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A NEW BEHAVIORAL FRAMEWORK TO ANALYZE PREFERENCE CONSTRUCTION AND DECISION PROCESSES WITHIN THE MODAL CHOICE

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This paper discusses a new framework to explain the decision-making process of modal choice. A specific approach, based on the behavioral framework developed by Ben-Akiva & Boccara (1987), is adopted to understand and analyze the decision processes of individuals. Precisely, we use the Analytic Hierarchy Process (AHP) to build the hierarchy of preferences from attitudes and perceptions. Through the hierarchy of preferences, we can apply three different methods to better explain the decision processes; namely a standard compensatory model, a non-compensatory model based on the decision rules, and different possible weightings of the AHP method. The random utility maximization is predominantly used in the transportation literature because of its strong theoretical background, its success in predicting many types of human behavior, and the simplicity of mathematical and statistical analyses and model estimation it offers. Despite that, we believe that non-compensatory approaches are better suited to understand both travel behaviors and decision processes for transportation modes when taking active modes into account. These approaches allow us to better explain the impacts of each modal attribute on the one hand and to build psychological profiles with respect to decision rules on the other hand. Thus, it is possible to simulate shocks all things being equal.

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1. Introduction

Today, especially in developed countries, we are facing a new paradigm: "from ownership to usership", or "from possession to use" (see washing machines and laundromat, but also all the new rental services like luxury bags...). Speaking about displacement, we are moving from transport to mobility (cf. private cars and car-sharing). Transport is defined as "*take or carry (people or goods) from one place to another by means of a vehicle, aircraft, or ship"* and mobility is defined as "*the ability to move or be moved freely and easily*"(Oxford Dictionary). With these definitions, we notice that transport refers to the *way* of moving – this is the engineering point of view – while mobility refers to the *manner* of moving – this is the sociological point of view.

Mobility is at the heart of people's lives. Holidays and work, safety and social interaction, equity and accessibility… deal with mobility. In fact, our life is about mobility. As a matter of fact, *« trip demand is a derived demand, an associated consumption which is of secondary importance to the activity it is linked to. Generally, people do not travel for travel's sake; they travel to perform an activity* » (Crozet & Lopez Ruiz, 2013, p299). That being said, one can distinguish the "*constrained mobility*" from the "*chosen mobility*"; the latter being an opportunity rather than a constraint. On the one hand, individuals minimize constraints; on the other hand, they maximize opportunities. Both behaviors are motivated by self-interest. To go further, in 2007, Cervero & al. "*believe that carshare members, mindful of the cumulative costs of driving, also have become more judicious and selective when deciding whether to drive, take public transit, walk, bike, or even forgo a trip. This behavior contrasts with the perverse incentive to drive a personal car because of the considerable sunk and hidden costs associated with private car ownership"(*Cervero & al., 2007, p79). This quote supports the new paradigm "from ownership to usership" which is the main reason why modal choice process is of growing interest and why we have to focus more on understanding modal choice process. Indeed, as new transportation modes are appearing and historical transportation mode usage is changing, the approach has to be updated.

In this paper, two complementary questions are addressed. First, what are the individual expectations in terms of mobility? Secondly, what are the individual processes used in order to choose transportation mode? To answer these questions, we try to understand both the "black box" of construction of preferences and the decision rules used in modal choice. A decision rule is an intellectual process used by individuals to make a choice among different alternatives. We also analyze mobility demand in more details while building a theoretical method which can be applied in an empirical way, meaning that variables used in the model are harvestable data. More specifically, we build a new analytical framework based on a behavioral framework initiated by Ben-Akiva & Boccara (1987) on the one hand and on a mathematical psychology

quantification method named Analytic Hierarchy Process (AHP) developed by Saaty (1977) on the other hand.

The contribution of this paper is mainly methodological and lies in the possibility to model changes, such as public policies or foresighting scenarios, all things being equal and analyze their effects on the mobility demand structure. In other words, it is used to analyze the effects on the theoretical transportation mode choice and so, on the modal shares. To do so, the behavioral framework presented in this paper allows a more detailed understanding of the construction of preferences through the importance attached to the attributes (attitudes), and the perceived level of these attributes (perceptions). Indeed, qualitative variables such as "comfort" or "ease to use" are taken into account to better explain the construction of preferences and to find the decision processes within the modal choice. To sum up, this new behavioral framework is initially used to find the mobility demand structure, speaking about socio-demography, attitudes, perceptions, preferences, modal portfolio, decision processes and then modal share. Finally, this framework allows to model changes in the mobility demand structure and analyze the impacts on the modal share.

The structure of the paper is as follows. In Section 2, the previous research and the contribution of this work are presented. The conceptual framework is explained in Section 3 with the definition of the concepts and the typologies used. In Section 4, preferences are constructed through the quantifying methodology of attitudes and perceptions. In Section 5, the different possible decision rules are defined and contextualized. Finally, Section 6 concludes with a discussion and future research.

2. Previous research and contribution of this work

To have an overview of the existing literature, see Soltanzadeh & Masoumi, 2014, detailing the mode choice determinants, the studied countries, the studied modes and the studied years. Existing research works about mode choice consider either few transportation modes, mainly cars and public transports (PT) (Temme & al., 2008; Rubens & al., 2011; Redman & al., 2013; Jou & Chen, 2014; Van & al., 2014; Broberg & Sarjala, 2015), and/or few activities, mostly commuting and leisure (Van & al., 2014; Danaf & al., 2014; Broberg & Sarjala, 2015), and/or few modes characteristics, in particular time, cost, comfort and security (Hensher & al., 2003; Daziano & Rizzi, 2015), and/or a specific type of individuals such as students (see the literature review from Danaf & al., 2014, Table 1, p145). Here, we consider all individuals, all activities grouped in a typology to highlight the different needs (see part 3.1), a larger set of modes including notably the "Internet" to account for immobility (see part 3.2), and the whole set of modes characteristics built by Brisbois (2011) and inspired by L. Steg and V. Kaufmann (see part 3.3).

