Aalborg University

Diploma Thesis

An interdisciplinary study of transport mode choice

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Preface

The current project studies transport mode choice using a multidisciplinary approach by combining a theory from social psychology (Theory of Material Possession) and a theory from urban planning (Urban structure and transport interaction). Fuzzy set theory and more specifically, fuzzy set qualitative analysis, is used as the analytical method of the project.

The sample consists of commuting students and academic staff in, mainly, four universities of Athens. The analysis was split into two main themes. The first studied transport mode choice through the agent while the second through urban structure. For the latter, the analysis was further split into two groups: the effects of residential location and the effects of workplace location. Throughout the analysis students and workers formed two separate groups.

The results indicate that there is a strong relation between instrumental reasoning and transport mode choice. From the perspective of urban structure, it was found that it has a strong influence on almost all modes of transport. Several typologies of urban structure were identifies which contribute to the use of different modes. These are often mutually exclusive. For instance car use is cause by not low density, medium distances to centre and long distances to rail while public transport use by high density, medium distance to the centre and not long distance to rail.

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Chapter 1

Introduction

1.1 Aims

The present thesis is situated within the field of urban planning and management. More specifically, it focuses on matters of travel behaviour when commuting in the urban environment. It's aim is to re-examine the relation between urban structure and travel behaviour, and more specifically transport mode choice, by taking into account factors from other disciplines that may affect the latter.

1.2 Why understanding transport mode choice is important?

People have to move if they want to get together and fulfil basic societal roles. Movement, as all other physical activities, has a clear spatial dimension. In a city, people need space to move as they need space to work and sleep. Thus an instinctive question for an urban planner would be: how much space do people need to move about? However, the answer is tricky as in our times there are several different transport mode options which have different requirements for space, both *quantitative* and *qualitative*. For instance, a quantitative difference would be the width of the lane used to accommodate cyclists and drivers. It is clear that the latter require a wider lane than the first. From a qualitative perspective, the rail road is different from the pedestrian street. From a traditional (positivist?) transport planning perspective the above question was transformed to "how much demand each mode of transport will have in the future?" and the guiding principle then was the famous "predict and provide". Planners would try (most of the times unsuccessfully) to predict the future demand for each mode and plan accordingly to satisfy that demand.

From a more critical perspective, it is fundamental for the critical planner to understand the workings of travel mode choice if she hopes to alter

it. At this point let us see why someone would like to influence travel mode choice. One of the most prominent reasons is energy consumption and emission. The transport sector is responsible for 32.6% of the total energy consumption in European Union. Moreover, in the field of Green House Gas emissions (GHG), road transportation is responsible for 70.9% of the total GHG by the transport sector DGET (2009). In the urban context, where the present thesis aims for, transport is responsible for 40% of the total CO2 emissions and for 70% of other emissions produced in the city. This is a major drawback for meeting the mitigation goals in order to achieve sustainable development.

In addition, modes also take up urban space both because they need to move and to park. This is crucial because economic-wise this space could be used for a different purpose and environmental-wise, because this space is taken from the natural environment. In extreme cases, such as Los Angeles, the road infrastructure takes up 35% of the total built up area of the city. Moreover, phenomenons such as traffic jams and urban heat island effect appear because of high use of a particular mode of transport–the automobile.

Moreover, certain transport modes are more prone to causing injuries than others. For instance, a collision between a car and a cyclist is more likely to seriously injure the person driving the bicycle, than a collision between two cyclists. What is more, it is more likely to have a high number of accidents when people use personal transport modes, where the sheer number of them increases the probabilities of a collision compared to when people use public transport.

1.3 How is transport mode choice conceptualized

By referring to *travel behaviour* we mean the behaviour of humans concerning travelling decisions. Traditionally, in transport planning, travel behaviour was broken down into four parts in a model known as *"Four-Step model"* Ortuzar and Willumsen (2006). The first part of the model, trip generation, is concerned with the number of trips that will be undertaken. This means how many trips will be conducted by a person or the inhabitants of a traffic analysis zone (TAZ) within a given time period (usually a day). The second part, trip distribution, is concerned with the final destination of the trips undertaken. The third part, mode choice, is concerned with the choice of the transport mode in a given trip. Finally, the fourth part, route choice, is concerned with the detailed route that will be chosen to conduct the given trip with the given mode. All in all, the model focuses on each particular trip that will be generated and tries to predict each attributes.

A more recent approach to travel behaviour conceptualization is the *Activity Based Approach* (McNally, 2000 in Hensher and Button, 2000:53). Under ABA, the focus point is the activities of humans, rather than the

more vague concept of "trip". Consequently, travel behaviour is split and studied separately for different activities such as, travelling to work, for shopping, for entertainment etc. Under this light, by commuting, we refer to those trips made to and from work and education. They differ from other trips because they tend to be more frequent (almost daily) and compulsory (bounded). Although this approach (ABA) is different compared to the *Four-Step Model*, travel mode choice is still a central question and study objective.

By placing travel mode choice as a central object of research, researchers abstract from the more concrete object of travel behaviour. Abstraction is particularly important, because according to Danermark et al. (2002) it is a great tool for gaining knowledge about the generative powers and mechanism of the phenomenon. However, what we know is greatly affected by what theories we use to produce this knowledge. Consequently, different disciplines posess different knowledge about travel mode choice, as they use different theoretical frameworks to grasp hold of it. In the following paragraphs three main approaches will be presented that I will use to build my research upon.

1.3.1 Rational Choice Theory

Rational Choice Theory (RCT), according to Archer and Tritter (2000):1 , is considered by some to be the "grand theory of modernity". According to Zafirovski (1999) its main principles are:

- The concept of Purposive Action
- The concept of (utilitarian-economic) Rationality
- The concept of Market Equilibrium
- The concept of Methodological Individualism
- The concept of Stable Preferences

By the concept of Purposive Action, RCT

> rejects the concept of social action as expressive, non-rational or irrational, or as caused by external factors with no teleological intermediation of intention or purpose
>
> Coleman (1989:5-9) in Zafirovski (1999)

The concept of (utilitarian-economic) rationality postulates that social action is guided by the intention of the individual to maximize his or her utility Zafirovski (1999). Utility is a term coming from neoclassical economy which quantifies the pleasure gained by an individual when consuming

a certain commodity. The concept of Market Equilibrium postulates that all social relations can be seen as the relations of commodities in a marketplace. Under this principle, in each market (such as marriage, political, religious etc) there is a supply and a demand, constructing prices for these "social commodities" and tending towards an equilibrium (Becker, 1976:3 in Zafirovski, 1999). The concept of Methodological Individualism postulates that, because social structures derive from individual action, they are weak in determining the individual action in an individual level. Finally, the concept of Stable Preferences assumes that individuals have stable preferences over time (Becker, 1991:ix-x in Zafirovski, 1999) and that these preferences determine (and can be used to understand) social action (Opp, 1989:6-7 in Zafirovski, 1999).

RCT has been extensively used by transport planners in order to conceptualize travel behaviour in general and travel mode choice in particular (Jara-Díaz, 2007:7, Ortuzar and Willumsen, 2006:223). According to it, every person tries to find a balance between leisure and work. More work time means higher wages which is translated to higher consumption capabilities which are related to leisure. However, more work time also means less time to enjoy the "fruits" of one's labour. In this equation travel time enters as time lost either from work or from leisure. The key is to find a balance between travel monetary costs and travel time costs. Practically, it means how much is someone willing to pay in order to work more (and thus increase his income) or rest and thus increase his leisure time. This is why travel in itself is always depicted as costly, as none really wants to travel for the sake of it (everybody would choose not to travel if they could). Furthermore it is vital that every element which counts as cost is entered into the equation as monetary or time cost Train and McFadden (1978). However, as will be presented below, RCT is challenged and therefore, so does its strength to explain travel mode choice.

1.3.2 Theory of Material Possession

Another school of thought emerges from researches who criticize the construct of rationality as defined in RCT, as being too reductionist. Critique is aimed at the use of the model of the "economic man" as the centre of a rational actor while turning a blind eye to his "social" as well as the "emotional" counterparts. For instance, Williams (Williams, 2000) argues that rationality often neglects the role of habit, emotion, moral and ethical values in its attempt to understand behaviour. He claims along with a long line of thinkers that emotions are the driving force behind rational actions. Emotions act like a catalyst, which accelerates the decision making process by filtering out certain alternatives, before handing over the reigns to instrumental rationality for the final decision to be made. Archer and Tritter (2000):48 claims that there are aspects of human behaviour, like attending

university at an old age, which do not cope well with aspects of the rational, utility-maximizer, "economic man". However, there are still mature students going against this stream of negative consequences.

Another line of criticism focuses on CRT's methodological individualism. By ruling out the effects of structure on agents RCT fails to acknowledge the link between behaviour according to one's budget and the social aspect of the later . Methodological individualism due to its nature, does not allow for a formation of social movements which in turn could transform society and "alter the structural principles of budgetary allocation". (Archer and Tritter, 2000):51. However as Archer claims, the behaviour of "man" could not be reduced to structural elements either. The over-socialized man, or "homo sociologicus", who sticks to social roles and plays them to the letter faces a new set of problems. For instance, the role of "mother" does not manifest in the same manner to all mothers. Moreover, as Archer claims, humans often go beyond their expected roles and the norms which surround them. This is obvious, because if it was the case there would be no need for penal law because everyone would behave accordingly to the norms and laws of society.

Finally, what is proposed is a behavioural model which acknowledges both structure and agency as well as "reason", "norms" and "emotions". One such, is the model for material possession developed by Dittmar (1992) (in Steg et al., 2001). Although transport mode choice is not a good in a strict sense, it can be viewed as purchasing a service, which is consumed on the spot Ortuzar and Willumsen, 2006:5. This allows transport mode choice to be viewed as a special kind of possession, which is bought (or chosen) and consumed, by realizing the travel which is intended. So, according to theory of material possession, the use of each possession is based on three motives: instrumental, symbolic and affective. Instrumental motives are the ones linked with the traditional concept of rationality and deal with speed, flexibility and safety. Symbolic motives refer to the use of the possession as a symbol to indicate a particular social status or lifestyle. Affective motives are linked with emotions evoked by the use of the possession, such as joy or thrill.

1.3.3 Urban Structure

A different school of research on transport mode choice, that of urban structure and transport interaction takes a more balanced approach between structure and agency. According to it, travel mode choice is affected by urban structure. Urban structure, according to Naess (2006), consists of:

- the geographical distribution and fabric of the building stock (the pattern of development);

- the mutual location of different functions (residences, workplaces, public institutions and service) within the building stock (the pattern of location);
- the transport system (road network, public transport provision, and parking conditions);
- water, sewage and energy supply and telecommunication systems;
- the urban green and blue structures (more or less natural areas within and close to the city, and lakes, rivers and creeks).

Research so far has wielded substantial results, with the work of Newman and Kenworthy (1989) considered by many, one of the most influential works on the field. More specifically, in a recent meta-study Ewing & Cervero Ewing and Cervero (2010), examine the relevant literature for influential factors. Vehicles Miles Travelled (VMT), which is a car use indicator, seem to be affected by destination accessibility, distance to down-town, design characteristics residential and job density and diversity of land uses in the neighbourhood. Walking is mainly influenced intersection density, jobs-housing balance and distance to stores as well as the distance to transit stops. Transit ridership is mainly influenced by proximity to transit stops, intersection density, street connectivity and mix of land uses.

In a similar meta-study in a nordic context, Næss (forthcoming in: Naess, 2012) finds that it is usually higher-level urban structure variables which influence travel behaviour. The most important are residential location relative to the city centre, overall city density and location of jobs.

In another meta-study, Banister (2005) also finds evidence for the relationship between urban structure and transport. As far as city size is concerned Banister finds conflicting evidence coming from Britain and the USA. Whilst in the former large city size is linked with low travel time and energy consumption, in the latter is linked with high travel distance, high car use and energy consumption. Residential density, another urban structure attribute, is linked with travel mode choice, travel distance and travel time. More specifically as density rises, travel time and distance drop, while mode choice becomes more sustainable (a turn to bus, metro, walking and cycling). The location of land uses also has an impact on travel behaviour. Centrally located new developments was reported to reduce car use while development outside of the city or on its edge favours car use. The proximity to transport infrastructure is another crucial factor. Generally the closer to a bus stop or a train station the higher the use of these modes instead of the car. Consequently, car use increases as the distance from the nearest bus stop increases.

Urban structure has an effect on travel behaviour because it alters the time-spatial geographical framework that human operate within. According to the much acclaimed time-geography of Hagerstrand (1970), people

activities have to satisfy certain constraints imposed to them; these are capability constraints, coupling constraints and authority constraints. The first category is concerned with constraints imposed by the biological needs and instrumental restriction. People have to eat and sleep as well as operate within the limits of the tools they possess, for instance use of certain transport modes. The second category, coupling constraints, refers to time- and location-specific activities because of the need to cooperate with others or use certain tools for production, consumption or transaction. For instance, commuting to work every day is part of coupling constraints because the individual has to interact with customers and partners (or even places, ie. a construction site) during a specific time and place as well as to make use of productive equipment, like the computer office. The third category, authority constraints, refer to constraints which are set by higher social powers and have to be followed. Authority constraints could be parking restrictions, the length of the working day, public transport schedules and traffic lights duration.

Under this light, by travelling people try to satisfy these constraints, while urban structure operates as a "middle-man", by hindering or aiding their satisfaction. For instance, people who live in a small city may satisfy coupling constraints (like commuting) easier, because the size of the city makes it possible to use a variety of transport modes (walking, cycling, car use) and thus they are not heavily influenced by capability constraints as one would if she live in a large city and did not own a car. Mode share is influenced to a large extend by the number of these constraints that are in operation. Waking up late and having to be at work in 15' while living in an area with small public transport provision and far from the workplace may lead more people into taking a taxi than a situation where one woke up at the appointed time and he had every mode of transport available because he is living in a relative central location with a bus and a train station nearby while his workplace is only 20' away on foot and the weather is nice.

1.4 Problem Formulation

As stated in the beginning, this thesis is situated in the field of urban planning. Hence, it is only logical to examine travel mode choice from an urban planner's perspective. Thus, the thesis will focus on the link between urban structure and travel mode choice. What is new, is the attempt of the thesis to solidify the claim that urban structure does indeed affect travel mode choice by taking into account the critique applied to Rational Choice Theory.

