Smart Governance Models to Optimise Urban Planning Under Uncertainty by Decision Trees

Chiara Garau[1(✉)], Giulia Desogus[1], Alfonso Annunziata[1(✉)], Mauro Coni[1], Claudio Crobu[2], and Massimo Di Francesco[2]

[1] Department of Civil and Environmental Engineering and Architecture, University of Cagliari, 09129 Cagliari, Italy
cgarau@unica.it

[2] Department of Mathematics and Computer Science, University of Cagliari, Via Ospedale 72, 09124 Cagliari, Italy

Abstract. In recent years, the applicative approach to smart governance in urban planning field has increasingly involved the decision-making processes of public administrations and has helped to solve economic, social and environmental challenges of cities. This approach has in fact allowed administrations to understand how changes are taking place in the territory and in real time, through big data, e-governance and city dashboards. However, the literature underlines the lack of decision-making models on which an agreement had been recognized for the organization and management of new projects on an urban scale. This need involves (1) understanding clearly the needs of all actors involved in a project (public or private financiers, public administration, control offices and stakeholders), (2) making optimal decisions w.r.t. the selected criteria, (3) providing a hedge against unexpected data changes. The main applicative goal is to have a full awareness of how much every single change means in economic, logistical and time lag terms. To this end, the authors investigate the viability of Decision Trees to support decision-making processes for urban planning.

Keywords: Replicability · Smart governance · Decision-making processes · Project sustainability · Project scalability

1 Introduction

The growing demand for transparency in decision-making processes and the plurality of contrasting interests involved in place-shaping actions calls for the development of

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techniques for supporting informed decisions within the context of urban planning and governance [1, 2].

Indeed, the always current problems of transparency/accountability and conflict (with its resolution) are central to the implementation of the smart city paradigm [3]. The smart city paradigm, in fact, focuses on the idea of using information and communication technologies to improve wellbeing, living conditions and democracy. Democracy implies participation and transparency; the conflict with different form of solutions is a frequent condition of cities, arising from different motivations, particularly in the case of competition for scarce resources.

This study investigates the usefulness of applying the decision tree model as a simple method to assist in decision-making processes on the identification of strategies for the transformation of the public space. In its simplest form a decision tree can be defined as a tree diagram, which is used for making decisions in business or computer programming by branches representing decisions or uncertain situations with associated risks, costs, results, or probabilities. Namely, it represents a model providing the identification of optimal solutions based on a hierarchical sequence of interdependent sub-decisions, probable results and postulated circumstances.

For these reasons, the decision tree model is a beneficial method for enhancing the judgement of decision-makers, solving possible conflicts and making understandable and transparent the rationale of decision-making processes. The proposed study presents the application of the decision tree model to the assessment of different strategies for the redevelopment of "via Roma", one of the main streets in Cagliari, Italy. The latter is a critical space, within the system of the Cagliari Metropolitan area, characterised by the concentration of different flows, practices, metropolitan and regional scale amenities, and by its ineliminable pre-eminent function as a corridor of mobility and accessibility.

The analysis aims to demonstrate the feasibility of utilizing the tree decision model as a technique for supporting the knowledge-based identification of urban planning strategies, while increasing transparency of the decision-making process and facilitating meaningful participation.

The article is structured on five sections: after this introduction, Sect. 2 analyses decision tree models applied to smart urban governance by identifying some shortcomings in the current literature. Subsequently, Sect. 3 presents the case study and Sect. 4 introduces some guidelines on the construction of decision trees. Section 5 illustrates the decision tree built for the case study at hand. Finally, Sect. 6 summarises the findings of the study and illustrates hypotheses for the future development of the research.