In connection with what has just been said about the set of modes' characteristics, it should be noted that, in his new approach to consumer theory, Lancaster (1966) stated that consumers do not acquire goods for themselves but for the characteristics they contain. The latter characteristics are called "attributes". Quite recently, Susilo & Cats (2014) explored the key determinants of travel satisfaction including service and quality. Redman & al. (2013) describe public transport service quality attribute as an aggregation of physical attributes (reliability, frequency, speed, accessibility, price, information provision, ease of transfers and vehicle condition) and perceived attributes (comfort, safety, convenience and aesthetics). In our paper, we assume every attribute as perceived. In fact, taking more attributes into account helps better explain the choice, and thus helps reduce the error term inherent to discrete choice models. Anable (2005) even distinguished instrumental journey attributes from affective ones. To go even further, Van & al. (2014) divided attributes into three categories, namely "Symbolic affective" (affective motives), "Instrumental" (functional) and "Social Orderliness" (environmental friendliness, safety, altruism, quietness, etc.). As we take into account more attributes, our approach allows us to explain the impacts of each attribute on modal choice in more details.

In our case, based on the behavioral frameworks developed by Ben-Akiva & Boccara (1987), we adopt a specific approach combining attitudes and perceptions to analyze the decision processes of individuals. Indeed, explanatory variables in a behavioral framework are not only stated preferences but also context, motivation, attitudes, perceptions, tastes, knowledge, beliefs, information, budgets, etc. Hunecke & al. (2008) supported the significance of attitudes in mobility behavior as well as how attitudes change across individuals. Furthermore, Heinen & al. (2010) argue that the inclusion of attitudes, next to socio-demographic characteristics, helps to improve the explanatory power of statistical models. Indeed, Morikawa & al. (2002) include modal comfort and convenience through attitudinal indicator variables. In general, attitudes are used as latent variables through discrete choice models with stated preferences as explanatory variables when maximizing utility to find the revealed preferences (the choice). In our framework, attitudes and perceptions are not latent variables but direct explanatory variables when building preferences.

Limited research has suggested that non-compensatory decision rules may be at work in transportation decisions and travel behavior (Foerster, 1979; Recker & Golob, 1979; Young, 1986; Swait & Ben-Akiva, 1987a, 1987b; Swait, 2001). Indeed, non-compensatory models focus on acceptability thresholds and in 2015, Obermeyer & al. state that *"thresholds might be important for predicting choice behavior* "(Obermeyer & al., 2015, p9). Rather, research works mainly focus on compensatory models to explain mode choice and these models become more and more complex. The compensatory approach mainly describes the time and cost sensitivity; and when it also includes other variables as comfort or ecology, it transposes them in a common

unit, namely money. Specifically, the random utility maximization is predominantly used in the transportation literature, because of its strong background in theory, its success in predicting many types of human behavior, and the simplicity of mathematical and statistical analyses and model estimation it offers (Ben-Akiva & Lerman, 1985; Koppelman & Bhat, 2006). Despite the latter advantages of the direct compensatory approach, we believe that the non-compensatory approach is better suited to understand travel behaviors and decision processes. This idea was already put forward in 1987 by Gensch & Javalgi, who stated that "*simultaneous compensatory evaluation models do not appear to reflect the cognitive process by which individuals make their choice*" (Gensch & Javalgi, 1987, p869). By contrast, non-compensatory models enable to process by attributes, considering more variables, including qualitative ones.

In this paper, our ambition is to focus on the choice process while quantifying qualitative data. To do so, standard research usually uses the Discrete Choice method (Ben-Akiva & Lerman, 1985) but our approach is inspired by other multi-attributes choice models. From Van Ittersum & al. (2007), we have a typology of these models depending on the information we have in terms of attributes and their level. For instance, if we have internal attribute information, meaning no attribute information and no attribute-level information, the free-elicitation method is recommended. Alternatively, when we have external attribute information, meaning attribute information and attribute-level information, there are four main models (*i.e*. the multi-attribute attitude method, the trade-off method, the swing-weight method and the conjoint method). In our case, we have consumers' values and desires, that is to say attribute information but no attribute-level information. Five main models are adapted in such a case. From the easiest to the most robust one, the direct-rating method, they are the direct-ranking method, the point allocation method, the analytical hierarchy process and the information display board. As we do not focus on the information effects on the one hand, and as Tversky and Shafir state that "*an examination of the empirical literature indicates that choice behavior is often inconsistent, **hierarchical** and context dependent*" (Tversky & Shafir, 2004, p493) on the other hand, we chose the Analytical Hierarchy Process (AHP).

3. Conceptual framework

In this part, we address the following question: **how can we explain the modal choice?** To do so, we use the behavioral framework developed by Ben-Akiva & Boccara (1987) below:

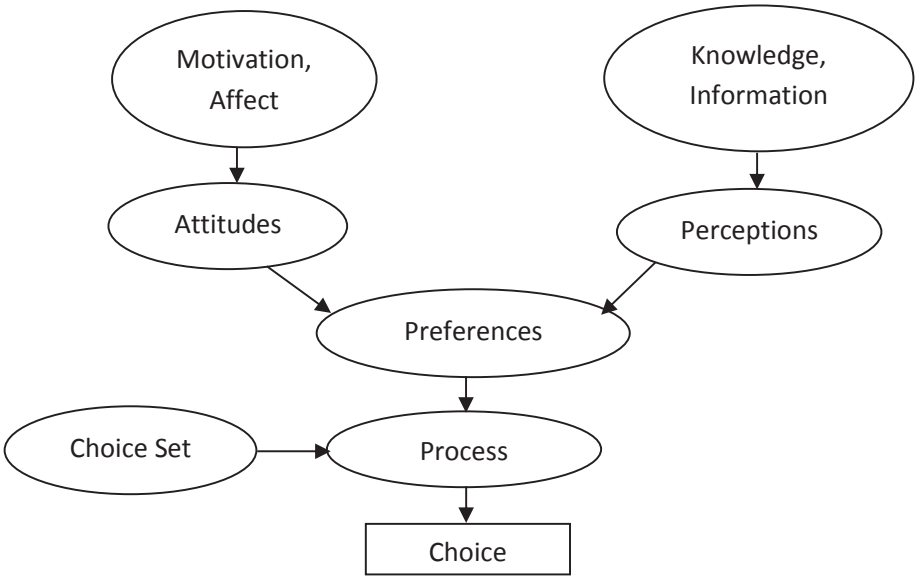


Figure 1: Behavioral framework

This behavioral framework allows us to analyze the determining factors of modal choice through attitudes and perceptions.