This is important because i would argue that research on the field so far makes extensive use of instrumental rationality, rather than a unified concept of rationality, either implicitly or explicitly. Thus if the fundamen-

tal concept of the decision-making model is challenged, so are the elements which affect it. For instance, to what extend has our previous "hero" who woke up on time and had all the transport mode in his disposal decided to use instrumental rationality? Did he take the car because that was the reasonable solution or because he wanted to highlight his status upon parking the car outside in front of the other employees? Disregarding mode choice based on mechanisms other than instrumental rationality poses a danger of attributing effects on urban structure which were silently produced by other mechanisms in the background. Similarly, the fact that a magnet levitates upon another magnet of equal magnetic charge does not mean that gravity is not working; it is the magnetic force which operates silently in the background. Identifying and understanding these background mechanisms is important for the urban planner in order to strengthen the role of urban structure as a policy lever to alter travel mode choice. The goal here is not to seek how norms or feelings could be altered by urban planners, but how they affect travel behaviour *in relation* to urban structure.

Under this light, the main research question of the thesis is:

> **What are the effects of the mechanisms of urban structure on travel mode choice for commuting, once the unified model of rationality is used?**

And it can be broken down to the following sub-questions:

- **To what extend do instrumental, symbolic and affective factors influence transport mode choice?**
- **How does residential location affect travel mode choice?**
- **How does workplace/education location affect travel mode choice?**

The sub-questions are analysed (Table 1.1) according to the information required to answer them, the theories that will be used to understand how data are linked to causal mechanisms and what type of empirical data contain the relevant information. Moreover a conceptual model is provided (Figure 1.1) that will be used to understand travel mode choice. According to it, travel mode choice is influenced both by agency and structure. Urban structure belongs to the structural sphere, while emotions, instrumental rationality and socio-demographic characteristics to agency. This does not imply that there are no structural elements affecting the emotional or instrumental part of the agent (after all, the theory of material possession comes from social psychology), but rather with which sphere are the elements of the study associated the most.

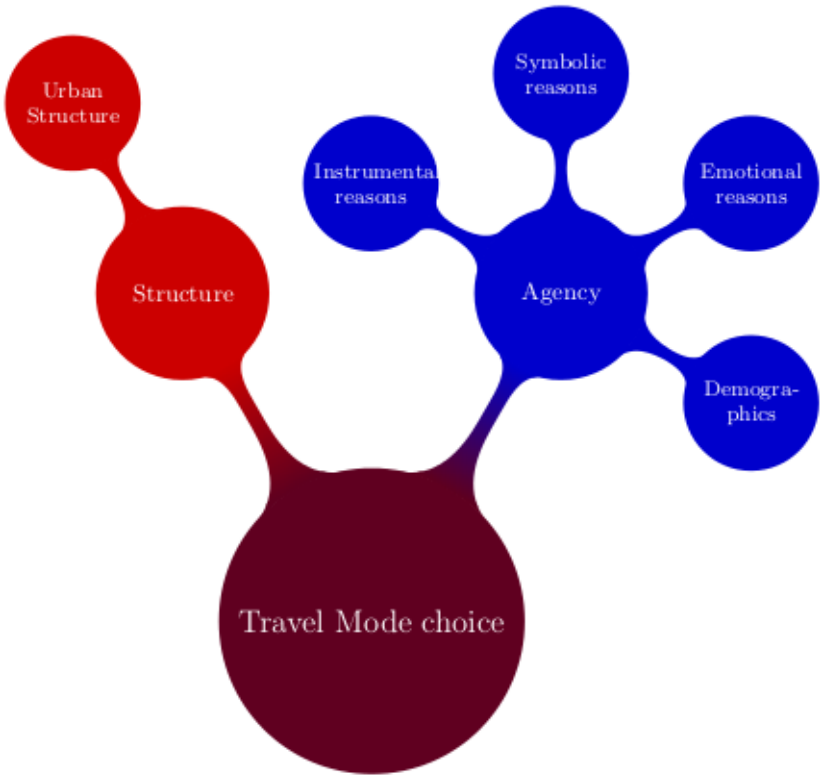

Figure 1.1: Conceptual model of travel mode choice

Research Questions	Information Needed	Theories Used	Empirical Data
To what extend do instrumental, symbolic and affective factors influence transport mode choice?	Preference of commuters	Theory of material possession	Travel Survey
How does residential location affect travel mode choice?	Mode used, distance from Workplace, Distance from city centre	Theory of time-geography, Theory of material possession	Travel survey, land-use map
How does workplace/education location affect travel mode choice?	Mode used, distance from residential locations, distance from city centre	Theory of time-geography, Theory of material possession	Travel survey, land-use map

Table 1.1: Analysis of the research questions

1.5 Project Structure

In the following chapter there will be a discussion concerning the methodology that will be followed in order to answer the questions set previously. In chapter 3, there is a presentation of the sample and some basic descriptives. Chapter 4 and 5 present the analysis of the sample. In chapter 4 the analysis focuses on the agent-based of factors which influence transport mode choice, while in chapter 5 the focus is on characteristics of residential and workplace location. Finally chapter 6 engages in a discussion about sustainable mobility.

Chapter 2

Methodology

2.1 Critical Realism

Throughout the introduction there were several implications to a specific philosophy of science, namely Critical Realism. In this section, Critical Realism will be presented and the problem will be framed further under the assumptions of this particular theory of science.

Firstly, under Critical Realism there are three dimensions of reality: the empirical, the actual and the real (Danermark et al., 2002:20). The empirical dimension consists of observed events, like an apple falling on the ground or in the case of this study the choice of a particular transport mode,recorded through a travel survey. In the actual dimension, there are also all the events that for one reason or another cannot be experienced directly, but happen nonetheless. The actual domain thus includes both the events observed by the researcher and all the events that are in principle observable but are not recorded so they can become empirical data in research. Or in other words: the empirical is a subset of the actual. In addition to the observed and unobserved elements of the actual, the third dimension, the real, includes the mechanisms which under their workings and interaction produce the effects which are manifested as events. The domain of the real thus includes unobservable causal power, but also the actual and the empirical, which are of course also parts of reality. The interaction of the mechanisms is done through their causal powers. The causal powers of the mechanisms can be either active, participating in the production of the event or inactive. So, the need for speed is a mechanism which is manifested, among others in the choice of the transport mode. Because mechanisms interact with each other they can "add up" or negate one another. For instance, if need for speed but also expressing an environmental identity is important the person might settle for a metro ride, rather than a driving or cycling for a long distance commute.

Another important aspect of Critical Realism is its view on the world

through strata, such as the physical, chemical, biological, psychological and social (Sayer, 1992:118). Of course the world exists as a concrete object, but for analytical purposes it can be abstracted in these strata. In each strata there are different mechanisms which create events. In addition, each strata produces or is produced by its adjacent by the way of emergence. Emergence is an ability of a strata to produce events on the lower strata which are more than the "add up" or negation of its mechanisms. The biological functions of living organisms cannot be explained by the chemical functions of its components. This is useful in our research because it allows for the emergence of psychological factors in the social strata and the study of behaviour and decisions in relation to the urban environment which is shaped by a social process in the sphere of planning institutions and organizations.

Another important concept is the division of systems under Critical Realism as closed or open (Danermark et al., 2002:66). Closed systems are those, whose parts can be isolated by any external factor in a laboratory experiment. On the contrary open systems consist of a multitude of factors which cannot be isolated, sometimes for practical reasons and other times for ethical. Cities are open systems whose operations do not differ only from city to city but from resident to resident. Thus, it is practically impossible to study a city in its entirety and therefore the researcher has to limit both his research variables and the generalization assumptions.

2.2 Quantity versus Quality

Qualitative versus quantitative data analysis has always been a heated discussion in social research. Quantitative methods allow scientists to study amounts and magnitudes and therefore are more suitable for answering questions like "how much" and "to what extend". Qualitative methods are concerned with description and categorization and therefore are more suitable for questions like "why" and "what".

For purposes of studying transport mode choice and urban structure using Theory of Rational Choice, quantitative methods were sufficient. This is because variables are quantifiable, such as distances, times and monetary costs. Even mode choice itself is quantifiable when used in the form of number of trips per transport mode. However, it is difficult to stay on the quantitative track if non-instrumental variables are entered. How can "excitement of ride" be measured in a consistent way for all people? And what would the scores of happiness mean in a constructed "index of happiness"?

On the other hand, pure qualitative results would be of little use to the urban planner, who deals with spatial attributes, such as distances and areas. If emotions and social norms cannot be quantified in some way in order to be included in quantitative analysis along with urban structure characteristics, the interaction between the two worlds cannot be observed. This problem

comes to solve fuzzy set-theoretic analysis, which will be presented below.

2.3 Fuzzy Sets Analysis

2.3.1 Introduction

Fuzzy logic is an alternative to binary logic, put forward by Zadeh (1965). Contrary to binary logic where objects either belong to a set or not, fuzzy logic allows objects to have degrees of membership in sets. For instance, a blue pair of jeans which has been washed several times is not "blue" or "white", but somewhere in between, say 60% blue and 40% white. In more technical terms, where binary logic talks about probabilities of an object being in a given set which range from one (always) to zero (never), fuzzy logic talks about degrees of membership of an object in a given set, from total inclusion (one) to total exclusion (zero).

In a more relative example, mode choice in the *Four-Step model* uses binary logic. Its output is the probability of an individual to choose from a variety of transport modes. Mode choice in a fuzzy set analysis would focus to the degree at which an individual belongs to the group of "car users", "public transport users", and so on. Note that, membership in one group does not exclude membership from other groups.

Set operations function different in fuzzy sets as well. The intersection between two sets (the logical *AND*) wields the minimum membership value of the two sets, whereas the union between two sets (the logical *OR*) wields the maximum membership value of the two. The negation (the logical) wields the same result with binary logic, that being the difference of the set membership from full membership (˜M=1-M).

In order for these operations to be understood, let's assume that there are two causal mechanisms which are likely to affect public transport use, namely close distance to rail station and high residential density. Let's also assume that a particular location has membership values 0.8 for the set "close distance to rail" and 0.5 for the set "high density". The membership value of the location in the set which is an intersection of the two sets (close distance to rail *AND* high density) is 0.5 . Because membership in both sets have to be satisfied, the membership of their intersection is the smallest value of the two. The location cannot belong in the new set more than its smallest membership in the sets which produce it. Likewise, a chain is as strong as its weakest link. On the other hand, membership in the union set (close distance to rail *AND* high density) is not concerned with the satisfaction of both memberships, hence the outcome is the larger of the two memberships (0.8). The location cannot belong less in the new set than its largest membership in the sets that constitute it. Likewise, a toolbox is as suitable for a job, as the most suitable tool for the job in the toolbox.

2.3.2 Set-based versus correlation-based thinking

In fuzzy set analysis the focus is given in forming set-based theories rather than correlation-based. According to Ragin (2008) when applying correlation-based analysis, in order to explain the relation between a causal mechanism and an outcome, researchers focus on the correlation between the two. If both the outcome and the causal mechanism are present, then the case supports the researcher's claim that there is a relation. So does the absence of both the causal mechanism and the outcome. However, the presence of either one coupled with the absence of the other, undermines the researcher's claim. This method of analysis is often called symmetric. A typical symmetric statement would be "As distance to the train station decreases, so does car use". This sentence has a two-way interpretation. It also implies that when distance from the train station is high, so is car use.

In set-based analysis this two-way interpretation is avoided. Research focuses on relation between sets and not correlation between them. The absence of the causal mechanism coupled with the presence of the outcome does not undermine the set relation. This relation between causal mechanisms and outcome is called asymmetric. For instance a set-based statement concerning distance and car use would be "when distance from the train station is long, car use is high". This statement does not imply that when the distance from the station is short, there may be other causal factors which produce high car use close to train stations that have not been taken into account.

On the contrary, absence of the outcome when the causal mechanism is present is considered problematic in correlation-based analysis. Because of the assumption of symmetric relationship between outcome and causal mechanism. Low car use far away from rail station would undermine the relationship between low car use close to rail stations (the correlation coefficient would be low). This problem is countered to a degree by the logistic or exponential transformation of the independent variable.

2.3.3 Sufficiency versus Necessity

Determining whether a particular causal mechanism is sufficient or necessary for a given outcome is very important as well. Of course, this has to be defined theoretically by the researcher but fuzzy set analysis can provide an insight if the results are consistent with the researcher's hypothesis. This is determined by comparing the degree of membership in the outcome with the degree of membership in the causal mechanisms for the cases in the sample.

To illustrate this, let us use the previous example. If the researcher claimed that long distance from the train station is in fact a sufficient but not necessary condition for high car use then the majority of cases should be having higher membership in the outcome (high car use) than the causal

mechanism (long distance from the train station). On the other hand, if the researcher claimed that owning a car is a necessary condition for high car use, then membership in the outcome (high car use) should be lower than membership in the causal condition (car ownership). Not all the car owners use their car for every trip, but in order to do so, one has to own a car.

However, one cannot infer that because a given sample has higher membership in an outcome than in a causal condition, this condition is necessary for the outcome. Arguments about necessity or sufficiency have to be based in theory and not in empiric results. That's where critical realism's concepts of formal and substantial relations (Danermark et al., 2002:46) become critical.

2.3.4 Consistency and coverage

Consistency and coverage are two central metrics in fuzzy set analysis (Ragin, 2008). Consistency deals with the degree that same causal mechanisms produce the same outcome in different cases, whereas coverage deals with the share of each causal mechanism in the outcome. In our previous example, consistency would determine the degree to which long distance from the train station does produce high car use (ie. 84% of cases with long distance from train station produce high car use), whereas coverage would assess the magnitude of this particular causal mechanism in explaining the overall high car use (ie. long distance from train station is responsible for the 34% of the cases of high car use). However, it should be highlighted that coverage is calculated only by those cases which are consistent with the outcome. The formulas for calculating the metrics are given below:

If causal mechanism is sufficient for the outcome:

1. Consistency=$(Xi \geq Yi) = \sum min(Xi, Yi) / \sum Xi$
2. Coverage=$(Xi \geq Yi) = \sum min(Xi, Yi) / \sum Yi$

If causal mechanism is necessary for the outcome:

1. Consistency=$(Xi \leq Yi) = \sum min(Xi, Yi) / \sum Yi$
2. Coverage=$(Xi \geq Yi) = \sum min(Xi, Yi) / \sum Xi$

Another function of coverage is that it can be partitioned to the components of its causal mechanisms. This means that the influence of each causal mechanism can be determined, much like the effect of each independent variable to the dependent in a multiple linear regression. In order for this to be possible, the coverage of each single causal mechanism has to be calculated along with the desired combination of the mechanisms. Once this is done, calculating individual coverage is achieved by just subtracting the unique coverage of each mechanism from the combined coverage of the mechanisms.