2 Decision Tree Models Applied to Urban Governance: Problem Identification and Construction

Chichernea (2014) argues that "the rapid evolution of Information and Communication Technologies (ICT), Cloud Computing Services, the Internet-of-Things, Everything-as-a-Service (XaaS), as well as the development of new mathematical models, artificial intelligence and data storage capabilities, position DSS at a unique advantage as a continuously improving tool in the process of planning and completing complex projects" [4, p. 1]. In literature, the DDS applied to the city are interpreted as a decision support

in the planning process [3, 5] linked to various aspects including the size of the city [6], urban distribution [7], ecology and sustainability [8].

Among all DSSs, decision trees are analytical models useful for representing and solving optimization problems with single criterion in an uncertain environment. The construction of a decision tree is based on a logical and systematic way, and makes the decision maker in the position of addressing a variety of problems. Once a criterion is selected, the tree reports the optimal decision as a path, which is obtained by decomposing the problem into smaller and more manageable parts.

In a nutshell, they are constructed through (1) the definition of a criterion, (2) the construction of the decision tree with the list of possible decisions and possible outcomes and (3) the assignment of probabilities. This process allows to monitor changes, manage risks during construction and make changes. Decision trees are widely used in operations research (e.g., statistics, data mining, machine learning) to support different disciplines (e.g., medicine, statistics, psychology, engineering and management) [9].

Regarding the urban planning field, several studies use decision trees as predictive models rather than prescriptive models for optimization [3, 10]. These mainly concern the field of transport where it is used for the choice analysis of the modality and of the pedestrian's satisfaction in the transport planning process [11–15], to improve travel time prediction [16], to prevent accidents, and to investigate driver behaviour [17, 18]. In the specific domain of urban planning, predictive decision trees focus on specific interventions without taking into account two critical components of urban governance within the paradigm of the smart city: transparency and resolution of the conflict.

The smart city paradigm, in fact, investigates the opportunities for creating efficient, equitable, sustainable urban environments, determined by the integration of information and communication technologies (ICT) in urban economic, social, political processes. Within the perspective of implementing the smart city and governing urban transformations, several issues emerge, involving spatial, social, economic aspects, entangled in an ethical dimension [19, 20]. These issues include propinquity, inequality, precarity, conflict, fear, environmental problems, demographic issues, health emergencies, political representation. In particular, this study focuses on the issues of participation and transparency. Participation and transparency are considered, in fact, as central and interrelated aspects of improving democracy and creating efficient urban environments. The effective engagement of the broad ecosystem of city actors and urban populations, engendered by transparent and participatory governance processes, emerges as a central aspect of successful smart city models. It facilitates the mobilization of individuals' perception and experience of the urban realm, providing councils and public administrations with useful information on competing needs, perspective and concerns of different social groups. More precisely, the relevance of participation in assisting planning processes intersects the centrality of participation as a central aspect of democracy and the demand for participation and transparency determined by the availability of ICT. Transparency can be defined as the guarantee of access to information related to governance processes relevant to the interests of all population groups. In this respect, the notion of transparency is strictly related to that of accountability: the extent to which public agencies are responsible for their policies and able to give a satisfactory reason for them. The relevance of transparency is increased by the emergence of conflict as an ineradicable component of

urban planning. Conflict can be defined as a condition of political antagonism revolving around the competition for limited resources. Three aspects of spatial planning determine the onset of conflict: first, decisions on land use are competitive and, often, mutually exclusive: space is a limited resource whose allocation for different land uses, each one respondent to the instances of a specific social group, constitutes the essential aspect of spatial planning. Moreover, decisions on land use are influenced by the system of relations of compatibility and incompatibility among different functions, determining the mutually exclusive relations among interests and instances of different groups.

Second, spatial planning determines the re-distribution of spatial capital. More precisely, planning defines, recognizes, amplifies symbolic and economic values and citizenship rights, by determining the conditions of access of different social and political groups to basic amenities and services. The ineliminable differences in the distribution of benefits, implies that distributive asymmetry is a peculiar component of spatial planning.

Lastly, a different form of asymmetry lies in the differences in the distribution of benefits and externalities of land use decisions, which reflects, in turn, the different dimensions of site involved in place shaping processes. Spatial planning, in fact, produces local transformations, engendering concentrated benefits and externalities that impact population groups at a non-local and trans-boundary scale.