Ben-Akiva and al. (1999) developed the latter framework for latent variables as follow:

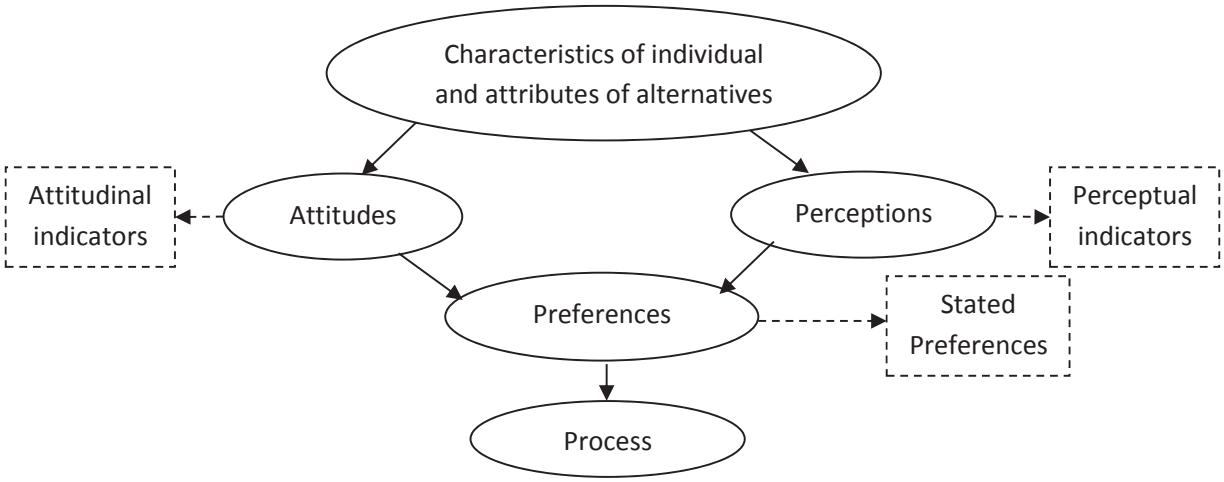


Figure 2: Behavioral framework for choice models with latent variables

This behavioral framework use the concepts of attitudes and perceptions as latent variables through behavioral questions. Moreover, preferences are stated.

All the aforementioned concepts are explained below:

Attributes of alternatives are the different characteristics of transportation modes.

Motivations and affect are the explanation of attitudes. Indeed, attitudes toward a mobility journey depend on motivations, constraints and expectations.

"*Attitudes* *reflect individuals' needs, values, tastes, and capabilities. They are formed over time and are affected by experience and external factors that include socioeconomic characteristics*" (Ben-Akiva and al., 1999).

In other words, attitudes are the preferences in terms of attributes. In our research work, attitudes consist of the ranking of modal attributes in the cognitive process for mode choice depending on each activity.

Knowledge and information are the causes of perceptions. Indeed, your perceptions about transportation modes depend on your knowledge about them and the information you have. In this paper, the knowledge and information effects are not analyzed ex-ante but ex-post through the concept of cognitive bias.

"*Perceptions* *are the individuals' beliefs or estimates of the levels of attributes of the alternatives. The choice process is expected to be based on perceived levels of attributes.*" (Ben-Akiva and al., 1999).

In our research work, perceptions are the ratings of modal attributes based on an acceptability threshold.

"*Preferences* *represent the desirability of the choice alternatives. These preferences are translated to decisions via a decision-making process. Various types of decision processes can be incorporated into this framework*" (Ben-Akiva and al., 1999).

In our research work, preferences consist of the ranking of transportation modes depending on their adequacy between attitudes and perceptions.

Sociodemographic variables (characteristics of individual) are gender, age, household type, house location, income, education, and so on.

Choice set is the set of all possible alternatives (transportation modes) among which individuals have to choose.

In our research work, we name it the modal portfolio. It consists of assets (mobility goods and mobility service subscriptions) and liabilities (accessibilities, available options).

Process is a type of decision rules that individuals use to make a choice. It is a function associating (and mapping) an observation with an appropriate action. A **decision rule** is an intellectual process used by individuals to make a choice among different alternatives.

In our research work, to draw the main factors, we compare a non-compensatory hierarchical model, a compensatory hierarchical model and the AHP method.

Choice is the actual mode choice made by individuals for each activity.

In our research work, it consists of the revealed choice, namely the transportation mode used for each activity.

Inspired by the frameworks above (Figure 1 and 2), we build a general framework to better explain, understand and analyze modal choice. It includes the construction of preferences directly quantified from attitudes and perceptions (not as latent variables as Ben-Akiva does). In other words, our framework explain how preferences are built instead of using stated preferences. Our framework also includes the *choice process*, the *choice set* constraints (defined as a modal-portfolio) as in Ben-Akiva's framework and the *real choice* to control our model. We also take into account "*system characteristics", "perceptions", "preferences", "situational constraints" and "behavior*" in our framework, as Tybout & al. (1978) advised.

The first part of the framework is used to answer the question "how can we explain the "black-box" of modal construction of preferences?" such as illustrated in Figure 3 below.

The second part is used to answer the question "which model best predicts modal choice?"