2.3.5 Calibration

Calibration (or fuzzification) is the transformation of ordinary interval data into fuzzy sets. By calibrating the dataset, the researcher assigns a membership value on each case for a given set. By calibrating, the researcher not only gives meaning to the data but inserts theoretical knowledge in the set (Ragin, 2008). For instance, the measurement of the distance from home to the closest train station does not contain any information whether this distance is "close" or "far". Likewise, different distances may have the same degree of membership in the set. The researcher has to set the limits for the degree of membership. The set has three important points. The threshold for full membership, the threshold for full non-membership and the point of maximum ambiguity. For instance, the researcher might set the threshold for full membership in the set "close to train station" at 300 meters and the threshold for full non-membership at 1500 members. Values below or above this level are considered to be fully in the set or not at all. The third limit defines the area where the researcher has the highest uncertainty whether a given value is more or less in or more or less out of the given set.

According to Ragin (2008), the calibration criteria "should be stated explicitly, and they also must be applied systematically and transparently". Thus, by calibrating the dataset, the theory-laddeness of knowledge becomes explicit and comes to the fore along with any claim concerning scientific objectivity.

2.3.6 Configurational Thinking

By configurational thinking, researches attempt to explain a given outcome by combining several causal mechanisms, which they believe are in operation. Configurational thinking is consistent with Critical Realism which states that events are produced by the combination of several causal mechanisms. In addition, because it is not compulsory for the causal mechanisms to operate constantly, certain events might have been produced by only a subset of those mechanisms. In configurational thinking, the power of certain causal mechanisms is tested in explaining certain events (outcomes).

Fuzzy sets analysis has an advantage in configurational thinking because it does not treat the effects of these causal mechanisms as independent, linear or additive. Thus, it cannot only indicate the strongest explanatory variable but also study "how different conditions combine and whether there is only one combination or several different combinations of conditions capable of generating the same outcome". This focus and sensitivity to combinations of causal mechanisms is very important for Critical Realism, because it allows causal mechanisms to produce emergent effects which would not have been spotted otherwise.

According to Ragin (2008), in order to compare several causal configu-

rations, the researcher has to:

1. Measure the degree of membership of the cases in each configuration. Each configuration has the form of Ri=min(C1, C2, C3, ..., Cn), where Ci is the number of causal mechanisms which participate in the given configuration.

2. Assess the consistency of each configuration as a subset of the outcome.

3. For those configuration which are consistent, calculate their coverage.

4. Compare the coverage values and pick the configuration with the highest.

2.4 The use of fuzzy set analysis in the project

Seen under the light of configurational thinking and the theories presented in the introduction, transport mode choice is an outcome of a combination of several causal mechanisms. These mechanisms are instrumental, symbolic and affective in nature and they may affect the outcome in more than one paths (configurations).

Both the outcome and the causal mechanisms are going to be fuzzified by the survey respondents. This means that the respondents themselves are going to state their degree of membership in the sets that will be constructed. This serves two purposes. First, it captures the respondents' perception and evaluation of their surroundings and themselves. This is important because decision making takes place inside the agent's mind, while he or she is affected by the surrounding structure. Secondly, as far as the outcome is concerned it taps on the whole knowledge of the respondent concerning his or her travel behaviour, rather than making assumptions about it using a travel diary. This is because certain behaviour might not be captured because is not manifested during the time period of the diary. These assumptions are necessary because of memory limitations and time restrictions from the user side. Neither it is possible to remember travel mode choice for a duration of say, more than 10 days, nor it is feasible to record travel behaviour for an extended period of time (at least within the limits of the thesis).

Because the thesis is focusing particularly on urban structure, the latter will be assessed by using external quantitative factors as well. This means that standard measurements like residential density and centrality as well as proximity to transport infrastructure will be carried out. These measurements will be calibrated using theoretical knowledge and will be inserted as another causal mechanisms in order to determine if they provide different results than the perceptions about urban structure have provided.

Check for multi-modality was left out due to the low percentage of the occurrence in Athens, being 1.7% for park & ride and 1.8% for kiss & ride AUTO (2007)

2.5 Measured variables

Transport mode use was measured in number of trips with a particular mode relative to the total number of trips per user. The time period that was covered was from the beginning of the semester. A discreet scale was used with a 10% step.

For the components of the Theory of Material Possession, instrumental characteristics of mode use were measured by four different variables, namely travel time, travel cost, ease of access and comfort. Symbolic factors were examined by three variables: expression of personality, expression of social status and expression of values and ideals. Finally, affective factors consisted of feelings of happiness, anger, fear an excitement caused by the use of a particular mode.

In order to study the effects of urban structure on travel mode choice the project used three variables: residential density, distance to the city centre and distance to the closest rail station. These variables were used both to determine the effects of residential location as well as the effects of work-place/university location on mode choice. Especially for public transport use the number of changes was also taken into account.

Finally, the main demographics variables which were used in the analysis were occupation (student/worker) and gender (male/female).

Chapter 3

Sample Description

3.1 General Demographics

The data used in this research were collected through an internet travel survey which was sent to all universities of Athens in order to be forwarded to their appropriate mailing lists and lasted from 26/11/2011 to 1/1/2012. It has to be clarified that the author was not notified whether the questionnaire was forwarded by the server administrators of each university. Nonetheless, 1024 respondents in total clicked on the web-link of the questionnaire. From those, 632 (62%) completed it fully, 146 (14%) partially and 243 (24%) discarded it. After inspecting the partially complete entries, 41 of them were accepted to be included in the sample because of the small and uncritical nature of their missing variables, bringing the sample size to 673.

As far as general demographics are concerned, the sample consists of 53% men and 47% women. The average age is 24.8 (sd=7.7). However, as it can be demonstrated better in figure 3.1 the survey was completed by ages up to 67. Consequently, the vast majority of the respondents were students (91%) of any level, 7% were research and teaching staff and 2% administrative staff.

The majority of the sample (74%) holds a driving license for a car while the rest 26% does not. On the contrary 16% of the sample holds a driving license for a motorbike while the 84% does not. Instead of transport mode ownership, respondents were asked to complete how often do they have the private transport modes (car, motorbike and bicycle) available, provided that they own a driving license for that mode. As far as car availability is concerned (figure 3.2) almost 35% of those who own a driving license have a car always at their disposal and only slightly more than 15% never have a car available (or own one). This means that the rest 50% has to share the car with other household members. Motorbike availability is slightly different (figure 3.3). Those who always have a motorbike at their disposal are a bit more than 40% while those who never do are slightly more than

35%. The rest 25% percent compete within the household for a share in the use of this mode. Finally bicycle availability in general is quite low (figure 3.4). Almost 65% of the respondents do not have access to a bicycle at all and only slightly more than 15% always do. Likewise the sharing of the mode within the household is quite low as well.

3.2 Transport mode use

Transport mode use is described by figure 3.5 and table 3.1. Table 3.1 shows the percentage of the membership of the respondents as users of each transport mode. Hence, for the car 9.81% of the respondents state that they belong fully in the car set, which means that they always use their car for commuting to the university. Respectively, 41.01% of the respondents have no membership in the "car users" set, meaning that they never use the car for this particular activity. Finally, the membership value of 0.5 indicates the highest degree of uncertainty as to whether a particular respondent belongs to the "car users" group or not. Figure 3.5 illustrates the same thing, only graphically. The pale yellow [1] colour indicates no membership, while the red [2] colour indicates full membership. The intermediate tones indicate various degrees of membership in a range from 0.1 to 0.9.

Based on the information portrayed on the above figure, it is concluded that the most popular modes for commuting are public transport and the car. This is because those modes have the most users with high membership values compared to the other four. Next come the motorbike and walking and last the bicycle and the taxi. The results of the survey are in line with those of O-D Household Travel Survey (AUTO, 2007). Although in the project's case the measured variable was the degree of membership in the set of each transport mode and in the case of AUTO (*ibid*) the measured variable was transport mode choice for each trip, the two results are similar. In the latter, the dominant modes are again public transport (34.2%) and the car (37.2%). Walking and the use of motorbike are really low (9.4% and 4.8% respectively), while taxi use and bicycle use are almost non-existent (1% and 2.3% respectively).

According to the same data source (AUTO, 2007), commuting to work constitutes the 21.2% of the total trips in Athens Metropolitan Area, whilst commuting to education only 3.5% [3]. The small percentage of education trips in the above survey, combined with the low response rate from non-students in the current survey, may not represent the whole population of Athens Metropolitan Area, but this was not the intention in the first place. As far as gender is concerned, women tend to travel more for educational

[1] white in the case of grayscale print
[2] black in the case of grayscale print
[3] the majority of trips (45.8%) represent "returning home" trips

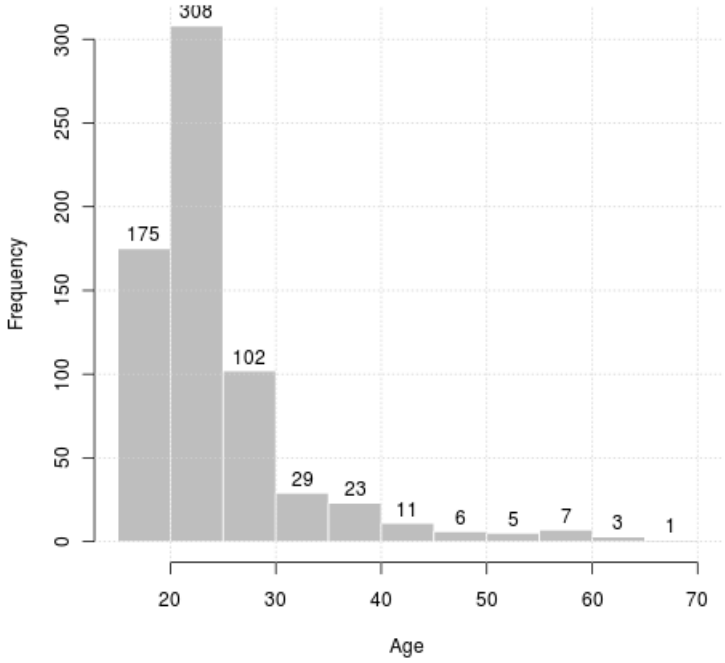

Figure 3.1: Age histogram of the sample.

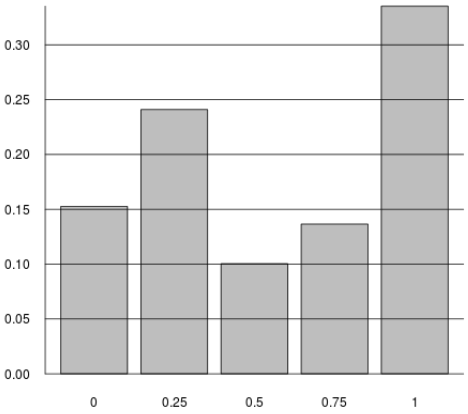

Figure 3.2: Membership of respondents with a car driving license in the "car always available" set.

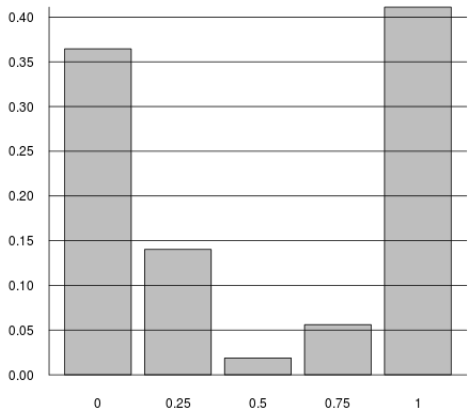

Figure 3.3: Membership of respondents with a motorbike driving license in the "motorbike always available" set.

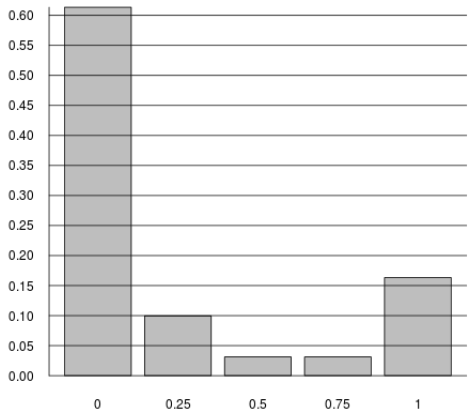

Figure 3.4: Membership of respondents in the "bicycle always available" set.

purposes than me (52.8% and 47.2% respectively), whilst the opposite holds for trips to workplaces where 54.8% of the trips are made by men and 45.4% by women.

	car	public transport	motorbike	bicycle	walking	taxi
0	41.01	20.51	89.75	92.42	78.45	81.43
0.1	20.06	12.63	2.82	3.42	6.69	15.60
0.2	6.39	3.86	0.45	0.89	3.27	1.93
0.3	3.42	2.38	0.45	0.45	1.78	0.45
0.4	1.49	3.27	0.45	0.59	1.63	0.00
0.5	2.23	3.86	0.74	0.30	1.63	0.30
0.6	1.04	4.90	0.15	0.30	0.59	0.15
0.7	2.08	7.58	0.89	0.15	0.45	0.00
0.8	5.35	10.10	1.04	0.45	1.19	0.15
0.9	7.13	17.68	2.23	0.89	1.19	0.00
1	9.81	13.22	1.04	0.15	3.12	0.00

Table 3.1: Membership of the sample as users of each transport mode.

3.2.1 Instrumental factors

In terms of travel speed (figure 3.6 the motorbike is the mode whose users think that it has the highest membership in the "fast" set. Almost 60% of them think that it has full membership while the rest think that it is more in that out as none has given it a membership value lower than 0.6. The motorbike is followed by the car, whose 20% of the users think that it has fully membership in the "fast" set and almost 90% percent thing that the mode belongs more in the "fast" set than out. Interestingly, the taxi has almost identical set membership with the car. It has to be noted that these three modes are both motorized and private. Because of this they can reach high travel speeds, travel directly from origin to destination with no stops or detours and are highly flexible because they can change routes to avoid traffic jams.

The rest three modes are the bicycle, walking and public transport. Public transport is thought to be the one with the least full membership in the "fast" set. Only 2% of its users think that it has full membership in the set. Almost 45% of its users think that it belongs more in than out in the set and 55% of its users think the opposite (more out than in). Walking is similar to public transport with the exception that it is the mode with the highest ambiguity concerning its "more in" or "more out" membership. Finally, the bicycle is thought to belong in the "fast" modes, with almost the 80% of its users thinking that it is "more in" than out in the set.