Therefore, the definition of a decision tree model for clarifying criteria, objectives, circumstances and results of decisions, addresses two aspects of the realization of the smart city paradigm: first, by offering a rationale for decision making processes and for managing conflict and competition for space engendered by spatial planning and, second, by increasing the understandability of governance processes.

3 The Case Study

This article focuses on the decision problem related to the urban regeneration of the area of "via Roma", one of the main streets in Cagliari, Italy (Figs. 1 and 2). Opened in 1883, "via Roma" comprises two carriageways – "Lato Portici" delimiting the compact structure of the historic centre and "Lato Porto" delimiting the area of the port – separated by a central tree-lined promenade. "via Roma" is a primary distributor, connecting portions of the urban area separated by the compact structure of the compact city. Moreover, several major buildings related to the political and commercial activity, such as the Civic Palace and the Regional Council, are aligned along its margins. After the Second World War, "via Roma" assumed the role of fundamental urban distributor, intensely frequented by pedestrians and engaged by large flows of private vehicles, trolleybuses and buses. The redevelopment of "via Roma" is an optimal case study because it involves the issues of conflict and transparency, determined by its centrality in the metropolitan area. This condition of centrality results from two factors: i) the concentration of metropolitan-scale services (educational, cultural, social ones) and of administrative functions in the compact city; ii) its topological centrality in the road system of the metropolitan area reinforcing its function as a distributor serving the metropolitan area, (Fig. 2). The relevance of this function is magnified by the reliance of mobility in the metropolitan area on private car-based travel, determining a strong pressure on arterial distributors and on the system of urban primary and secondary distributors. Recent surveys measure

164.637 cars entering the urban area of Cagliari in an average week day and 130.336 cars leaving the urban centre (Comune di Cagliari, 2012), on a population of 156.538 residents (Comune di Cagliari, 2017; iii) the strong commitment of local authorities in policies able to foster sustainable modes of transport [21]; iv) the diversity and density of primary and secondary uses, determining the character of "via Roma" as a multi-modal and multi-functional space, and, thus, engendering a strong competition for space among different practices and social groups [22].

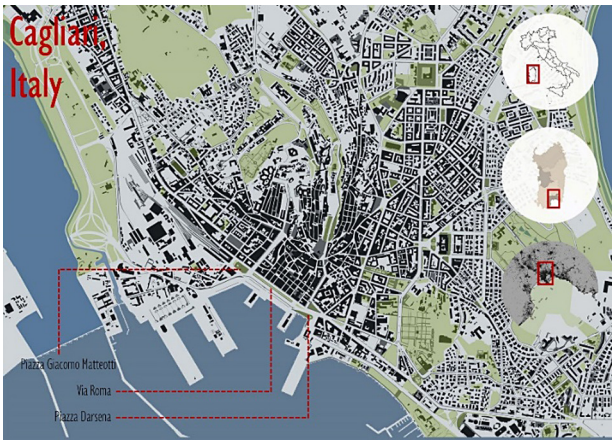

Fig. 1. The area of study: "via Roma" in Cagliari, Italy.

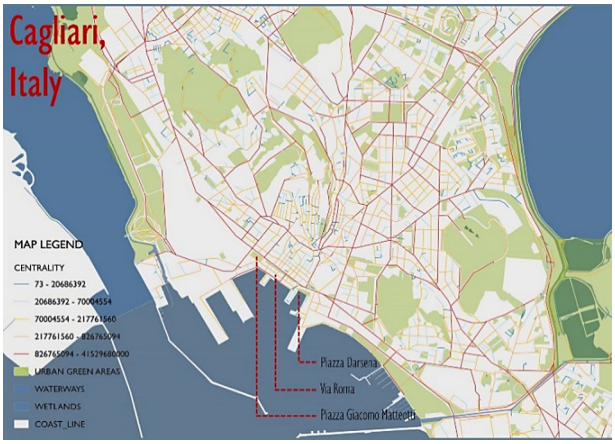

Fig. 2. Centrality, conceptualized as the potential as transit spaces, of streets in the central districts of Cagliari, Italy.