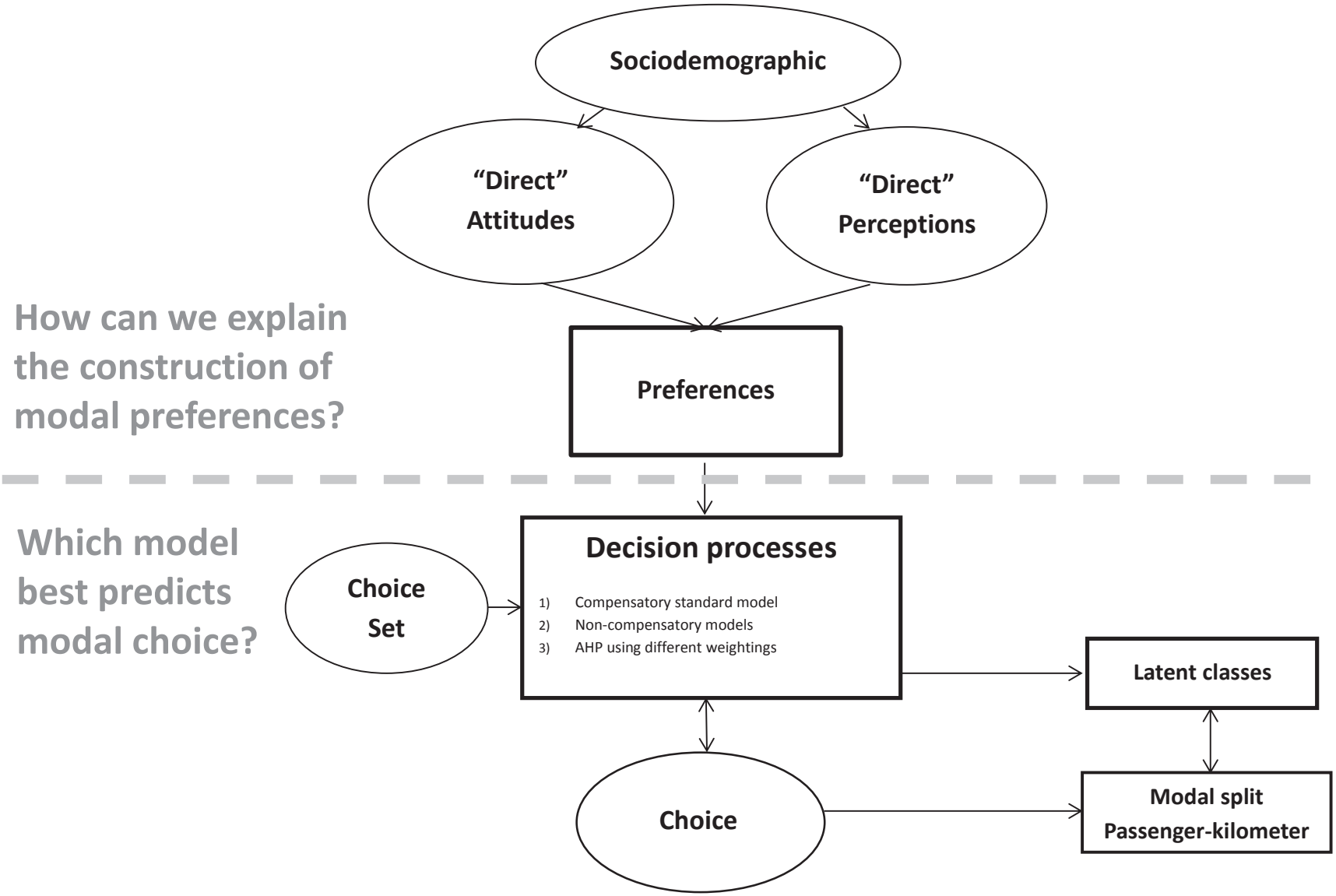


Figure 3: Global conceptual framework for choice mode with AHP method

Latent classes are clusters of individuals who share the same decision rule.

Passenger-kilometer is the "volume" (the "amount") of mobility.

Modal split is the mobility distribution among transportation modes.

3.1. Activities

Activities are the main reasons to travel. Here, we consider a typology with four types of activities pooled from the National Institute of Statistics and Economic Studies (INSEE)'s typology.

Activities	Definition
Home – Work/Studies	Going to work or to study from home and coming back
Shopping / Services	Grocery shopping. Going to the haircutter's, to the mayor's office or to the doctor's
Accompanying	Accompanying a friend, or picking him up
Leisure	Going to do sports, arts, recreation, going to the restaurant, shopping or visiting a relative in your city or nearby.

Table 1: Activities typology

3.2. Modes

In what follows, the "choice set" refers to the different transportation modes considered in this study, namely:

Transportation modes	Description
Walking	Walking, transit, perambulation…
Bike & Mobility objects	Possessed bike, scooter, rollerblades, skateboard...
Shared Bike	Vélib', V'cub, Yélo, vélhop: bike-sharing services
Motorized two-wheelers	Moped, motorized scooter, motorcycle
Private car (not electric)	Driver (or passenger) in a private car owned by relatives
Private Electric car	Driver (or passenger) in a private electric car owned by relatives
Car-sharing	Station-based or free-floating car-sharing system: Autolib', Ouicar…
Car-pooling driver	Carpooling as a driver with its own private car and non-relative passengers
Car-pooling passenger	Carpooling as a passenger within a private car owned by non-relatives
Taxi	Taxi, cabs, Uber, Heetch
Bus, subway, tramway…	All Public road Transports: City bus, Bus Rapid Transit, tramway, subway…
Train	All trains from low-speed trains to high-speed trains
Intermodality	Public Transport + individual mode (to be specified)
Internet	Use of internet to avoid a journey (e-shopping, e-services, teleworking…)

Table 2: Transportation modes typology

3.3. Attributes

Attributes are the whole set of transportation mode characteristics. In other words, any mode can be evaluated in terms of this common set of attributes.

This attribute's structure is inspired by Brisbois' work which consists of a Principal Component Analysis about the modal choice criteria (Brisbois, 2011). In this paper, complementarity or substitutability of attributes are not taken into account since we consider attributes as independent.