In terms of travel costs (figure 3.7), walking and cycling are considered to

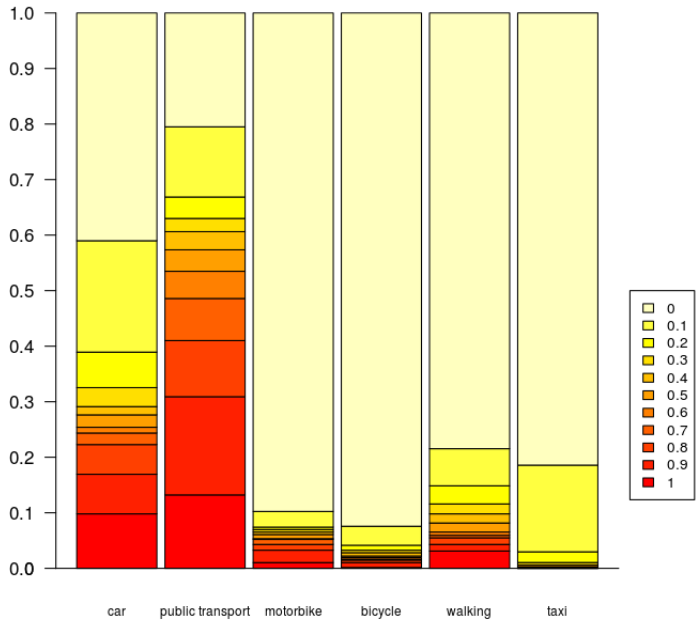

Figure 3.5: Membership of the sample as users of each transport mode.

be the most inexpensive. This is intuitive because they are the only modes which are human powered. Over 90% of the walkers think that walking fully belongs to the "no cost" set, whilst this view is held for the bicycle by over 60% of the cyclists. Motorbike follows next where 80% of its users think that it belongs more in the "no cost" set than it does not. However, only a small fraction (less than 10%) attributes full membership in the set. As far as the car and public transport are concerned, although they share the same really low percentage of full membership in the "no cost" set, the membership of public transport in the set is considered to be higher than the car's. More specifically, public transport is considered to be more in than out by the 65% of its users, whilst this value for the car is only 20%. This is expected, since the sample is mainly composed by students, whose financial capabilities may be limited and therefore public transport is favoured over the car. Finally the taxi is considered the most expensive mode with zero full membership in the "no cost" set. In fact, almost all taxi users think that the taxi belongs more out than in for the "no cost set". Almost 30% of its user find the cost "forbidding".

In terms of ease of access (figure 3.8), the motorbike is the mode which is considered to belong more in than out of the "ease of access" set. Almost 50% of motorbike users think that this mode belongs fully in the set. Second follow the car and the taxi. The same amount (over 80%) of their respective users think that these modes belong more in than out of the set, while at the

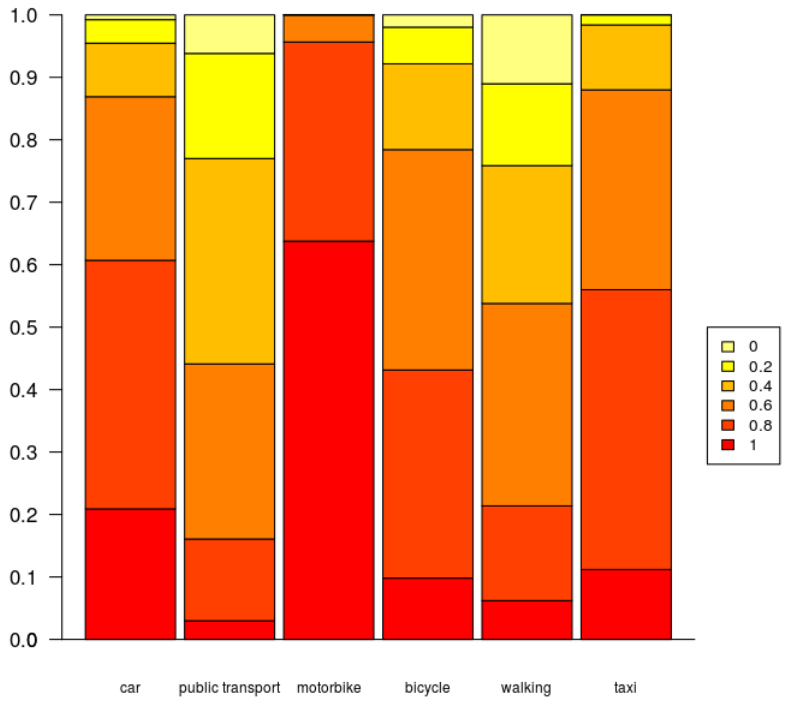

Figure 3.6: Frequency of membership of each transport mode in the set "fast".

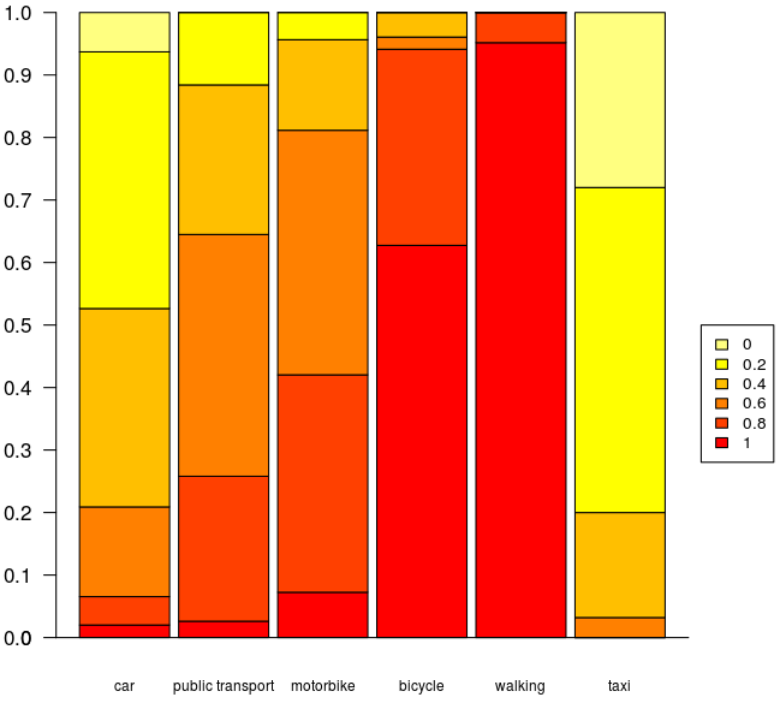

Figure 3.7: Frequency of membership of each transport mode in the set "no cost".

same time 35% of the car users attribute full membership, whereas 20% of taxi users think the same about taxi. Third comes walking, with 20% of the walkers thinking that it has full membership in the set (the same amount with taxi) but only 65% of the users think that walking belongs more in than out of the set. Next follows the bicycle with less full membership in the set (only 12% of its users think that) compared with walking, but with the same amount of users who think that the bicycle belong more in than out of the set (a bit less than 70%). Finally, with public transport, one has the lowest ease of access to the universities. Only less than 10% of its users think that public transport has full membership in the "easily accessible" set and only 60% think that public transport is more in than out of the set. Both values are the lowest compared to the other modes.

As far as physical and mental exhaustion are concerned (figure 3.9) the most comfortable modes are considered to be the car and the taxi. Both modes share almost identical membership values, with 40% of their users thinking that they belong fully in the "comfortable" set and 90% of the users thinking that they belong more in than out. Next follows the motorbike. Although it shares the same amount of users who think that it belongs more in than out of the "comfortable" set, the amount of users who think that it has full membership is slightly higher than 20%. Walking, cycling and public transport use follow with the same amount of users who think that they belong more in than out of the set (only 35%). However, in the case of cycling almost none thinks that cycling has full membership in the set "comfortable", while 2% does for public transport and almost 10% for walking. Interestingly, the amount of users who think that cycling has full non-membership in the set (5%) is lower than the amount of walkers (almost 20%) and public transport users (15%).

3.2.2 Symbolic factors

The three symbolic factors for transport mode choice were: "expression of important personality traits", "expression of social status" and "expression of personal values and ideals". It seems that for the first set (figure 3.10), "expression of important personality traits", the bicycle is the one which fulfils better that role. Almost 25% of its users attribute full membership of the mode in the set, while almost 80% of them think that by using the bicycle they symbolize important personality traits than not. Next follows the use of motorbike with 15% of its user stating that it belongs fully in the set and almost 50% of them that it is more in than out. Motorbike is followed closely by walking where although less amount of its users (10%) think that it belongs fully in the set, almost 65% state that it is more in than out. Car and public transport are almost identical. Although about 30% of their users state that they express personality traits more than they don't, only a small fraction (about 2%) states that these mode have full

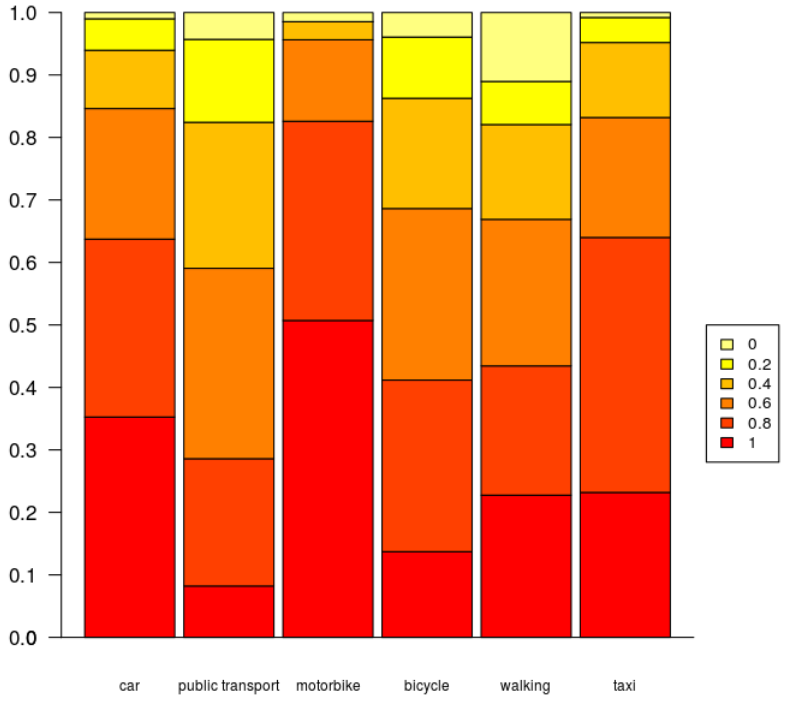

Figure 3.8: Frequency of membership of each transport mode in the set "ease of access".

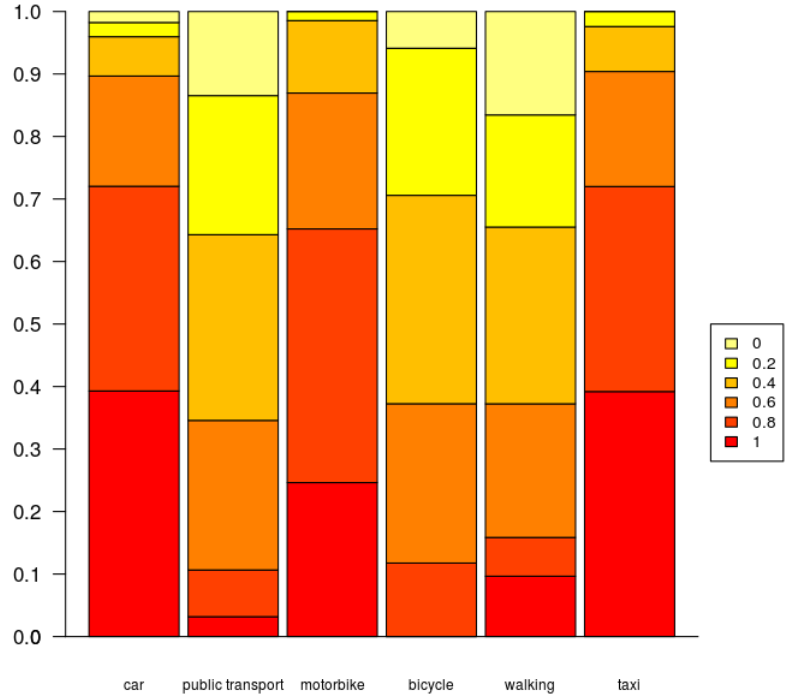

Figure 3.9: Frequency of membership of each transport mode in the set "comfortable".

membership in the set. Finally, the smallest membership values are for the taxi, where only 15% of the taxi users stated that it belongs more in the set than out and only 1% that it fully symbolizes important personality traits.

Almost a minority of users of all the transport modes believe that the use of a particular mode symbolizes the social status (figure 3.11). The vast majority of users think that their modes belong more out than in this symbolic set. The 35% of the cyclists and walkers think that the use of this mode symbolizes social status, while the rest modes fall beneath public transport where 25% of the people think that it has a membership value greater than 0.5.

The last symbolic set is that of personal values and ideals (figure 3.12. We see that cyclists believe strongly that bicycle use symbolizes this set. Almost 80% of the users think that the bicycle has a membership value in the set greater than 0.5, while 30% of them think that it has full membership. This is really high, if we consider the fact that almost 15% of car users, 20% of the taxi users and 35% of the public transport and motorbike users believe that their modes have a membership value greater than 0.5. Close to the bicycle comes walking with almost 60% of its users believing that it has a membership value greater than 0.5 and 20% believing that it has full membership.

3.2.3 Affective factors

The final group of causal mechanisms that took part in the survey are the affective factors. These are happiness, anger, fear and enjoyment which are caused by the use of each mode. According to the survey (figure 3.13), the happiest users are the cyclists, with 80% of them believing that cycling has a value membership greater than 0.5 in the "happiness" set. Moreover, over 20% of them believe that it has full membership. Second follows the motorbike with the same amount of users who attribute it full membership in the set but with lower amount of users who believe that it has a value membership greater than 0.5 (65%). It seems that using the car and walking are the modes with the highest uncertainty when it comes to happiness. Almost 50% of their users believe that these modes have membership value greater than 0.5. Finally, public transport and taxi use are rather unhappy modes, with only 15% of their users attributing to them a membership value greater than 0.5.