4 Guidelines on the Construction of Decision Trees

The construction of the decision tree model to structure the decision problem related to the regeneration of "via Roma" is a process articulated on three stages. The first step in decision trees is the definition of the criterion for evaluating the impact of alternative policies.

A possible criterion is the quality of the process. The quality of the process incorporates both the increase in quality of life produced by the regeneration of the urban space and the feasibility of the process in terms of its cost and duration. More precisely, the increase in quality of life encompasses the increase in the usability of the public space, the reconnection of the sea-front with the compact urban fabric of the historic centre, the increase in the accessibility of primary and secondary uses concentrated in the historic districts.

The second step is the construction of the decision tree based on a list of alternative decisions and a list of possible outcomes. Decisions are represented by decision nodes and alternative actions on a specific decision are represented by branches originating from the decision node. Uncertain circumstances affecting the decision-making process are represented by event nodes. Possible outcomes of an event are represented by branches originating from the event node. A central distinction between decision nodes and event nodes concerns the nature of respective consequences: branches originating from a decision node represent strategies selected by the decision-maker according to the criterion. On the other hand, branches emanating from event nodes represent outcomes of uncertain circumstances and the decision-maker does not have choice to opt for one of these branches. The outcomes in an event node are requested to be mutually exclusive and collectively exhaustive. The first property means that alternative outcomes could not be observed at the same time. The second property implies that all possible outcomes are considered, and any non-represented outcome cannot be observed.

The third step is the determination of probability values for each branch emanating from event nodes. The probability of a branch indicates the possibility to observe the random outcome associated to each branch. The sum of probabilities of the branches originating from a specific node must be 1, in order to satisfy the requirements of mutual exclusivity and collective exhaustivity of random outcomes of uncertain events.

5 A Decision Tree for the Case of "Via Roma"

This section shows the construction of the decision tree model for structuring the decision problem for the regeneration of "via Roma". The tree is reported in Fig. 3, 3a and 3b.

The root decision is the projected expansion of the light rail system, and its connection with the railway network. This intervention is expected to be completed in 2023 and reintroduces the question of the comprehensive regeneration of Via Roma. The alternative strategies of regeneration of the road space depend on the uncertain amount of available financial resources and include a large infrastructural intervention, a moderate re-configuration of the urban space and of the road network, and the management of the present situation, via regulation of practices and of mobility, and via interventions on the composition of the road space. The large infrastructural intervention includes the