Attributes	Sub-attributes	Definition
Cost	Financial accessibility	Cost of path / of the mode
	Time productivity	Benefits from the use of travel time / within the mode
Security	Accidents	Security feeling about road hazards / about mode hazards
	Assaults	Security feeling about other individuals / within the mode
Efficiency	Spatial accessibility	Potential moving distance / mode distance
	Temporal accessibility	Potential moving speed / mode speed
	Reliability / Flexibility	Sensitivity to the unexpected and potential of adaptation / of the mode
Comfort	Psychological comfort	Atmosphere, journey privacy / mode privacy
	Physical comfort	Seat during the journey / mode's comfort
Identity	Status	Mobility as a status for others / mode as a status
	Sensations / Control	Mobility as an identity for itself / mode as an identity
Ease of use	Cognitive accessibility	Ease of understanding of the journey / of the mode
	Physical accessibility	Ease of physical skills to be mobilized for the journey / to use the mode

Table 3: Typology of attributes

Saaty & Ozdemir stated "*that to serve both consistency and redundancy, it is best to keep the number of elements seven or less. It appears that George Miller's seven plus or minus two is indeed a limit, a channel capacity, on our ability to process information*" (Saaty & Ozdemir, 2003, p244). It fits with our typology in which there are six attributes.

4. The Analytic Hierarchy Process (AHP) method

"*The Analytic Hierarchy Process (AHP) is a general theory of measurement*" (Saaty, 1987, p161), and more specifically a hierarchical multi-criteria choice model to find out modal preferences. This method is used to quantify attitudes (see part 4.1) and perceptions (see part 4.2). Combining attitudes and perceptions, we built modal preferences (see part 4.3).

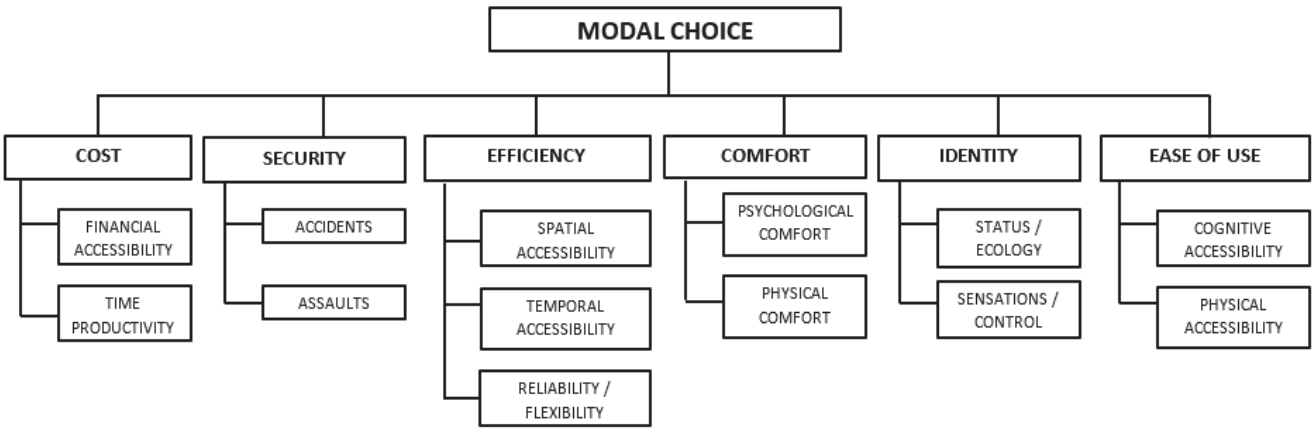


Figure 4: Structure of attributes

The Figure 4 above represents the structure of the set of attributes as represented for the AHP method. Each attribute is composed of two or three sub-attributes which define it. These attributes and sub-attributes are detailed above in Table 3.

4.1. Attitudes: relative measurement

4.1.1. Principles

This part explains the main principles of AHP method developed by Saaty.

"*To make a decision in an organized way to generate priorities, we need to decompose the decision into the following steps:*

1) Define the problem and determine the kind of knowledge sought.

2) Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

3) Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

4) Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then, for each element in the level below, add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained." (Saaty, 2008, p85)

The next step is to derive the weights of priorities. It has been shown that this scale is obtained by solving for the principal eigenvector of the matrix and then normalizing the result" (Saaty, 1987, p165).

Indeed, "*the principal eigenvector is a necessary representation of the priorities"* (Saaty, 2003).

To make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property used to compare them. Table 4 exhibits the scale in question.

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Table 4: Saaty's AHP scale
(Saaty, 1977)

The axioms of AHP are the following:

- *"Reciprocity*: *This axiom says that the comparison matrices we construct are formed of paired reciprocal comparisons, for if one stone is judged to be five times heavier than another, then the other must perforce be one-fifth as heavy as the first. It is this simple but powerful relationship that is the basis of the AHP*.[…]
- *Homogeneity*: *Homogeneity is essential for meaningful comparisons, as the mind cannot compare widely disparate elements*. […]
- *Dependency*: *Let H be a hierarchy with levels* L_1, L_2 ,..., L_h,. *For each* L_k, $k = 1, 2, .., h - 1$:
  - *(1)* L_{k+1}, *is outer dependent on Lk;*
  - *(2)* L_{k+1} *is not inner dependent with respect to all* $x \in L_k$;
  - *(3)* L_k, *is not outer dependent on* L_{k+1}[…]
- *Expectations*: *This axiom is merely the statement that thoughtful individuals who have reasons for their beliefs should make sure that their ideas are adequately represented in the model. All alternatives, criteria and expectations (explicit and implicit) can be and*

should be represented in the hierarchy. This axiom does not assume rationality. People are known at times to harbor irrational expectations and such expectations can be accommodated. […]" (Saaty, 1987, p166-169)

In other words, let "X_i" be an attribute from i=1 to 6 and "$\alpha_{i,j}$" be the weight of the pairwise comparison between attribute i and attribute j with i=1 to 6 and j=1 to 6.