The anger set was inverted to the "not-anger" set (figure 3.14) in order to be directly comparable with the rest. High membership in the set encourages the use of the mode rather than discourages it. The name "not-anger" was preferred over a similar opposite adjective like "serenity" or "calmness" because it is precisely fear that is being measured and it is possible that use of those terms would have caused semantic and explanatory problems. According to the survey, the modes which are least associated with anger

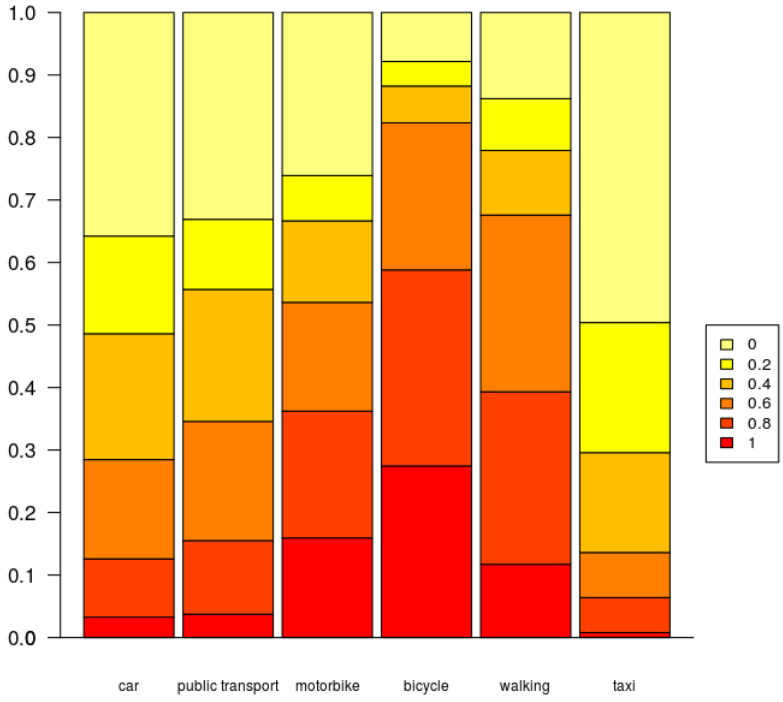

Figure 3.10: Frequency of membership of each transport mode in the set "expression of important personality traits".

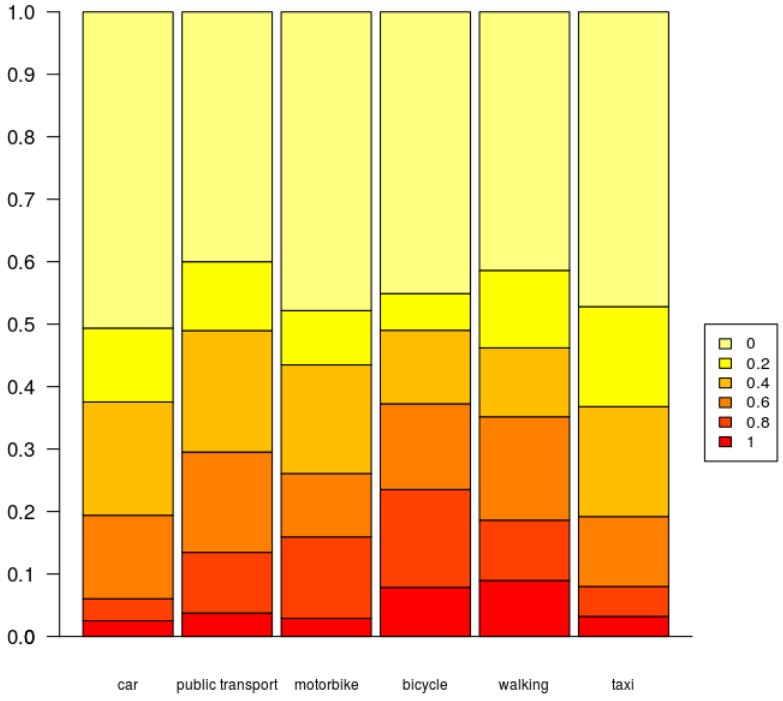

Figure 3.11: Frequency of membership of each transport mode in the set "expression of social status".

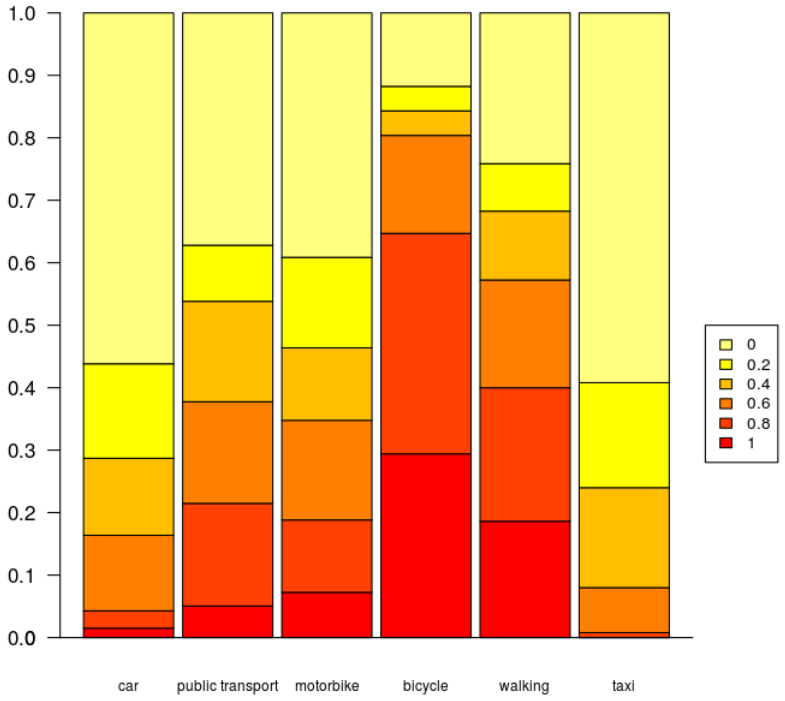

Figure 3.12: Frequency of membership of each transport mode in the set "expression of personal values and ideals".

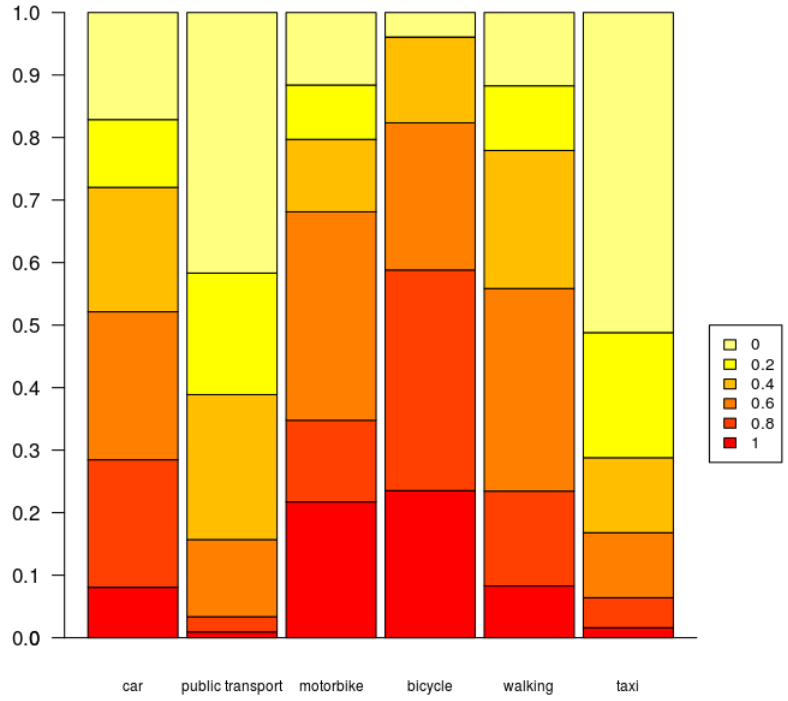

Figure 3.13: Frequency of membership of each transport mode in the set "happiness caused by use".

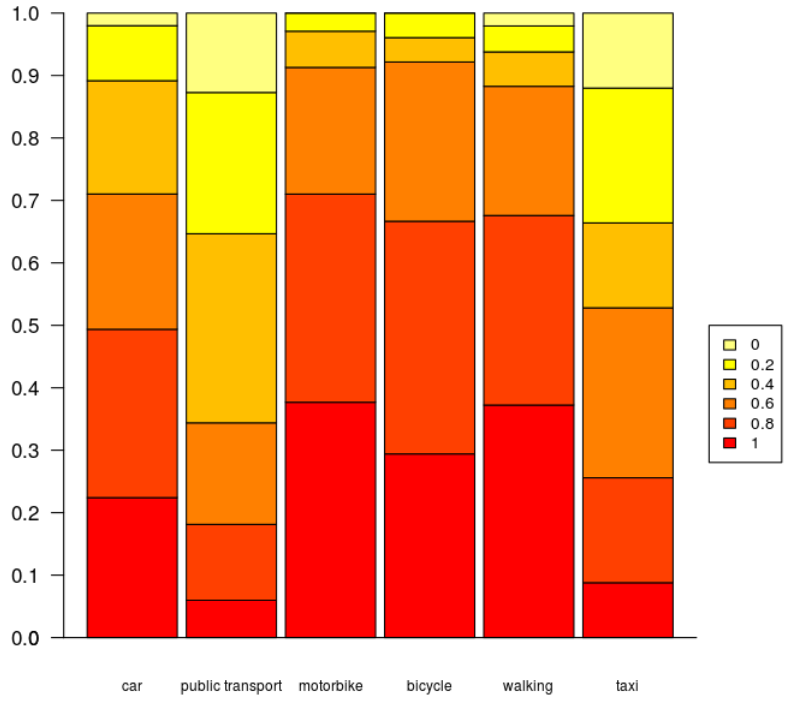

Figure 3.14: Frequency of membership of each transport mode in the set "not-anger caused by use".

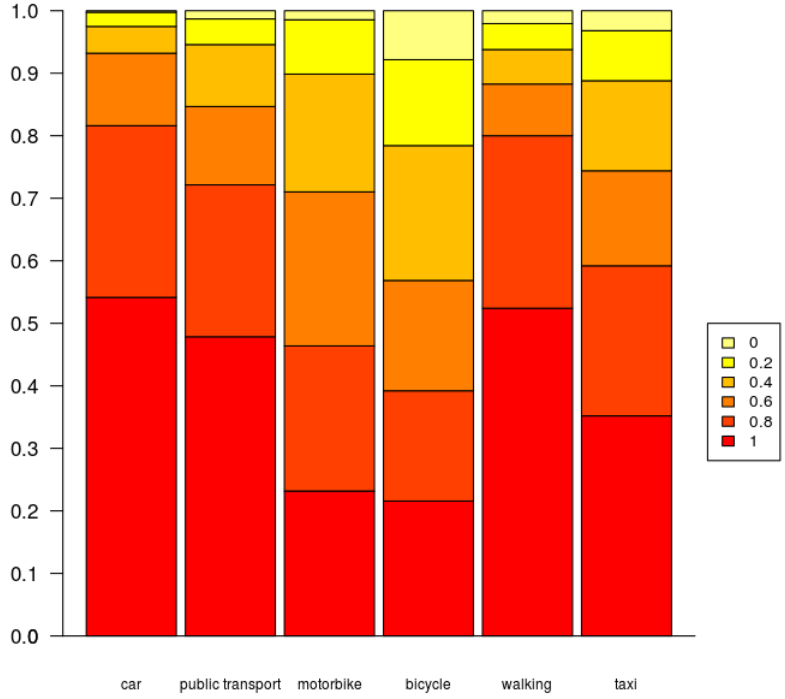

Figure 3.15: Frequency of membership of each transport mode in the set "not-fear caused by use".

are walking, cycling and the motorbike. Almost 90% of their users attribute them with a membership value greater than 0.5, while 35% of motor-bikers and walkers and 30% of the cyclists think that their modes have full membership in the set. Car users think that the car belongs more in the non-angry set than not. 30% of give to the car a membership value greater than 0.5 and almost 20% think that it completely belongs to the set. Taxi's membership in the set is most uncertain, because 50% of the users think that its membership value is greater than 0.5 and 50% that is lower. Finally, public transport has the most angry users. Only slightly more than 30% believe that its membership value is greater than 0.5 and only 5% give public transport full membership in the set. All in all the three most versatile modes evoke the least feelings of anger to their users. The users of those modes can bypass a traffic jam, insert roads closed to traffic and generally enjoy the fewest constraints in terms of their movement. However, versatility is not to be confused with travel time. On the other hand, public transport users are the most captive to the structure of the network. Buses have fixed routes and are frequently delayed by other road users (mainly car users) who do not respect the driving code. Moreover, the buses are often so crowded that arguments are caused amongst the passengers for a variety reasons (positioning, harassment, theft, personal hygiene etc).

The set fear was transformed to "not-fear" for the aforementioned purposes. According to the results of the survey for the set (figure 3.15). The mode with the highest membership in the set was the car. More than the 90% of its users have given it a value membership greater than 0.5 in the set with over 50% of them believing that it has full membership. The car is followed closely by public transport and walking. An interesting result is the membership of the taxi in the set. Although it has a high membership, with almost 75% of its users believing that it has a membership value greater than 0.5, the value is lower than the car's. This may seem a little bit odd, as car drivers are amateurs whilst taxi drivers are professionals. However, taxi drivers in Greece and especially in Athens are infamous for their driving behaviour (which is different to driving skill) which is aggressive most of the times thus causing the feelings of fear and discomfort to the passengers. Finally the last two modes, motorbike and bicycle have almost similar membership in the set. In both cases 20% of their users believe that they have full membership in the set. However more motorbike users (70%) than cyclists (50%) believe that the value membership of their mode is higher than 0.5. In addition, we have to note that the bicycle has the most uncertain membership in the set. This can be explained in terms of safety. Cyclists are the most vulnerable road users, followed by the motorbike users. Their small volume and high versatility makes them hard to spot by car and bus drivers. There is also a general feeling of neglect for these two users. Sometimes car and bus drivers forget that there are other road users besides themselves. This makes it really dangerous to ride a motorbike or

a bicycle in Athens. The difference in membership between the two modes is attributed to the fact that users of motorbike are more frequent on the streets and have learned to cope with the situation, whereas the bikers have made their appearance in the past decade.