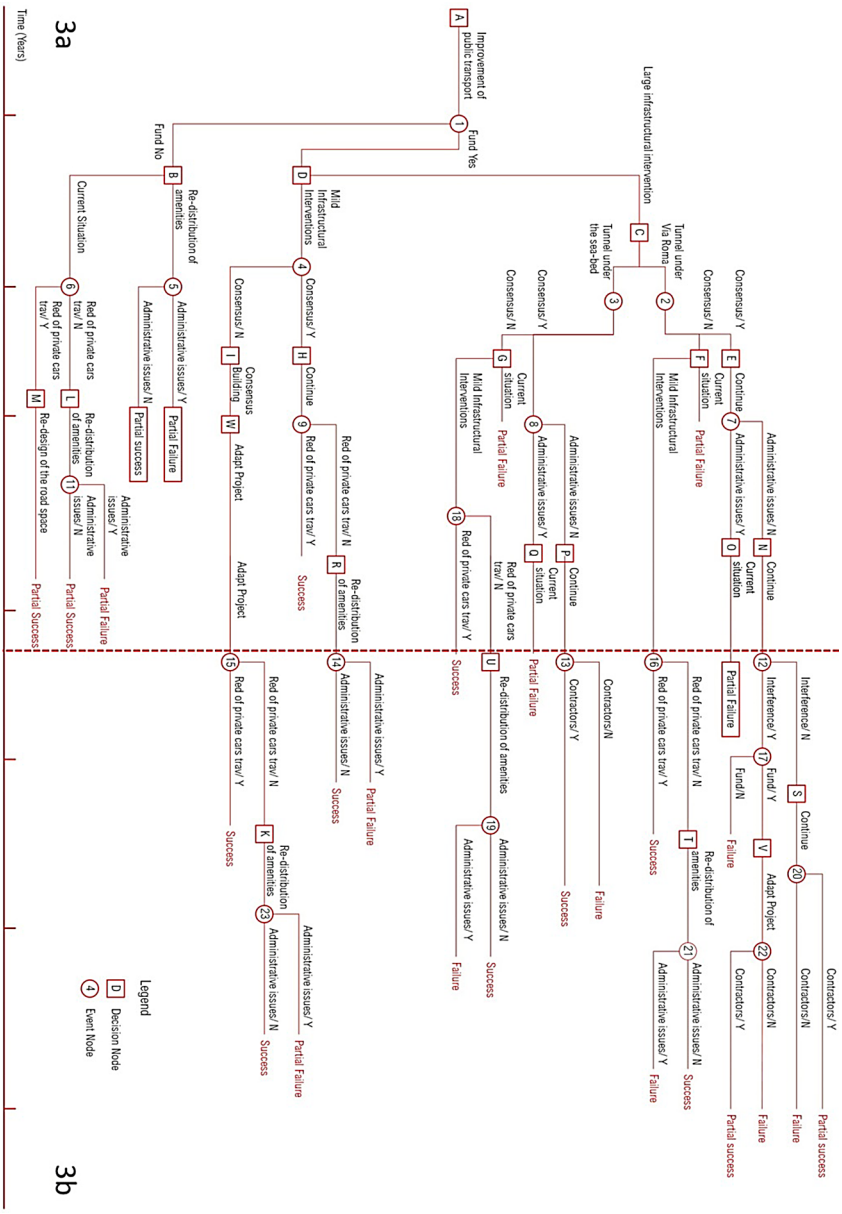

Fig. 3. Construction of the Decision Tree Model for structuring the decision problem related to the regeneration of Roma Main Street. The Decision Tree Model is divided in two parts (3a and 3b), presented separately in the sub-sequent pages.

alternative options of the construction of a road tunnel under the road space and of the construction of a road tunnel under the seabed. This strategy is based on the distinction and separation of spaces of mobility aimed at the realization of a large pedestrian