From AHP method, we have the following "Saaty's" matrix:

	X_1	X_2	X_3	X_4	X_5	X_6
X_1	$\alpha_{1,1}$	$\alpha_{1,2}$	$\alpha_{1,3}$	$\alpha_{1,4}$	$\alpha_{1,5}$	$\alpha_{1,6}$
X_2	$\alpha_{2,1}$	$\alpha_{2,2}$	$\alpha_{2,3}$	$\alpha_{2,4}$	$\alpha_{2,5}$	$\alpha_{2,6}$
X_3	$\alpha_{3,1}$	$\alpha_{3,2}$	$\alpha_{3,3}$	$\alpha_{3,4}$	$\alpha_{3,5}$	$\alpha_{3,6}$
X_4	$\alpha_{4,1}$	$\alpha_{4,2}$	$\alpha_{4,3}$	$\alpha_{4,4}$	$\alpha_{4,5}$	$\alpha_{4,6}$
X_5	$\alpha_{5,1}$	$\alpha_{5,2}$	$\alpha_{5,3}$	$\alpha_{5,4}$	$\alpha_{5,5}$	$\alpha_{5,6}$
X_6	$\alpha_{6,1}$	$\alpha_{6,2}$	$\alpha_{6,3}$	$\alpha_{6,4}$	$\alpha_{6,5}$	$\alpha_{6,6}$

Matrix 1: Matrix of attitudes

with $\alpha_{i,j} = 1/\alpha_{j,i}$

To calculate the weight of attributes, we need to find the principal eigenvector as shown in the last column of Matrix 2 below. Let A be a *n* x *n* matrix. The number λ is an eigenvalue of A if there exists a non-zero vector v such that Av= λv. In this case, vector v is called an eigenvector of A corresponding to λ.

	X_1	X_2	X_3	X_4	X_5	X_6	**Priority vector**
X_1	1	$\alpha_{1,2}$	$\alpha_{1,3}$	$\alpha_{1,4}$	$\alpha_{1,5}$	$\alpha_{1,6}$	w_1
X_2	$1/\alpha_{1,2}$	1	$\alpha_{2,3}$	$\alpha_{2,4}$	$\alpha_{2,5}$	$\alpha_{2,6}$	w_2
X_3	$1/\alpha_{1,3}$	$1/\alpha_{2,3}$	1	$\alpha_{3,4}$	$\alpha_{3,5}$	$\alpha_{3,6}$	w_3
X_4	$1/\alpha_{1,4}$	$1/\alpha_{2,4}$	$1/\alpha_{3,4}$	1	$\alpha_{4,5}$	$\alpha_{4,6}$	w_4
X_5	$1/\alpha_{1,5}$	$1/\alpha_{2,5}$	$1/\alpha_{3,5}$	$1/\alpha_{4,5}$	1	$\alpha_{5,6}$	w_5
X_6	$1/\alpha_{1,6}$	$1/\alpha_{2,6}$	$1/\alpha_{3,6}$	$1/\alpha_{4,6}$	$1/\alpha_{5,6}$	1	w_6

Matrix 2: Saaty's matrix with priority vector

As we need to ask individuals for pairwise comparison through a survey, we try to reduce the amount of pairwise comparisons in order to shorten the length of the questionnaire. To do so, the General Transitivity Rule (GRT) from Srdjevic & al., 2014, for a matrix of order six, and missing entry $\alpha_{5,6}$, tells us there are only four first-level transitions, namely $\alpha_{5,6} = \alpha_{5,1} \cdot \alpha_{1,6} = \alpha_{5,2} \cdot \alpha_{2,6} = \alpha_{5,3} \cdot \alpha_{3,6} = \alpha_{5,4} \cdot \alpha_{4,6}$.

Srdjevic & al., 2014 allow us to find $\alpha_{i,j}$ knowing all first-level transitions averaging geometrically and round the result to the closest numerical value from Saaty's scale. If the value found is out of the scale, then authors propose to scale it to make it fall within the range of Saaty's scale. In our case of a matrix of order six, we can find three pairwise comparisons with respect to a specific condition. Indeed, we can find $\alpha_{i,j}$, $\alpha_{k,l}$ and $\alpha_{m,n}$, knowing all their first-level transitions. It is the case when $i \neq j \neq k \neq l \neq m \neq n$:

$\alpha_{i,j} = \alpha_{i,k} \cdot \alpha_{k,j} = \alpha_{i,l} \cdot \alpha_{l,j} = \alpha_{i,m} \cdot \alpha_{m,j} = \alpha_{i,n} \cdot \alpha_{n,j}$

$\alpha_{k,l} = \alpha_{k,i} \cdot \alpha_{i,l} = \alpha_{k,j} \cdot \alpha_{j,l} = \alpha_{k,m} \cdot \alpha_{m,l} = \alpha_{k,n} \cdot \alpha_{n,l}$

$\alpha_{m,n} = \alpha_{m,i} \cdot \alpha_{i,n} = \alpha_{m,j} \cdot \alpha_{j,n} = \alpha_{m,k} \cdot \alpha_{k,n} = \alpha_{m,l} \cdot \alpha_{l,n}$

4.1.2. Transitivity solution

Transitivity is one of the important axiom dealing with preferences in economy. This axiom states that if the alternative A is preferred to B and the alternative B is preferred to C, then, A is preferred to C. In this paper, for a multi-criteria decision making, transitivity obviously needs to be satisfied. Ji & Jiang, 2003 therefore criticized the AHP method saying that it suffers from scale intransitivity. This is why they derived a transitive scale for the AHP. The scale is composed of two parts: a verbal one and a numerical one. The AHP scale respects the transitivity property if its verbal component follows an arithmetic progression and the numerical part a geometric one.

Let $D = \{d_{ij}\}$ denote the judgment matrix defined on the digitized verbal part, and $A = \{\alpha_{ij}\}$ the judgment matrix defined on a geometric scale. D and A are connected by the mapping: $a_{ij} = u^{d_{ij}}$ with "u" the geometric progression parameter.

Transitivity holds if $d_{ik} = d_{ij} + d_{jk}$ and if $\alpha_{ik} = \alpha_{ij} \times \alpha_{jk}$. To find the value of "u", Ji & Jiang, 2003 proposed this formula: $\sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{ij}^{Saaty} = \sum_{i=1}^{n}\sum_{j=1}^{n} u^{d_{ij}}$.