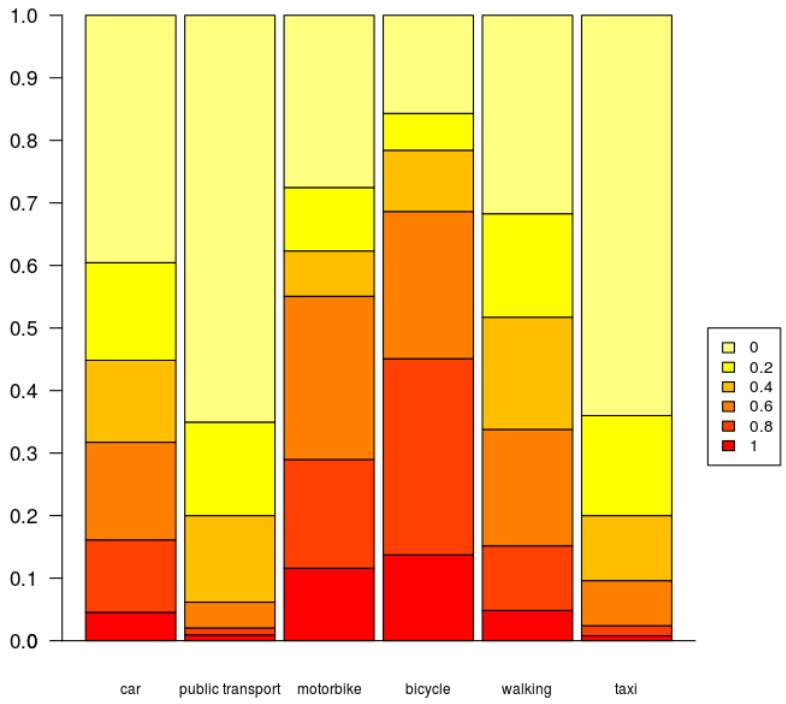

Figure 3.16: Frequency of membership of each transport mode in the set "excitement caused by use".

The final set of the affective factors is "excitement" which is described in figure 3.16. According to it, the most excitement is extracted by the use of the bicycle. Almost 70% of the cyclists think that the membership value of the bicycle in the set is greater than 0.5 and slightly more than 10% that it is 1 (full membership). The motorbike is the most uncertain mode in terms of excitement with 55% of its users believing that its membership value is greater than 0.5 and 45% that it is not. The rest modes are less exciting to use. It seems that the nadir of excitement is public transport followed by taxi use, where only 5% and 10% of their users respectively, think that they have a membership value greater than 0.5.

Chapter 4

Inside the agent's mind

In this chapter we will take a look into the agent's mind and analyse how he or she takes decisions for transport mode choice. Urban structure is going to be examined as it is being interpreted by the agent. Two main explanatory models will be used. The first one groups the causal mechanisms into the three causal sets, the instrumental, the symbolic and the affective. This way there are only seven possible combinations of the causal mechanisms: only instrumental, only symbolic, only affective, only instrumental and symbolic, only instrumental and affective, only symbolic and affective and finally all three combined. In the second model, each causal mechanism is examined separately from the others, thus wielding 2047 possible combinations.

4.1 The simple model

Although the first model is simpler in its conception it grands a broader view on how the mechanisms influence travel mode choice. The basic assumption for this model is that the agent acts by trying to satisfy all the factors within each set.

4.1.1 Public Transport use

For the simple model all the possible combinations of the three sets were consistent with the sample (Table 4.1). The overall explanatory power of the whole model is 49%. Seen in isolation, the strongest explanatory recipe is the set of instrumentals factors (39%), followed by the set of symbolic factors (26%). The other recipes although consistent, had a low coverage which indicated that the cases adhering to this particular combination were a minority of the overall sample.

In terms of unique coverage, the instrumental factors seem to have the largest explanatory power. More specifically, instrumental factors explain 19% of the total outcome, namely public transport use. If we consider the

fact that the total explanatory power of this model is 49%, we conclude that almost 40% of the total explained behaviour is due to instrumental factors only. In addition, symbolic reasons are a small fraction among students for high public transport use. The affective set has zero unique coverage which indicates that, when alone, it plays no part in determining users' behaviour.

The case of the rest causal recipes, where agents try to satisfy more than one set of causal factors is especially interesting. According to the analysis, 9% of the students who use public transport, do it for both instrumental and symbolic reasons, 4% for instrumental and affective, 2% for symbolic and affective and 7% for instrumental, symbolic and affective. The last recipe indicates that for the 7% of the students, public transport meets all their needs according to the theory of material possession.

According to this model, only 10% of its explanatory power does not include instrumental factors. For the rest 39% of the outcome, instrumental factors participate either alone or in combination with other factors. This clearly demonstrates the importance of instrumental factors for explaining transport mode choice among other causal mechanisms.

Recipes	Consistency	Coverage	Unique Coverage
I	0.88	0.39	0.19
S	0.86	0.26	0.08
A	0.90	0.13	0
I+S	0.91	0.16	0.09
I+A	0.92	0.11	0.04
S+A	0.94	0.08	0.02
I+S+A	0.94	0.07	0.07
		Total	0.49

Table 4.1: Output of the simple model for public transport use among students.

According to the model (Table 4.2), the single recipe that better describes workers' public transport ridership is the set of instrumental factors (54%). Both the sets of symbolic and affective factors are inconsistent with the outcome (consistency < 0.75). This means that public transport ridership cannot be explained by symbolic or affective factors alone.

If the consistent recipes are combined, the explanatory power of the model increases to 66% of the total outcome. Again, the sample is strongly influenced by instrumental factors, which have a unique coverage of 24%. This means that for one out of four workers who use public transport, satisfaction of instrumentals reasons is enough to exert use of the mode for commuting purposes. Additionally, satisfaction of all sets (instrumental, symbolic, affective) causes public transport ridership for the 15% of the workers' who are commuting by public transport.

The difference between the two groups (students and workers) is that workers tend to be more influenced by instrumental factors than students. For the workers group, instrumental factors are part of all the consistent recipes, and therefore take part in almost all explanatory capacity of the model (62%), which is also greater than the student's model (49%). However, in both groups, instrumentals factors dominate as causal mechanism which produce public transport ridership.

Recipes	Consistency	Coverage	Unique Coverage
I	0.78	0.54	0.24
I+S	0.86	0.23	0.08
I+A	0.77	0.22	0.07
S+A	0.77	0.18	0.04
I+S+A	0.81	0.14	0.15
		Total	0.58

Table 4.2: Output of the simple model for public transport use among workers.

4.1.2 Car use

The consistent recipes for car use in students were the instrumental reasons, the instrumentals and symbolic reasons, the instrumental and affective reasons and the instrumental, symbolic and affective reasons together (Table 4.3). The consistency for all the recipes was quiet low and the greatest coverage was for the group of instrumental reasons. The explanatory power of all the recipes combined is 48%. The unique coverage of each recipe reveals that the recipes with the strongest participation in the outcome are the instrumental factors (18%), the instrumental and affective factors (14%) and all the factors combined (14%).

The above illustrates the importance of the instrumentals factors for car use. More specifically, we observe that for the 18% of the users instrumentals reasons are enough to exert this kind of behaviour. Moreover, symbolic or affective reasons alone are not sufficient to cause car use. However, when combined together with instrumentals they cause an important part of the outcome. This is a clear demonstration of the emergent powers of causal mechanisms whose combination produces outcomes that them alone could not produce. We observe that for 14% of the users, car use is caused because the car satisfies both their instrumental and affective needs, whilst for another 14% high car use is caused because of all the conditions put forth by the Theory of Material Possession.

For the workers who show car use (Table 4.4), all the recipes are highly consistent. Instrumental factors are once again the recipe with the highest

Recipes	Consistency	Coverage	Unique Coverage
I	0.76	0.48	0.18
I+S	0.79	0.26	0.02
I+A	0.79	0.28	0.14
S+A	0.70	0.15	0.02
I+S+A	0.79	0.13	0.14
		Total	0.48

Table 4.3: Output of the simple model for car use among students.

explanatory power. In contrast with the students group, the consistency of the only symbolic and only affective recipes indicates that there are agents in this category that operate solely on symbolic and affective factors. A possible explanation would be that people in this group can afford to buy their own car which is the source of the symbolic and affective factors, while students use mostly the car of their parents or a budget car, which satisfies only instrumental needs.

The overall explanatory power of the model is 47% which indicates that only half of the outcome can be predicted by the model. Here, instrumentals factors absolutely dwarf the explanatory power of the other recipes. They explain more than half of the explained outcome, and more than one fourth of the total. However, there is still a small percentage of people for whom symbolic and affective factors are the cause of car use.

Recipes	Consistency	Coverage	Unique Coverage
I	0.89	0.40	0.27
S	0.89	0.13	0.02
A	0.94	0.16	0.03
I+S	0.93	0.09	0.02
I+A	0.97	0.11	0.04
S+A	1.00	0.08	0.02
I+S+A	1.00	0.07	0.07
		Total	0.47

Table 4.4: Output of the simple model for car use among workers.

4.1.3 Walking

For walking among students only four out of the seven recipes are consistent. Together, they explain 66% of the total outcome. The results show that purely symbolic or affective reasons (or their combination) are not sufficient for a person to walk for commuting purposes. On the other hand,

instrumental reasons alone cause 18% of the sample to engage in this activity. However, this doesn't mean that agents do not satisfy their symbolic or affective needs. Almost two thirds of the explanatory recipes are combinations of instrumentals factors with symbolic or affective or both.

Recipes	Consistency	Coverage	Unique Coverage
I	0.79	0.66	0.18
I+S	0.81	0.28	0.09
I+A	0.81	0.39	0.19
I+S+A	0.79	0.19	0.19
		Total	0.66

Table 4.5: Output of the simple model for bicycle use among students.

4.1.4 Bike use

In this category, the prominent recipe is once again the group of instrumental factors, although every recipe is consistent (Table 4.6). A combined model explains 79% of the total outcome. Here, although the unique coverage of instrumental factors is quiet important, both the recipe of instrumental and affective factors and the recipe of all the factors combined have a largest part in the explanation. This is in contrast with the previous modes, where instrumentals factors dominated the explanatory capabilities of the model. This indicates that use of the motorbike satisfies more than instrumentals factors. There is even a small portion of agents which uses the motorbike because of only symbolic or affective reasons.

Recipes	Consistency	Coverage	Unique Coverage
I	0.80	0.72	0.20
S	0.75	0.35	0.02
A	0.78	0.50	0.02
I+S	0.79	0.30	0.07
I+A	0.80	0.44	0.22
S+A	0.77	0.26	0.03
I+S+A	0.78	0.23	0.22
		Total	0.79

Table 4.6: Output of the simple model for motorbike use (drivers) among students.

4.1.5 Cycle use

Cycling is not consistent with any combination of the causal factors. However the recipe with the highest consistency (0.74 – only 0.01 below the threshold for acceptance) is the combination of all the three factors together and has a unique coverage of 36%. This allows us to state with caution that bicycle use tends to be affected by the satisfaction of all mechanisms.

4.2 The complex model

The second model reveals the plurality of human thought by taking into account all the possible combinations of the causal mechanisms and testing them against the sample. Therefore, as it will be shown below, the analysis will return a large number of consistent recipes. All of the recipes are ways that humans make decisions concerning transport mode choice. Others are more consistent and others cover a larger area of the sample. The drawback of this method is that because the number of the recipes is too large the unique coverage of each recipe is very small. In other words there is great overlap between the sets.

For this reason, in order to make the most out of this, the frequency of each factor in the final complex solution is going to be assessed. Obviously, when the factor has high frequency in the solution its presence is really important. On the contrary when the frequency of a factor in the final solution is low then its importance is low as well. Following the logic of fuzzy set, the presence of each factor can be transformed into a fuzzy set according to its frequency in the final solution.

4.2.1 Public Transport use

The analysis wielded 40 consistent recipes which explain 66% of the total outcome. Unique coverage scores were low, similar to car use. However, the consistency of the solution (0.82) is much higher than the one in car use (0.72). In this model, the factor with the highest frequency is "no-anger" feeling of the agents, which appears in 32 out of 40 recipes (80%). The second highest factor is easy access to the university with a percentage of 60%. The low cost of public transport ("no-cost") appears in 55% of the recipes while the expression of values and ideals appears in 50% of the recipes.

The low appearance of almost every factor (Table 4.7) in the final solution indicates that aside from not feeling angry there is no other definitive factor (at least among these eleven), which contributes to public transport use. As far as instrumental factors are concerned easy access and no-cost barely stand out as common factors in every recipe. The position of no-cost suggests that public transport may be overpriced when it comes to students.

Speed and comfort do not contribute to public transport use as they did in car use. It is true, that public transport speed is quiet low in Athens, with only three metro lines and with very low amount of lanes dedicated to buses and trams (more in the following chapter). When it comes to comfort, the low frequency of buses coupled with high demand create a situation which is most unfavourable for comfort.

The contribution of symbolic factors is low as well. The highest among them is the expression of values and ideals, which may suggest an expression of environmental awareness and concern which leads to public transport use. Similarly, affective factors other than not feeling angry are low as well. Especially positive the positive feelings such as happiness and excitement are almost non-existence. Even not feeling afraid does not contribute to public transport use greatly. This suggests that public transport use is at least connected with an uncertainty during commuting (not to say fear). Reasons for this uncertainty might be the way that public transport drivers behave and fear of possible harassment or theft.

Causal Factor	Frequency
Not feeling angry	0.8
Ease of access	0.6
No cost	0.55
Expression of values and ideals	0.5
Speed	0.43
Comfort	0.35
Expression of personality	0.35
Not feeling afraid	0.3
Expression of social status	0.25
Feeling happy	0.1
Feeling excited	0.03

frequency cut-off: 2, consistency cut-off: 0.85, solution coverage: 0.66 , solution consistency: 0.82

Table 4.7: Frequency of causal factors for public transport use among students.

For workers, the analysis wielded 15 consistent recipes for public transport use. Together they explain 70% of the total outcome. Unlike public transport use among students, there are several factors with strong presence for this group (Table 4.8) . The most prominent is ease of access, comfort, not feeling angry, speed and expression of personality. Although there is a significant difference between students and workers who use public transport, the factors which influence public transport among worker are the same with those which influence car use among workers. Namely, comfort and not feeling angry share the same appearance in the recipes, while ease

of access seems to be more important for public transport users than car users, whereas speed is more important for the later. Also, expression of personality and expression of values and ideals are stronger for workers who use public transport, while the influence of cost is the same.