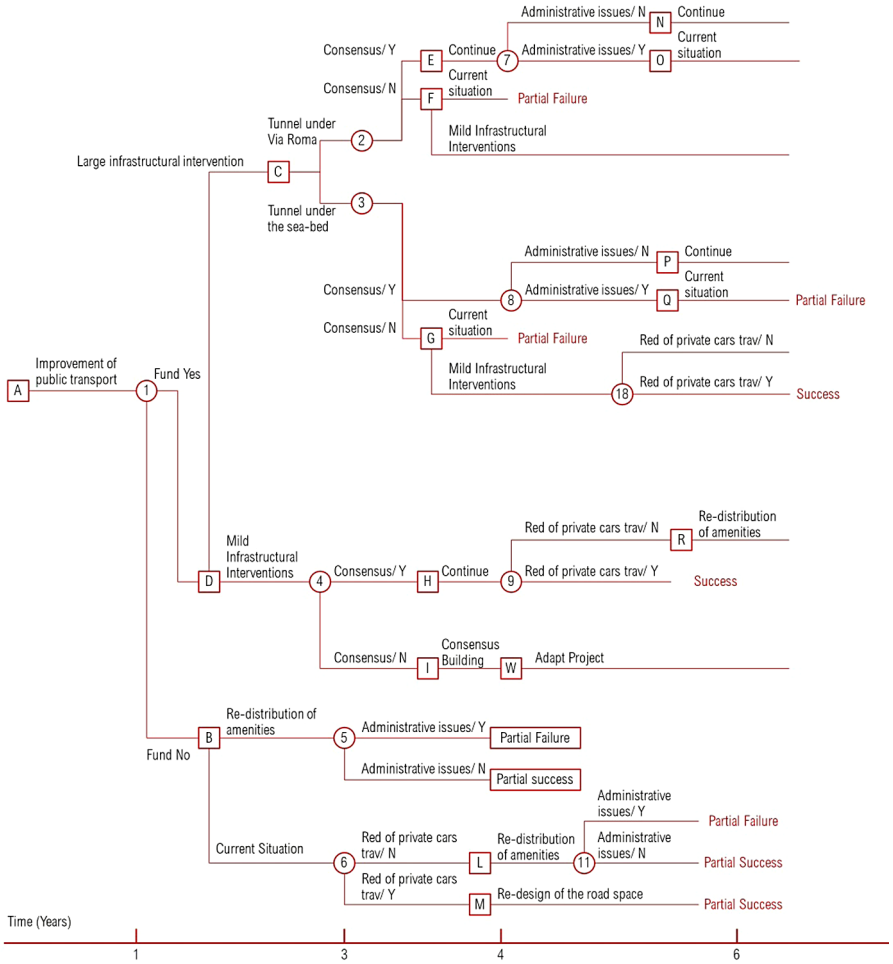

Fig. 3a. Construction of the Decision Tree Model for structuring the decision problem related to the regeneration of Roma Main Street. First part, events and decision nodes concerning first stages of the regeneration of Via Roma (years 0–6).

surface connecting the seafront and the urban fabric of the historic centre. The mild infrastructural intervention includes a modular strategy based on interdependent interventions aimed at: realizing parking areas along the edge of the historic centre, building connections to the public transport system, reducing the spaces destined to mobility, expanding and redesigning pedestrian surfaces, redesigning intersections among "via Roma" and adjacent primary streets. The layout of the decision tree model underlines three significant aspects.

The first is the uncertainty of strategies of regeneration based on large infrastructural interventions. This uncertainty is determined by the plurality of circumstances increasing the impedance of the process. Unfavourable circumstances include the complexity of