Our new behavioral framework is based on this geometric scale given by Ji & Jiang, 2003. Applying this geometric scale to the matrix of attitudes leads to a transitive matrix. Using the different values of "u", we can build clusters to have a more detailed analysis, so each cluster has its own "u". Here, "u" refers to the substitutability level between attributes. In other words, when "u" increases, substitutability of attributes decreases. If "u"= 1, then attributes are perfectly substitutable. Complementarity (perfect or partial) between attributes is not present here because we use a geometric progression. And even if "u" goes to infinity, attributes are less and less substitutable but never not substitutable.

The next step consists in determining a corresponding arithmetic progression for the verbal scale. The relation between Saaty's scale and the geometric progression is given and we find the arithmetic and verbal scales, as reported in Table 5 below:

Saaty's scale	1/9	1/7	1/5	1/3	1	3	5	7	9
Geometric Transitive $u^{(x-1)}$	u^{-8}	u^{-6}	u^{-4}	u^{-2}	u^{0}	u^{2}	u^{4}	u^{6}	u^{8}
Arithmetic scale	-4	-3	-2	-1	0	1	2	3	4
Verbal scale	Absolutely less	Strongly less	Less	Slightly less	Equally **important**	Slightly more	More	Strongly more	Absolutely more

Table 5: Scales' correspondence

"u" represents the utility convexity. In other words, the marginal satisfaction is an increasing function of the 1 to 9 grade. In this case, each individual has their own value of "u". Depending on this value, we are able on the one hand to analyze the degree of utility convexity for each individual and on the other hand to see the extent to which this concavity is distributed among individuals. Indeed, Gensch & Javalgi, 1987, p880 support the fact that "non-comparable scalings are common in real-world choice problems".

The importance of the value of "u" is supported by Ji & Jiang, 2003 who said that "a specific problem has a specific priority vector". This determines a different use of frequencies of relative importance gradations and requires a different value of "u".

Using this geometric progression and having a fix set of attributes imply that there is no rank reversal possibility. In other words, thanks to this AHP method, we have two kinds of output: a weighted (or cardinal) hierarchy of attributes, and a simple (or ordinal) hierarchy with no weight (as there is no rank reversal possibility).

Knowing the simple hierarchy is particularly useful to test different decision rules (compensatory and non-compensatory rules).

Moreover, these two kinds of outputs will be used at a later time to test the predictability of the three different models presented above. It is however not part of this paper because of data non-attendance, as already said above.

4.2. Perceptions: absolute measurement

4.2.1. Principles

In the first version of the AHP method, each alternative has to be compared pairwise with all the others with respect to each criterion. This relative method is more accurate. But in 2008, Saaty stated that "*the ratings method has the advantage that one can rate large numbers of alternatives rather quickly, and the results are adequately close*" (Saaty, 2008, p90).

To obtain priorities from absolute measurement method, rating categories have to be established for each criterion. In our paper, we use a common rating category (explained in part 4.2.2) because of the qualitative aspect of the criteria (Saaty, 1986, p327).

"The idealized priorities are always used for ratings" (Saaty, 2008, p90). The idealized priorities are the priorities normalized by the largest priority (dividing by the largest priority).

A considerable advantage of absolute measurement is that there is no rank reversal of alternatives even if a new alternative is added or deleted. It is a good point in the sense that we do not have to fix a set of alternatives not to change it. Otherwise it would have been necessary to repeat the complete method again from the beginning. (Saaty, 1986, p327)

In the present research work, the rating categories for each criterion are built based on a 1-9 scale, and are common to all criteria because of their qualitative aspect:

Verbal scale	Not important	Very poor	Poor	Below average	Average	Above average	Good	Very good	Perfect
Arithmetic scale	0	0,5	1	1,5	2	2,5	3	3,5	4
Saaty's scale	1	2	3	4	5	6	7	8	9

Table 6: Absolute measurement correspondence between verbal and arithmetic scales

For further details about absolute measurement, we refer the reader to Saaty, 1986.

4.2.2. Transitivity matrix on a 1-9 scale

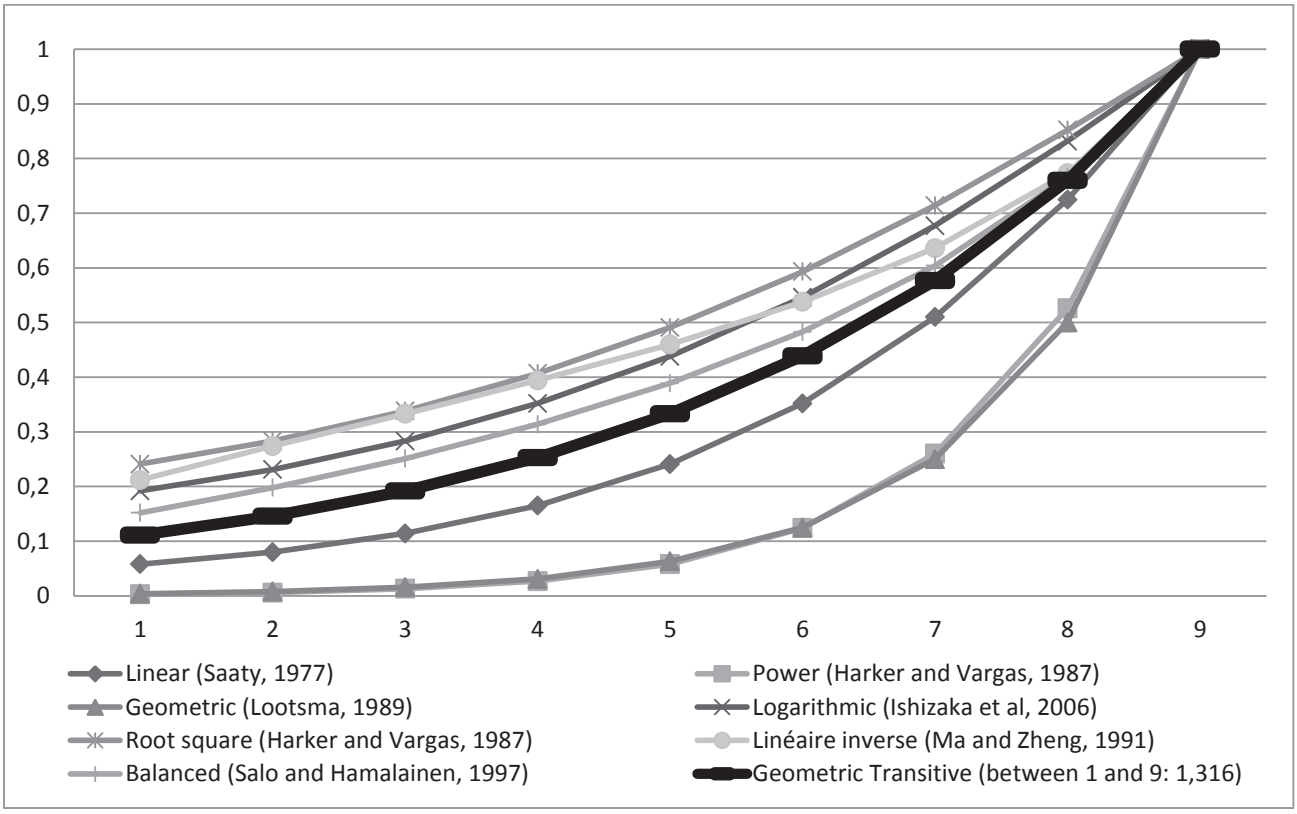
In this paper, identifying a common scale for all the attributes is needed. As attributes are qualitative and subjective and since absolute measurement is possible, we use the transitive rules proposed by Ji & Jiang, 2003 above (with "u"= 1.316, meaning that the geometric progression is $1.316^{(x-1)}$) to build a perfectly transitive and perfectly consistent judgment matrix on a 1-9 scale:

