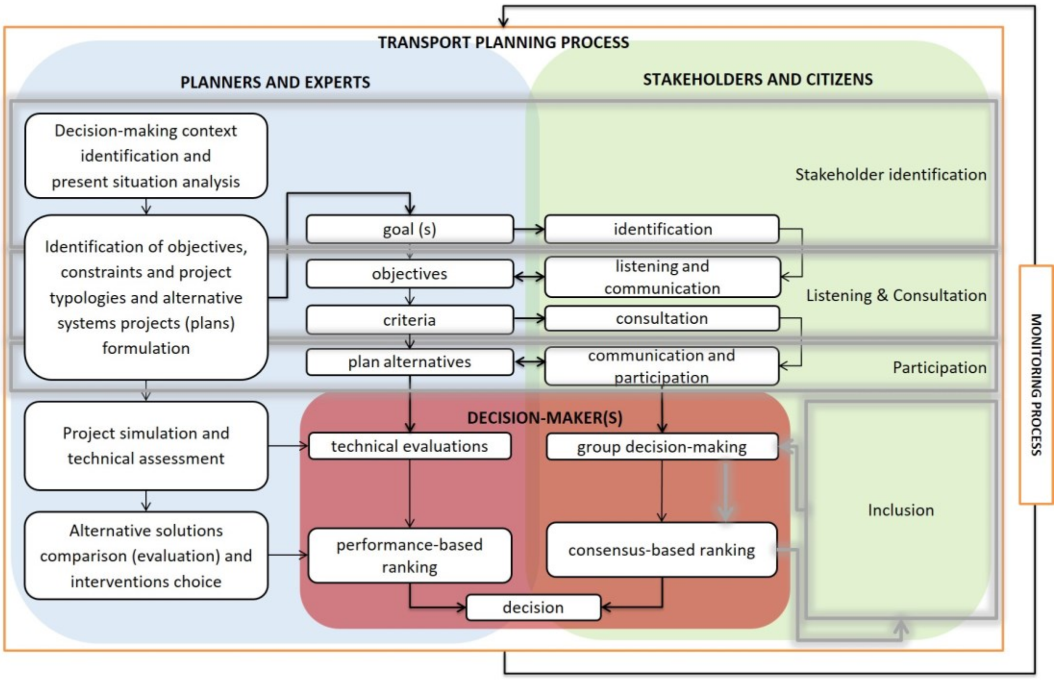


Figure 52 – Framework of the participatory transport planning process.

As already said, quantitative methods and agent-based models can help practitioners in dealing with effective involvement processes aimed at stakeholder-driven decisions.

7.3. Guiding participation with the help of quantitative methods and agent-based simulations

Guiding an efficient participation process is not easy, because of the complexity and peculiarity of each decision to be made. Despite that, the attempt made with this thesis is to provide some tools that can help to analyse each problem and have a clear insight on the main elements influencing a participation process. The methodology presented is mainly based on:

1) Agent-based modelling and simulations, to reproduce participation processes involving stakeholders linked in social networks, understanding the role of interaction in finding a shared decision with the help of opinion dynamics models and investigating some important parameters such as stakeholder influence, degree of connection, level of communication for the success of the interaction process.
2) Group multi-criteria decision-making/aiding (MCDM/A) methods, to assist the group decision-making process, by structuring the

problem to include different criteria of judgments and points of views, in order to deal with the complexity of decisions regarding "wicked problems".

In the framework of participatory transport planning (Figure 52), the models and methods analysed can be used to guide stakeholder involvement process.

Group **MCDM/A** methods, such as MA-AHP used in case studies 3 and 4 (see sections 5.5, 6.3 and 6.4), are useful to structure the problem (from the goal(s) of the plan, to the plan alternatives), elicit stakeholder preferences, e.g. in terms of importance weights about the elements that compose the problem. Besides, a combination of MCDM/A with participation methods (e.g. Delphi-AHP method of case study 4), proved to be suitable to support complex group decision-making processes. In this respect, the cooperation of the panel of experts in structuring the problem and sharing criteria, relevant indicators and alternative measures increased the probability to have a good convergence of opinions after only one step of anonymous interaction. MCDM/A are also usually used by planners for alternative solutions comparisons based on the results of project simulations and technical assessment.