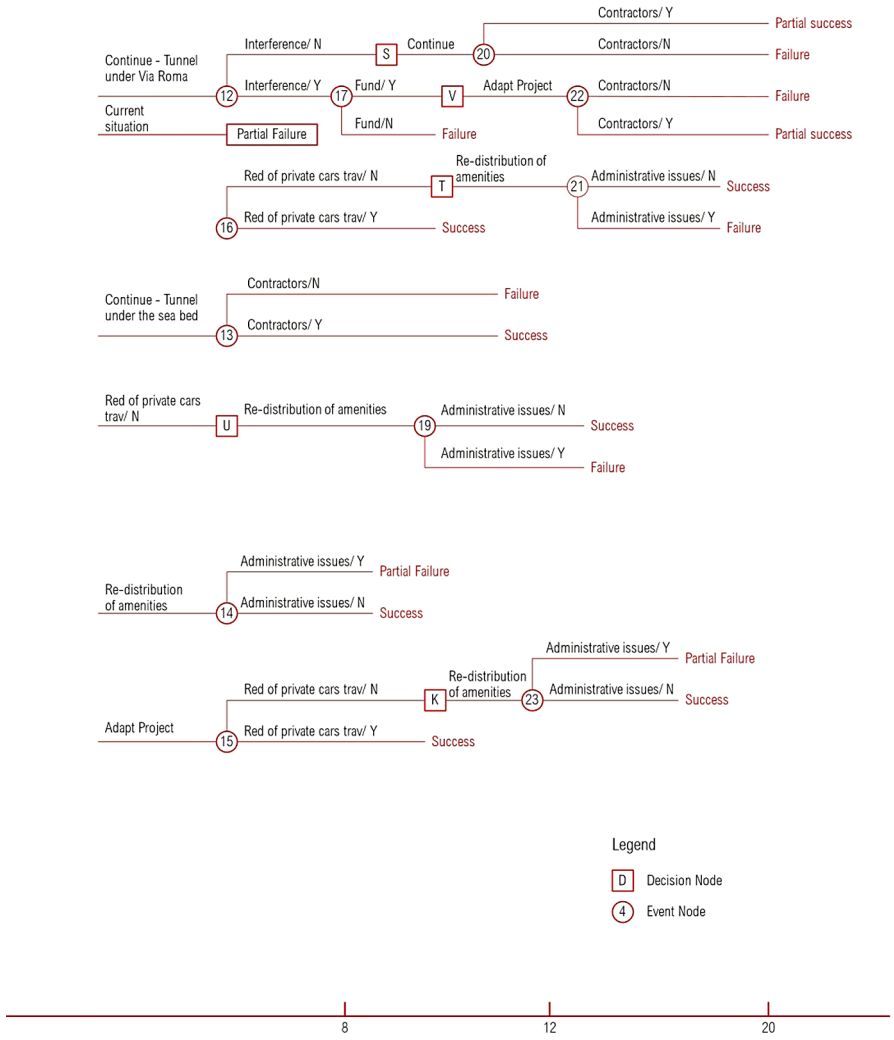

Fig. 3b. Construction of the Decision Tree Model for structuring the decision problem related to the regeneration of Roma Main Street. Second part, probable circumstances and relevant decisions after year 6.

the administrative process, and the duration of the process, increased by the involvement of several agencies, the probability of social protest, determined by the concentration of high financial resources on a single intervention, thus engendering conditions of inequality, and the probability of interferences of the construction site with archaeological remains and with the drainage basin. More precisely, a significant circumstance is represented by the event node consensus; consensus refers to the probability that radical infrastructural interventions in a vulnerable environment meets with the opposition of groups of residents and users directly involved in the transformation of a space.

The second aspect concerns the dependence of the increase in quality of life, engendered by the mild-infrastructural intervention strategy, on the actual reduction of traffic levels along the primary streets crossing the historic centre. Therefore, a policy of redistribution of amenities actually concentrated in the central districts of the Cagliari urban area is recognized as a strategy instrumental to engender equal access conditions to primary and secondary uses across the metropolitan area, and to reduce commuting, which affect levels of traffic along the system of urban arterial and primary streets and along "via Roma", particularly.

The third aspect concerns the marginal utility of a conservative strategy, based on the management of the current situation, via regulation and interventions on the compositional aspect of the road space.

This strategy, if not sustained by the re-configuration of the system of arterial roads, by the re-design of central intersections ("Piazza Giacomo Matteotti" [Giacomo Matteotti square] and "Piazza Darsena" [Darsena square]), and by the re-design of pedestrian spaces could not impact significantly on the conditions of mobility and the usability of the road space, thus determining a marginal increase in quality of life.

6 Discussions and Conclusions

Decision Trees suggest a new way to think about urban smart governance tool and represent a promising support system for administrative decisions in the urban field. More precisely, the relevance of the decision tree model is twofold: on the one hand it offers a rationale for decision making, by providing a conceptual framework for identifying and explicating the multiple phases, circumstances and decisions comprising the planning process. On the other hand, the decision-tree model is a tool for increasing the accessibility and understandability of information related to decision making processes affecting place-shaping mechanisms. They allow to observe how the preliminary knowledge of random events and uncertainties is necessary to implement smart place-based policies in an urban planning project. The relationship between smart governance and decision tree was first presented theoretically and subsequently discussed through the case study of the city of Cagliari.

In this paper a decision tree was built to represent the main decisions and the most relevant sources of uncertainty for evaluating several possible policies on the regeneration of "via Roma". The possible criterion could be the quality of life of the residents, of people who come from other parts of Sardinia and tourists. In fact, "via Roma" is a central node that connects the historic city to the waterfront, where the most important railway hub in Sardinia and the largest cruise terminal on the entire island are located.