Causal Factor	Frequency
Ease of access	1
Comfort	0.87
Not feeling angry	0.8
Speed	0.73
Expression of personality	0.73
No cost	0.53
Expression of values and ideals	0.53
Not feeling afraid	0.53
Feeling happy	0.47
Feeling excited	0.2
Expression of social status	0.13

frequency cut-off: 1, consistency cut-off: 0.80, solution coverage: 0.70, solution consistency: 0.78

Table 4.8: Frequency of causal factors for public transport use among workers.

4.2.2 Car use

According to the model, a summary of which is presented in Table 4.9 there are 10 recipes which are likely to cause car use. The final solution explains 54% of the total outcome. The raw coverage of each participating recipe is low as expected when there is a combination of 11 factors. According to the complex solution, speed and not being afraid to use the car are the most important factors. They participate in every recipe which forms the complex solution. Comfort and easy access to the university follow closely with a frequency value of 9 out of 10 recipes. Personality and the absence of anger to use the car appear in 50% of the recipes. Happiness follows with a 40% of appearance in the final solution, while no cost, status and enjoyment have appear in three out of ten recipes. Finally, the weakest factor seems to be the personal values and ideals, which appear only in two recipes.

From the above we can conclude that instrumental factors have a strong influence for car use among the students. In addition, the position of the cost of car use indicates that most students are aware of its negative impact on their behaviour. However, the fact that it is still present in the solution indicates that at least some students think that the car is an almost costless transport mode. This may be because there is a tendency (or tradition) in

greek families to cover the expenses of the car for their young members (and life in general). This is especially true when the young member is still living in the same household where a second car is usually a "common" mode for all the family.

The position of symbolic reasons indicates that it is more likely that they do not play an important part in car use. This may be because as explained above, the common family car cannot express the individual. It is intuitive, that at least for the majority of cases a common car satisfies more instrumental criteria such as low price, low fuel consumption, low taxation, practicality and so on. However, the position of "expression of personality" suggests that there is at least some identification with the car.

Finally, as far as affective criteria are concerned the strongest factor is not being afraid to use the car. Although it seems intuitive that someone who uses a particular mode is not afraid of it, evidence from the following analyses suggest otherwise. Fear of car use may be caused because of congestion and stressful driving conditions during the morning commute. However, it seems that students are unaffected by these conditions when it comes to being afraid. On the other hand, the same conditions may lead to anger which clearly affects car use among students. Its position demonstrates that not feeling angry is not a strong factor for car use. Finally, happiness and excitement during car use are relatively low. However, their presence indicates that they play a part in car use.

Causal Factor	Frequency
Speed	1
Not feeling afraid	1
Ease of access	0.9
Comfort	0.9
Not feeling angry	0.5
Expression of personality	0.5
Feeling happy	0.4
Expression of social status	0.3
No cost	0.3
Feeling excited	0.3
Expression of values and ideals	0.2

frequency cut-off: 2, consistency cut-off: 0.75, solution coverage: 0.54 , solution consistency: 0.72

Table 4.9: Frequency of causal factors for using the car among students.

As far as workers are concerned, there are 15 consistent recipes that explain car use. The combination of those explains 54% of the outcome and its consistency it 0.72. Workers express quiet identical reasons for car use than students (Table 4.10).

The three instrumental reasons for car use have high membership in this solution as well. However, their appearance is somewhat lower. An important difference is the fact that not feeling angry and not feeling afraid switch places. This may be caused because of the workers' higher overall experience in driving conditions during commuting. They are more likely to not feel angry because they are more familiar with unfavourable commuting conditions and not only expect them but filter them out. However, the position of "not feeling afraid" indicates that they are aware that mishaps are possible occur.

The fact that the appearance of symbolic criteria is identical to the student group and therefore quiet low. Since the economic criterion is gone, it is more likely that workers think that car use is less related to self-expression. Finally, feeling happy or excited have the same participation than the students' model.

Causal Factor	Frequency
Comfort	0.87
Not feeling angry	0.87
Speed	0.8
Ease of access	0.8
Not feeling afraid	0.53
Expression of personality	0.53
Feeling happy	0.5
No cost	0.5
Feeling excited	0.33
Expression of social status	0.27
Expression of values and ideals	0.27

frequency cut-off: 1, consistency cut-off: 0.82, solution coverage: 0.63, solution consistency: 0.82

Table 4.10: Frequency of causal factors for using the car among workers.

4.2.3 Walking

For students who walk to the university there were 18 consistent recipes, which when joined together explain 74% of the total outcome. As expected, the most prominent factor is the fact that walking is free of charge. Besides this, ease of access to the university is a very important factor for walking. In walking, ease of access represents mainly the distance from the residential place to the university. In the next chapter this distance will be examined more closely. Likewise, speed is likely to represent the distance as well. However, the difference between ease of access and speed suggests that agents will walk to the university anyway, if they are close, without

considering too much their actual speed (and hence travel time).

In addition, the symbolic factors are rather weak. It is clear that walking is not caused because it expresses the social status of the agent. However, the same cannot be said for the other two symbolic factors, expression of personality and expression of values and ideals with the same certainty. As far as the affective factors are concerned, not feeling afraid and angry seem to be contributing almost equally high to the outcome. Happiness has a moderate contribution to the outcome whilst the contribution of excitement is rather weak. The low contribution was expected because the surrounding environment in which walking to the university is at the most cases rather boring and dull. One has to really love walking in order to be excited with such conditions!

Causal Factor	Frequency
No cost	1
Ease of access	0.83
Not feeling afraid	0.83
Not feeling angry	0.72
Speed	0.61
Comfort	0.50
Expression of personality	0.44
Feeling happy	0.44
Expression of values and ideals	0.39
Feeling excited	0.22
Expression of social status	0.06

frequency cut-off: 1, consistency cut-off: 0.75, solution coverage: 0.74, solution consistency: 0.73

Table 4.11: Frequency of causal factors for walking among students

4.2.4 Bike use

According to the solution of the complex model, bike use satisfies most of the factors in the study. More specifically, the model wielded 17 consistent recipes which explain 72% of the total outcome with a combined consistency of 0.83. Statistic-wise this is the most consistent and robust model yet. Once again, the most influential factors are either instrumental or affective. Not surprisingly, speed and ease of access are the most influential factors. This is consistent with the factors which influence car use (1 and 0.9 respectively), because the two modes share the same road network. In addition, what motorbikes lacks in (top) speed, it makes up for average speed due to its size and versatility. Another really important factor is the fact that the use of motorbikes does not cause anger to its users. It is easy for a biker to

manoeuvre her way out of congestion and to find easily a parking space in the university. Feeling happy when using the mode is also an important factor for its use. Compared to the previous modes, this is the only mode that its use is influenced by positive affective feelings. Finally the last factors with a strong presence in the model is comfort and no cost. This last two complete the set of instrumental reasons which affect transport mode choice, making the motorbike the first mode to satisfy all the instrumentals reasons in the study. This demonstrates the dynamic of the motorbike in Athens's transportation context.

The model suggests that it is not clear whether students use their motorbike because they want to express their personality, because they're not afraid to use it or because they feel excited. However the difference levels of appearance in the solution suggest that if one of them would influence their decision, it would more likely be expression of personality. Likewise, feeling excited would most likely not influence their decision. This is intuitive, because excitement because of bike driving is not likely to be manifested during morning rush hour. Finally, neither the expression of values nor social status seem to influence students to use the motorbike.

Causal Factor	Frequency
Speed	1
Ease of access	0.94
Not feeling angry	0.88
Feeling happy	0.71
Comfort	0.71
No cost	0.65
Expression of personality	0.59
Not feeling afraid	0.47
Feeling excited	0.41
Expression of values and ideals	0.36
Expression of social status	0.12

frequency cut-off: 1, consistency cut-off: 0.80, solution coverage: 0.72, solution consistency: 0.83

Table 4.12: Frequency of causal factors for driving the motorbike among students

For workers (Table 4.13), once again, it is instrumental causal mechanisms who make it to the top of the frequency list. The motorbike is preferred because it has no cost, it has easy access to the university and it is fast and relatively comfortable. On top of that it's use symbolizes important personality traits of the agent. It is interesting to compare the role of the cost in bike use. For students the low cost of using a motorbike was not so strong a factor as in the case of workers. Of course, this is intuitive as the

workers earn enough to money to think that the motorbike has almost no cost. However, the students are eager to use the motorbike because of the quiet strong feeling of happiness that it's use exerts.

Causal Factor	Frequency
No cost	1
Ease of access	1
Speed	1
Comfort	0.75
Expression of personality	0.75
Feeling happy	0.5
Not feeling afraid	0.25
Not feeling angry	0.25
Expression of values and ideals	0.25
Feeling excited	0.25
Expression of social status	0.25

frequency cut-off: 1, consistency cut-off: 0.9, solution coverage: 0.76, solution consistency: 0.91

Table 4.13: Frequency of causal factors for driving the motorbike among workers

4.2.5 Cycle use

The complex model has wielded a final solution which is based on 3 combinations of the causal mechanisms. The overall explanatory power of the final model is 43%. It seems that students cycle because they think that it is a fast mode without cost and it contributes to their overall well-being. More specifically, even in morning rush hour and with unfavourable urban conditions cycling is exciting and makes the users happy. In addition, because of the versatility of the bicycle, its hard for someone to get angry when using it. Bicycles can manoeuvre around slow traffic, climb and move over pavements and go both ways in an one-way street.

In addition, the easy access to the university and the expression of personality traits and social status also contribute to a moderate degree to the use of bicycle. Even this moderate contribution of access to the use of bicycle is surprising, if one considers that there is no bicycle infrastructure to support commuting trips to the universities. In addition, the moderate influence of the symbolic factors can be attributed to the relatively new but fast-growing cycle culture that has been developing in Greece and in Athens in particular in the last decade.

Finally, the mechanisms which do not seem to influence bicycle use is comfort, not feeling afraid and expression of personal values and ideas. The

first two can be linked with the absence of cycling infrastructure.

Causal Factor	Frequency
Speed	1
No cost	1
Feeling excited	1
Feeling happy	1
Not feeling angry	1
Ease of access	0.66
Expression of personality	0.66
Expression of social status	0.66
Comfort	0.33
Not feeling afraid	0.33
Expression of values and ideals	0.33

frequency cut-off: 1, consistency cut-off: 0.75, solution coverage: 0.74, solution consistency: 0.43

Table 4.14: Frequency of causal factors for driving the motorbike among workers

4.3 Concluding Remarks

Transport mode choice in this chapter was studied from the side of the agent. The causal mechanisms which affect mode choice were nothing more than perceptions of users. Under this light, the causal mechanisms cannot be quantified because it's not the value itself that makes people to act but rather the qualitative perception of it. Some people may think that a thirty-minute commuting trip by car is slow, while others may think that a forty-minute commute by bus is fast. However, the important factor is the perception of the trip as fast or slow and not the numerical value of speed.

The results of the simple model indicate that mode use is mainly driven by instrumental causal mechanisms. Symbolic and affective factors have little effect on their own on the agents' actions. However, when combined with instrumental reasons they affect a significant portion of mode choice. This is especially true for the combination of instrumental and affective reasons and for the combination of all three together. This leads to the conclusion that instrumental factors are the cornerstone of mode choice. Sometimes instrumental reasons alone may not be sufficient enough to contribute to mode choice but for the majority of cases it seems that they are necessary as part of the causal combination.

The complex model wielded more detailed results about each causal mechanism. The car is being used by students and workers because it is

considered fast, comfortable and with easy access to the university and because it is not associated with fear or anger. On the other hand it seems that public transport is used mainly by students because of the lack other alternatives, as there are no causal mechanisms which appear consistently in each combination. On the contrary, workers seems to appreciate the instrumental characteristics of public transport and consider it quiet fast and comfortable while offering easy access to the university. The fact that there are no strong mechanisms which drive public transport use among students is a problem, because it increases the likelihood of switching to other modes, and especially to the car, once an opportunity is presented. Finally, the bicycle which is an emerging transport mode in Athens and Greece in general seems to be appreciated for all the instrumental factors as well as because it symbolizes the personality of the person. However, the lack of bicycle infrastructure and the prevailing negative cycling conditions in general do not allow the cyclists not to feel afraid or angry when using it. This is something that has to be changed in order for the bicycle to become more attractive to the broader population.

Chapter 5

Structural Influence

In this chapter the focus will be on the influence of urban structure on travel mode choice. This is because theoretically, the perceptions of agents when it comes to the instrumental side of mode choice are formed because of the broader urban structure which influences travel in general. Empirically, it was demonstrated in the previous chapter that there is indeed a major influence on transport mode choice by instrumental factors and therefore by urban structure.

The main urban structure characteristics that were taken into account were:

- The distance from the origin to the closest metro station
- The distance from origin to the city centre
- The distance from the destination to the closest metro station
- The distance from destination to the city centre
- The density of the origin's municipality.
- The density of the destination's municipality.

Additionally, for public transport use, the number of changes needed to reach the destination was also taken into account.

Each variable was fuzzified into two sets: the "low" and "high" set (Table 5.1). For instance, density was fuzzified as "low density" or as "high density" and distance as "short" or "long". The two respective sets are not opposite. "Not low" density does not mean "high" density. This has been done with the help of three values: the full membership value, the full non-membership value and the crossover point. The first two represent the values beyond which there is no ambiguity for the membership of a value in the set. For instance, any residential density below 100 persons/ha is considered to have full membership in the "low density" set and any density higher than 400

persons/ha is considered to have full non-membership. Finally, the crossover point represents the value with the highest ambiguity when it comes to defining its membership a set.

Variable	Full Membership Value	Crossover Value	Full non-membership value
Low Density (persons/ha)	100	200	400
High Density (persons/ha)	500	400	200
Long distance to centre (m)	15000	10000	5000
Short distance to centre (m)	3000	5000	7000
Short commuting distance (m)	3000	5000	7000
Long commuting distance (m)	15000	10000	5000
Long distance to rail station (m)	1500	800	500
Short distance to rail station (m)	300	500	800

Table 5.1: Fuzzification values for each set.

5.1 Public Transport use

According to the analysis for students, there are five combinations with which residential location contributes to public transport use (Table 5.2) and when combined they explain 82% of the total outcome. The two most influential combinations (in the combined solution) are the first and the third. These can be reduced further by taking into account that both of them have at least two different sets which represent the same factor. This way the first combination can be reduced to three factors, namely "not low density", "not short distance to centre" and "medium distance to rail station". It is clear that this combination describes a residential location outside the core centre of Athens where the densities are not low and there is a rail station in the broader vicinity which can be reached either by foot or a bus. Likewise, the third combination can be reduced to "high density", "not long distance to centre", "not long distance to rail" and "no changes" and is indicative of a neighbourhood close to the centre of Athens with high densities, not far away from a rail station and with the additional benefit of offering direct access to the university either by bus or by rail. The rest three combinations are too weak in the combined solutions for an explanatory attempt to be attempted.