Agent-based modelling (**ABM**) of opinion dynamics on stakeholder networks is helpful for a preventive analysis of the possible results of an interactive dynamic process, e.g. consultation about a single decision (I model, section 5.2), participation in a preference ranking process (II model, section 5.3), cyclical/multilevel involvement in inclusive group decision-making processes (III model, section 5.4). Simulations of different interaction processes can give suggestions about (i) which network topologies are suitable to help the opinion exchange process, (ii) how stakeholder influence can affect the final outcome, (iii) the probability of a convergence of opinions towards a final shared decision after repeated interaction. In this respect, simulations using stylized social networks and different combinations of the parameter space (case studies 1 and 2, see sections 6.1 and 6.2) allow to investigate the complex phenomenon of making collective decisions, e.g. the problem of decision deadlock due to the "Condorcet paradox" (see chapter 3), while empirical data from participation experiences are necessary to validate the models.

Besides, other methods and tools can help practitioners to have an insight on the stakeholders involved in transport decisions. Once stakeholders have been identified, it is important to understand what role they play in the decision-making process and how to engage them. Representing stakeholders in social networks allows to understand the relationships among them and the influence of each node of the network based on the linkages with the others.

In this respect, Social Network analysis (**SNA**) applied to stakeholder analysis is helpful to understand the centrality of the stakeholders, assessed via centrality indexes (see subsection 1.3.2).

After stakeholder identification and analysis, listening and communication are necessary to elicit their objectives and preferences, e.g. from in-depth interviews with few key actors to stated preference questionnaires to multiple diverse stakeholders. In this case, the approach of discrete choice modelling (**DCM**) can be used to generalize the results of surveys to a discrete sample, by statistically relating the preference expressed by each person to the attributes of the person and the attributes of the alternatives available to the person. This approach is particularly interesting when the heterogeneity of people is considered, i.e. with an agent-specific approach to discrete choice modelling (Marcucci et al., 2013a).

Besides, data from SNA and from econometric models such as DCM can be used to feed the agent-based models, as done in case study 5 about urban freight transport policy-making (see section 6.5).

In particular, a combination of DCM with ABM seems promising to model stakeholder involvement in decision-making, allowing to overcome their intrinsic limits. Indeed, DCMs can provide sophisticated agent-specific data accounting for personal heterogeneity in preferences but they cannot reproduce the dynamic interaction among agents; vice versa ABMs simulate dynamic processes and therefore interaction, but often they are not fed with specific data on the base of sound micro-economic theory.

Figure 53 overlaps the framework of participatory transport planning with the methods and models that can be used to guide the planning process.

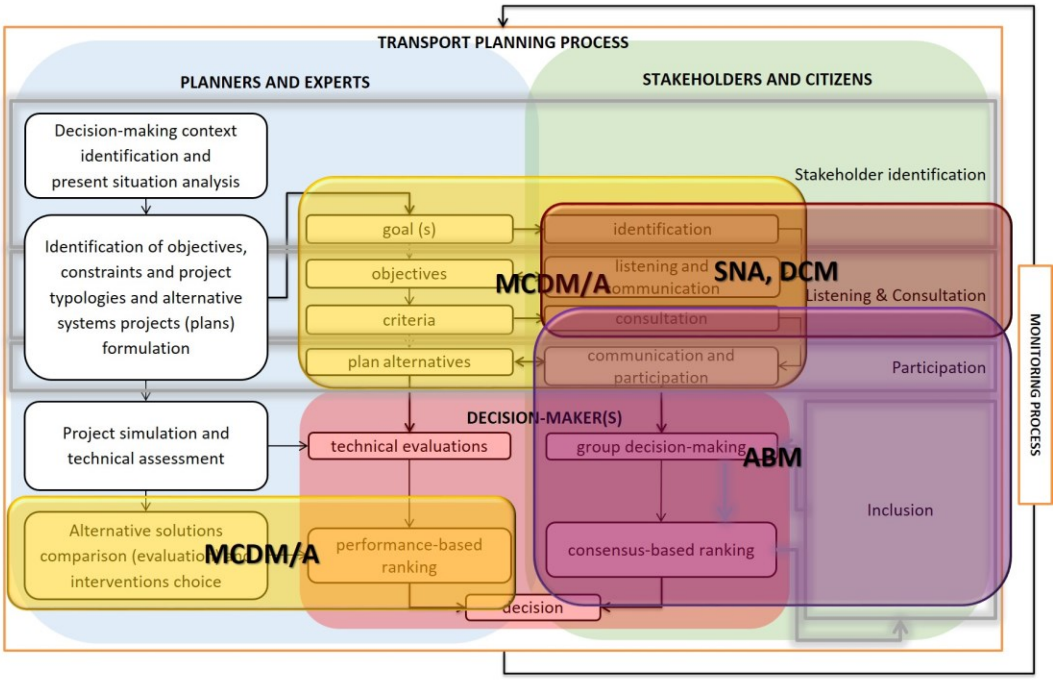


Figure 53 – Methods and models to guide participation in the framework of participatory transport planning process.