In addition to the project itself, the theoretical process has allowed to understand how this decision-making tool can help evaluate the two most critical components of a policy based on smart governance (transparency and conflict) from the beginning of the project. In fact, as analysed in Sect. 2, transparency and conflict are increasingly critical issues between political choice in the urban planning field.

The (political and administrative) criterion of choice looks often unclear and undefined at the beginning of public works, and, particularly in Italy, the project is often modified or blocked upon the change of political mandate. The characteristics of the

tree's construction, given a criterion (improving the quality of life), allow to determine an optimal solution from the city's viewpoint, while accounting for several sources of uncertainty (e.g., urban changes).

This, in the first instance, allows to make two distinct considerations on the use of the decision tree to define optimal political choices in the urban field:

1. The constructive logic of the decision tree favours the transparency of the administration through a synthetic representation of i) the political choice; ii) the goal intended to achieve; and especially iii) the interplay between decisions and uncertain situations. This allows to constantly monitor the works that are realised, as well as it is possible to monitor actions in progress or to ascertain renunciations in progress by the administration. Namely, if events external to the project modify the intervention (e.g., example the change of administration), through the decision tree the population can understand not only the logic used for the modification or interruption of the project, but also the criteria of the new administration and its choices.
2. The decision tree allows administrations to follow the logic of improving the quality of life of citizens, through a project management that allows to monitor and modify the process at every stage. In addition, at the time of the decision, the trees allow to measure variables and uncertainties to identify the optimal process that leads to the defined goal, even if this is a long process, such as urbanization works.

These two characteristics of the decision tree show that it can make possible a better planning. This is not only because it allows, a priori, to understand which is the best solution for a given context w.r.t. the objective to be pursued, but also because, once the work has begun, it can evaluate any changes to the project by expecting in advance what events may occur. The latter is fundamental in the field of urban governance. In fact, the interventions in the urban planning field, at the starting point, have a high rate of uncertainty that depends on different (physical, economic, administrative and social) dynamics, which make the entire project vary during construction. Generally speaking, it is essential for good planning to have a method determining the best decisions right from the start and understand what must be done when changes to the initial project occur.

Furthermore, these analyses highlight the importance of using the decision tree in a smart governance perspective that focuses on dual use of technology/social aspect, for two reasons:

1) the digital data produced in the last 20 years based on static and dynamic indicators provided in real time, make possible to automate these models, turning them into urban e-governance tools through, for example, city dashboards;
2) the use of the decision tree offers the population greater involvement by allowing not only the dissemination of information relating to the results of the decision-making process, but above all access to information relating to the structure of the process, its criteria and purposes.

However, some weaknesses in the use of the decision tree in urban planning need to be investigated. In fact, an extension of the method to a larger area than the single project

(e.g., insertion of the subway in "Via Roma") could complicate the tree design process. Furthermore, planning requires a multidisciplinarity that would make the predictions of variables and uncertainties extremely challenging at the moment of the decision, while compromising the choice of the optimal process. Another critical point in the use of this methodology could be the risk of using a synthetic support system for urban planning that could not allow a total visualization of the process phases and may be affected by the specific choices on the distributions of probability.

Despite this, the decision tree still appears to be an excellent planning support system and, for further research, this study makes possible to have a methodological approach as a starting point for developing a set of indicators that identify a common criterion for a decision tree for urban policies in a smart governance context. With this in mind, future research will go in three different but complementary directions: (i) the theoretical approach proposed will be implemented with indicators and probability values that will objectively define the decision-making process; (ii) the proposed methodological approach could also be tested in other contexts to underline the potential that the decision tree has for making decisions in the urban field; (ii) the study will focus on the impact that the decision can have on the spatial dimension, and (iii) the authors will analyse how public administrations can include such decision-making tools in their daily practice.

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