As far as university location is concerned, the analysis wielded one causal combination which explains public transport use almost completely (by 97%, Table 5.3). This causal combination is theoretically intuitive, as accessibility by public transport is high in places with high density which are located not

far away from the centre. However, such a high coverage value is also caused by the fact that all the universities of the study shared more or less the same location characteristics. Under these circumstances, the consistency value of the causal combination might be more useful, because it represents the outcome (public transport) relative to this particular combination only, rather than the outcome of this combination relative to all combinations. The consistency of the particular solution is 71%, which means that only 71% of the cases of this combination is sufficient to cause public transport use.

Causal Combination	Raw Coverage	Unique Coverage
not low density + not short distance to centre + not long distance to rail + not short distance to rail	0.63	0.14
not low density + not long distance to centre + not short distance to centre + not short distance to rail + no changes	0.46	0.01
high density + not low density + not long distance to centre + not long distance to rail + no changes	0.24	0.11
not high density + long distance to centre + not short distance to centre + long distance to rail + not short distance to rail + no changes	0.22	0.02
not high density + not low density + not long distance to centre + not short distance to centre + not long distance to rail + not short distance to rail + no changes	0.03	0.01

solutions coverage: 0.82, frequency cut-off: 4, consistency cut-off: 0.8

Table 5.2: Effects of residential location on public transport use among students

Causal Combination	Raw Coverage	Unique Coverage
high density + not low density + not long distance to centre	0.97	0.97

solution coverage: 0.97, frequency cutoff: 217, consistency cut-off: 0.78

Table 5.3: Effects of university location on public transport use among students

For workers, the analysis of residential locations characteristics wielded

three combinations of causal mechanisms (Table 5.4) which together explain 47% of the total public transport use. However the first and the third are the stronger in explaining the phenomenon uniquely. After the merging of similar sets of variables the first combination consists of “high density”, “medium distance to centre”, “not long distance to rail“ and “no changes”. Once again these characteristics are indicative of a neighbourhood close to the centre with a rail station nearby and with good access to the university. The third combinations can be reduced to “high density”, long distance to centre”, “long distance to rail” and “no changes”. For this case it seems that the important factors are the high density and the easy access by bus to the university.

As for workplace location (Table 5.5), it seems that the only factor influencing public transport use is the not long distance to the closest rail station.

Causal Combination	Raw Coverage	Unique Coverage
high density + not low density + not long distance to centre + short distance to centre + not long distance to rail + no changes	0.01	0.11
high density + not low density + not long distance to centre + not short distance to centre + short distance to rail + no changes	0.07	0.05
high density + not low density + long distance to centre + not short distance to centre + long distance to rail + not short distance to rail + no changes	0.30	0.28
solution coverage: 0.47, frequency cut-off: 1 , consistency cut-off: 0.79		

Table 5.4: Effects of residential location on public transport use among workers

Causal Combination	Raw Coverage	Unique Coverage
not long distance to rail	0.48	0.48
solution coverage: 0.48, frequency cut-off: 1, consistency cut-off: 0.87, solution consistency: 0.79		

Table 5.5: Effects of university location on public transport use among workers

5.2 Car use

The effects of residential location on car use for students are presented in Table 5.6). The analysis wielded five consistent combination of causal mechanisms, which together explain 47% of the total car use. However, when combined, only the first one shows significant unique coverage. This does not mean that the rest combinations are useless because they are responsible for 20% of the total outcome through different combinations of causal combinations. If the first combination is reworked into a more dense form the resulting mechanisms are "not high density", "long distance to the centre" and "long distance to rail". This condition is fully compatible with theoretical expectations about car use. Additionally, the second causal combination points to approximately the same causal mechanisms. According to it, a small proportion of car use is caused by even "medium" mechanisms: distances to the city centre do not have to be long but rather not short and distances to rail can be medium instead of long when at the same time the residential density is not low rather than not high.

Causal Combination	Raw Coverage	Unique Coverage
not high density + long distance to centre + not short distance to centre + long distance to rail + not short distance to rail	0.34	0.27
not low density + not short distance to centre + not long distance to rail + not short distance to rail	0.17	0.05
not high density + not low density + not long distance to centre + short distance to centre + not short distance to rail	0.06	0.02
not high density + not low density + not short distance to centre + not long distance to rail	0.10	0.00
not low density + long distance to centre + not short distance to centre + not long distance to rail	0.10	0.00

solution coverage: 0.47, frequency cut-off: 1, consistency cut-off: 0.75

Table 5.6: Effects of residential location on car use among students

For workers, there are five combinations of residential location characteristics which influence car use (Table 5.7). However, their effect is rather limited as only 27% of the total outcome is explained by their combination. The most influential of them highlights the factors which are expected theoretically to influence car use. After the merging of relevant sets, car use is influenced by "low density", "long distance to the city centre" and "long

distance to rail". Moreover the second combinations demonstrates, as with students, that car use is influenced not only by low density but with higher densities and the centrality of the location and its proximity to rail station can not only be long but not short.

The analysis for the effects of workplace location characteristics wielded no consistent causal mechanisms for car use for both students and workers. This means that car use cannot be adequately explained by the location of the university. However, if we take into account that universities are located more or less in areas with similar characteristics we can conclude that, it is these particular location characteristics that cannot explain car use.

Causal Combination	Raw Coverage	Unique Coverage
not high density + low density + long distance to centre + not short distance to centre + long distance to rail + not short distance to rail	0.12	0.09
not low density + not short distance to centre + not long distance to centre + not short distance to rail	0.17	0.05
not high density + not low density + not long distance to centre + short distance to centre + not short distance to rail	0.06	0.02
not high density + not low density + not short density to centre + not long distance to rail	0.10	0.00
not low density + long distance to centre + not short distance to rail + not long distance to rail	0.10	0.00

solution coverage: 0.29, frequency cut-off: 1, consistency cut-off: 0.78

Table 5.7: Effects of residential location on car use among workers

5.3 Walking

For walking the analysis did not return any consistent recipes neither for residential location nor for workplace location.

5.4 Bike use

The effects of residential locations on bike use among students are better described by four combinations of causal mechanisms with a total explanatory power of 47% (Table 5.8). The most dominant solution can be reduced to three factors namely, "not low density", "long distance to centre" and "long distance to rail". This combination is similar to the one that contributes

to car use among student with the only difference that instead of not high density it requires not low density. This is intuitive since in conditions were the residential density is not low, parking problems (and car practicality problems in general) start to appear. Therefore, bike use is boosted, since it is the closest mode to car, being both private and motorized.

For workers (Table 5.9), there is only one combination of mechanisms related to residential location that affects bike use. Moreover it is rather strong, explaining 66% of the total outcome. According to it, "high density", "not long distance to centre" and "long distance to rail" are the (merged) factors which influence bike use. Both high density and proximity to the centre are factors which hinder the ownership and use of the car and hence, boost the use of the second private and non-motorized mode, especially when there is no metro station nearby.

Causal Combination	Raw Coverage	Unique Coverage
not low density + long distance to centre + not short distance to centre + long distance to rail + not short distance to rail	0.34	0.27
not high density + not low density + long distance to centre + not short distance to centre + not long distance to rail	0.11	0.04
high density + not low density + not long distance to centre + short distance to centre + short distance to rail	0.05	0.03
not high density + not low density + not long distance to centre + short distance to centre + not long distance to rail + not short distance to rail	0.05	0.01

solution coverage: 0.43, frequency cut-off: 1, consistency cut-off: 0.77

Table 5.8: Effects of residential location on bike use among students

Causal Combination	Raw Coverage	Unique Coverage
high density + not low density + not long distance to centre + long distance to rail + not short distance to rail	0.66	0.66

solution coverage: 0.66, frequency cut-off: 1, consistency cut-off: 0.77

Table 5.9: Effects of residential location on bike use among workers

For workplace location, there is only one combination of causal mecha-

nisms which influences bike use for students (Table 5.11). According to it, bike use is influenced if the university is located in a high density area and in a medium distance both from the centre and from the closest rail station. The effects of workplace location are similar to workers as well (Table 5.11). There is only one combinations of causal mechanisms, which however explains 90% of the total bike use. The difference between the two is that in the case of workers, the distance of the university to the centre has to be not long instead of medium. It seems that workers are eager to use the motorbike even if the university is close to the centre, whereas the students use the motorbike if the university is slightly away from it.

Causal Combination	Raw Coverage	Unique Coverage
not low density + high density + not short distance to centre + not long distance to centre + not short distance to rail + not long distance to rail	0.2	0.2

solution coverage: 0.20, frequency cut-off: 1 , consistency cut-off: 0.76

Table 5.10: Effects of university location on bike use among students

Causal Combination	Raw Coverage	Unique Coverage
high density + not low density + not long distance to centre + long distance to rail + not short distance to rail	0.90	0.90

solution coverage: 0.90, frequency cut-off: 4, consistency cut-off: 0.740635

Table 5.11: Effects of university location on bike use among workers

5.5 Cycle use

Cycling among students is best explained by three combinations of residential locations characteristics (Table 5.12). Together they explain 49% of the total outcome. According to the first one high density and long distance both from the centre and the rail station explain 21% of the cycling. In addition, 12% of cycling is cause by low density and long distance both from centre and the rail station. It can be concluded that the main causal factors which influence cycling is the long distance to the centre and the long distance to rail. As far as density is concerned, high density is more likely to cause cycle use than low density once the two other criteria are met. Finally

a small amount of cycling can be caused in medium densities and distance from the city centre as long as the distance to the rail station is still long.

Causal Combination	Raw Coverage	Unique Coverage
high density + not low density + long distance to centre + not short distance to centre + long distance to rail + not short distance to rail	0.33	0.21
not high density + low density + long distance to centre + not short distance to centre + long distance to rail + not short distance to rail	0.22	0.12
not high density + low density + not long distance to centre + short distance to centre + long distance to rail + not short distance to rail	0.09	0.04

solution coverage: 0.49, frequency cut-off: 1, consistency cut-off: 0.73

Table 5.12: Effects of residential location on cycling among students

Finally, the location of the university seems to have no effect on cycling, as the analysis did not wield any consistent causal combination.

5.6 Concluding Remarks

In this chapter transport mode use was studied under the light of three urban structure characteristics: residential density, distance from the city centre and distance from the closest rail station. Because these characteristics were transformed into sets and then it was the interaction of these sets that was analysed, the analysis wielded more of a description of neighbourhoods which are likely to affect transport mode choice rather than separate effects of each variable. For instance, one of the causal combinations which affects public transport use is a residential area with high density, not long distance from the city centre with a metro station in short distance and a transport system organized in such a way that one needs not to change modes in order to reach the university. This description of the area is quiet precise. All of the urban characteristics which were mentioned are needed in order for public transport use to be manifested. This is important for planning, because under this way the outcome of the analysis is closer to the concrete built environment than to abstract variable interrelations.

Another important and interesting outcome of the analysis was the fact that urban structure characteristics of both residential and workplace location explain the use of public transport better than car use. As Athens is a particularly compact city, the weakness in explaining car use may lie in the fact that car users are habitual users or somewhat impervious to the effects

of the built environment. This is probably where the Theory of Material Possession enters the picture, offering alternative paths for transport mode choice different from instrumentality as well as instrumental factors, such as comfort. (especially for students, for whom the combination of instrumental and affective reasons was almost as important as instrumental reasons alone).

Chapter 6

Contribution to urban planning

The aim of this chapter is to place the knowledge produced from the project into the wider picture of urban planning. Firstly, by adopting a broader model than Rational Choice Theory for decision making, it was possible to evaluate other factors which affect transport mode choice. More specifically, the model of the Theory of Material Possession, makes it possible for the agent to base his or her decisions to factors other than instrumental, namely symbolic and affective. This ability was utilized in the project in order to highlight the importance of instrumental factors as cornerstone of agent behaviour. In the analysis, it was demonstrated that although both symbolic and affective factors influence transport mode choice this is done in combination with instrumental factors. From a critical realist perspective, symbolic and instrumental causal mechanisms emerge only if instrumental factors are present as well.

Since instrumental factors play such a central role in causing transport mode choice, then it is intuitive that urban structure shares this role as well. Three out of four factors, namely speed, cost and ease of access are almost direct products of how we plan and built our cities. In addition, the effects of urban structure to different modes is selective rather than horizontal. This means that particular types of built environment favour or hinder different modes. As was shown in the analysis, public transport is affected by a completely different combination of causal mechanisms than car use.

As was stated in the introduction, the reason for studying transport mode choice is not only just to acquire a scholarly understanding of it but also to change it. From an urban planning perspective, this can be done by creating a built environment which favours particular modes and, if possible, puts barriers to other less desirable. Under this light, the project uncovered the residential or workplace characteristics that contribute to the use of each mode. Since these characteristics are often mutually exclusive for different

modes, the ones which affect public transport have a central role, as public transport is arguably the cornerstone for sustainable mobility.

Another contribution to the field is the application of fuzzy set theory as an analytical tool. Fuzzy set qualitative analysis is a powerful tool for planning because it allows the planner to determine the meaning of each variable. For instance, it is up to the researcher to decide what is meant by high residential density or short way to the metro station. This way the outcome of the analysis is set within a theoretical or practical framework. For instance, there were few municipalities whose density could be considered as low (below 100 person/ha) for the case of Athens. By setting these limits on the values the analysis showed that it is not low density that contributes to car use but rather not high density. Of course, setting these threshold values is both challenging and crucial for the analysis.

Finally, in fuzzy set qualitative analysis the focus is on the effects of particular combinations of causal mechanisms on the outcome rather than on the effects of each variable on the outcome. This way the analysis is sensitive to different combinations of the mechanisms which produce the same outcome. This is important because the role of each mechanism may be different from combination to combination. For example, proximity to the rail station may not have the same effect in an area which is close to the city centre (where there are other public transport alternatives) and in an area far away from the centre (where rail might be the only option). In the first case it's not that important for public transport use, while in the second case it is critical. This effect cannot be captured if the particular causal mechanisms are studied in isolation. Hence, each combination describes an almost concrete type of built environment which affects transport mode choice.

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