7.4. Final remarks

In conclusion, as already stated in the introduction, the aim of this research was to give a contribution and an insight on the complex field of collective decision-making and stakeholder involvement in transport planning, by analysing the role of decision-support methods and agent-based modelling in suggesting how to tackle the complexity of participation processes. It is not intended as a practical guideline on how to do participation in transport planning; conversely, it is aimed at providing a deep knowledge and comprehension of the complex phenomena emerging from social interaction and consensus building processes. Many research questions motivated the work and some of them still lack a complete answer, paving the way for further research. In particular, it is not clear how to link the result of stakeholder involvement (i.e. the final collective choice) with that derived from technical assessment and alternative solutions comparison. The final decision remains in charge of the decision-maker, who has to take into consideration the quality of the decision to be made. This is the result of two elements: acceptability and feasibility. A high-quality decision is the one that has a good probability of acceptance (i.e. high acceptability) and a high performance of technical feasible solutions. Investigating how these two aspects of the decision-making process can be linked is an interesting and quite unexplored field of research.

Figure 54 is a scheme which resumes the research carried out, with MCDM/A and the modelling approach to investigate Community Involvement in Transport Planning.

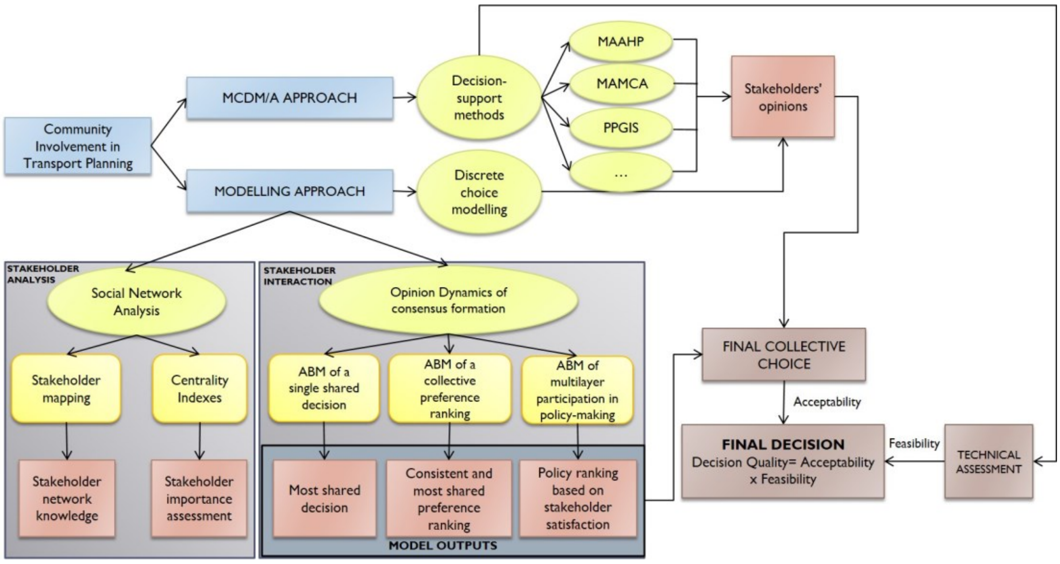


Figure 54 – Outline of the research.

Finally, some general remarks based on the seven "Core Values for the Practice of Public Participation" by the International Association of Public Participation (IAP2[35]):

1. *"Public participation is based on the belief that those who are affected by a decision have a* ***right*** *to be involved in the decision-making process."*

   Changing the perspective is necessary to understand that transport decisions cannot simply derive from technical evaluations, but need to be taken with those who will be affected by the decisions, and therefore deserve a right to participate in the decision-making process.

2. *"Public participation includes the promise that the public's contribution will* ***influence*** *the decision."*

[35] http://www.iap2.org

Involvement is effective only if people have the feeling that their opinions will affect the final decision; otherwise, they will be more reluctant to participate, resulting in time (and money) waste.

3. *Public participation promotes sustainable decisions by recognizing and communicating the* ***needs*** *and* ***interests*** *of all participants, including decision makers.*

Stakeholder contribution can represent a valuable input for new solutions considering their needs and interests. Besides, taking into account heterogeneity is fundamental when dealing with multiple (often conflicting) needs and interests. To this purpose, an agent-based approach is advisable to analyse the involvement process, e.g. by means of agent-based modelling.

4. *Public participation seeks out and* ***facilitates*** *the involvement of those potentially affected by or interested in a decision.*

Organizing involvement can be a very tough task, starting from identification of all those potentially affected by or interested in the decision. Nevertheless, there are methods that can help to have an insight on the actors to involve, e.g. Social Network Analysis, that allows to evaluate their centrality in the decision-making process according to the relationships with the other actors.

5. *Public participation seeks* ***input*** *from participants in designing how they participate.*

There is no formula for good participation (Quick and Bryson, 2016) and each situation presents its peculiarity; therefore, seeking input from participants can be helpful not only to design the participation process, but also to increase the realism of the models that reproduce it, making stakeholders contribute in the model implementation and validation (i.e. the "companion modelling" approach by Bousquet et al., 1999).

6. *Public participation provides participants with the* ***information*** *they need to participate in a meaningful way.*

Decision-support methods, such as multi-criteria decision-making/aiding methods, are helpful to carry out the participatory decision-making process, but they have to be clearly understood by stakeholders. Sometimes, simple methods are better than more sophisticated and precise methods that are likely to be seen as "black boxes" by stakeholders. Therefore, clarity and transparency are fundamental to engage in a meaningful way.

7. *Public participation communicates to participants how their input **affected** the decision.*

The way stakeholders' input affects the final decision largely depends on the level of desired involvement in the decision-making process, which has to be clearly declared at the beginning of the participation process. As said above, in general the final decision remains in charge of the decision-maker, having received inputs from stakeholder participation and from technical evaluations. A good solution originates from a trade-off between the most shared solution, which will be likely accepted, and the best one from a technical point of view. In this respect, the ability of transport planners is to *"design solutions which are technically consistent and, at the same time, maximize stakeholder consensus."* (Cascetta et al., 2015).

CONCLUSION

> *"The idea of citizen participation is a little like eating spinach; no one is against it in principle because it is good for you."*
>
> Arnstein, 1969

The intent of this PhD thesis was to address the issue of public participation in transport planning with a methodical and modelling approach, aimed at (i) providing a deep knowledge and comprehension of the complex phenomena emerging from social interaction and consensus building processes and (ii) suggesting methods and models that can help to tackle the complexity of participation in transport planning.

The complexity of the task stems from some basic elements: transport systems are complex systems that affect the social, economic and environmental dimensions of a territorial community with several impacts and feedbacks not easy to be foreseen. Further complexity is added by the procedural issues related to construction and operation of the transport systems and mostly for the many actors involved with often conflicting interests (see chapter 1). In view of this, decisions must be based on several criteria of judgments and multiple points of view. Decision-support methods, such as multi-criteria decision-making/aiding methods (MCDM/A), are then necessary to carry out effective decision-making processes considering multiple criteria of judgments (see chapter 2). In addition, appropriate methods are needed to deal with the plurality of stakeholders characterized by heterogeneity of interests and objectives. In this respect, techniques such as Social Network Analysis (SNA) and agent-specific discrete choice modelling (DCM) help to have a clear insight on the role the actors play in the decision-making process and their individual preferences (see subsections 1.3.2 and 1.3.3). An agent-based approach is thus necessary, especially when the dynamic of social interaction that can lead to a convergence of opinions is to be investigated, via agent-based models (ABMs) (see chapter 4).

Based on these premises, the methodology proposed mainly consist of the implementation of three ABMs of opinion dynamics on stakeholder networks that allow to reproduce different contexts of decision-making processes involving stakeholders, understanding the role of network topology and other sensitive variables in reaching a convergence of opinions and avoiding the risk of decision deadlock due to inconsistency (see chapter 5). In this respect, some problems arising from preference aggregations, which have been largely studied by social choice theory, have been analysed (see chapter 3); in particular, the probability of "Condorcet paradox", i.e. an intransitive collective list of preferences resulting from the aggregation of transitive individual lists, has been investigated via ABM.

The ABMs are not intended as operative participative decision-making tools, but as a strategic and preventive mean to plan and guide effective participation processes and to predict the possible results of stakeholder interaction towards a shared decision. In order to test the models and verify their reliability, several simulations were done. In particular, tailored participation experiments regarding transport decisions were carried out with the help of MCDM/A methods and traditional participation techniques (i.e. the Delphi method), serving as case studies and as a basis for model validation (see chapter 6).

The three ABMs and their applications demonstrate that participatory decision-making processes can be at multiple levels, from single stakeholder consultation or participation, to inclusive extended participation, and that interaction is fundamental to foster consensus building towards a collective decision (see chapter 7).

In conclusion, in the framework of participatory transport planning, quantitative methods (e.g. SNA, DCM, MCDM/A) and ABM provide a support for decision-makers and practitioners to deal with multiple stakeholders towards effective participation processes.

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