	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Priorities**	**Ideal**
9	1	**1,316**	1,732	2,28	3	3,948	5,196	6,839	9	0,262	**1,000**
8	0,76	1	1,316	1,732	2,28	3	3,948	5,196	6,839	0,199	**0,760**
7	0,577	0,76	1	1,316	1,732	2,28	3	3,948	5,196	0,151	**0,577**
6	0,439	0,577	0,76	1	1,316	1,732	2,28	3	3,948	0,115	**0,439**
5	0,333	0,439	0,577	0,76	1	1,316	1,732	2,28	3	0,087	**0,333**
4	0,253	0,333	0,439	0,577	0,76	1	1,316	1,732	2,28	0,066	**0,253**
3	0,192	0,253	0,333	0,439	0,577	0,76	1	1,316	1,732	0,050	**0,192**
2	0,146	0,192	0,253	0,333	0,439	0,577	0,76	1	1,316	0,038	**0,146**
1	0,111	0,146	0,192	0,253	0,333	0,439	0,577	0,76	1	0,029	**0,111**

Matrix 3: Perfectly consistent and transitive matrix for absolute measurement on a 1-9 scale

In terms of perceptions, we obviously need to use idealized priorities since the best grade represents the perfection from the individual's point of view. This way, each weight corresponds to each absolute measurement of transportation mode's attributes from 1 to 9.

As we already said above, "u" represents the degree of substitutability. Here, 1.316 is the value of "u" representing the perfect substitutability level between perception levels for a 1-9 scale. As already said, the marginal satisfaction is an increasing function of the 1 to 9 grade.



Graph 1: AHP scales in absolute measurement

Figure 4 above helps to compare the different scales used in the literature for AHP method. It also shows that the "Geometric Transitive" convex curve lies between the other curves; this suggests that this geometric progression is not absurd at all.

Let "Z_i" be the alternatives and "$\beta_{i,j}$" be the absolute measurement of mode i about attribute j. It gives the following matrix:

	X_1	X_2	X_3	X_4	X_5	X_6
Z_1	$\beta_{1,1}$	$\beta_{1,2}$	$\beta_{1,3}$	$\beta_{1,4}$	$\beta_{1,5}$	$\beta_{1,6}$
Z_2	$\beta_{2,1}$	$\beta_{2,2}$	$\beta_{2,3}$	$\beta_{2,4}$	$\beta_{2,5}$	$\beta_{2,6}$
Z_n	$\beta_{n,1}$	$\beta_{n,2}$	$\beta_{n,3}$	$\beta_{n,4}$	$\beta_{n,5}$	$\beta_{n,6}$

Matrix 4: Matrix of perceptions

4.3. Preferences

Preferences are determined by combining weight of attributes and their attribute-level for each alternative. This leads to the following Table:

priority vector	w_1	w_2	w_3	w_4	w_5	w_6	Preferences weights	Normalized preferences
	X_1	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**		
Z_1	$\beta_{1,1}$	$\beta_{1,2}$	$\beta_{1,3}$	$\beta_{1,4}$	$\beta_{1,5}$	$\beta_{1,6}$	$\sum_{i=1}^{6}(w_i \times \beta_{1,i})$	$\frac{\sum_{i=1}^{6}(w_i \times \beta_{1,i})}{\sum_z(\sum_i(w_i \times \beta_{z,i}))}$
Z_2	$\beta_{2,1}$	$\beta_{2,2}$	$\beta_{2,3}$	$\beta_{2,4}$	$\beta_{2,5}$	$\beta_{2,6}$	$\sum_{i=1}^{6}(w_i \times \beta_{2,i})$	$\frac{\sum_{i=1}^{6}(w_i \times \beta_{2,i})}{\sum_z(\sum_i(w_i \times \beta_{z,i}))}$
Z_n	$\beta_{n,1}$	$\beta_{n,2}$	$\beta_{n,3}$	$\beta_{n,4}$	$\beta_{n,5}$	$\beta_{n,6}$	$\sum_{i=1}^{6}(w_i \times \beta_{3,i})$	$\frac{\sum_{i=1}^{6}(w_i \times \beta_{n,i})}{\sum_z(\sum_i(w_i \times \beta_{z,i}))}$

Table 7: Preferences

By combining attitudes and perceptions, we have obtained a hierarchy of alternative preferences.

In AHP method, the model ends at this stage. In the same manner, and to highlight the theoretical preferences of transportation modes, we can also stop the method here by taking the choice set constraint or modal portfolio into account and then predict the final mode choice. Instead and as already said above, we prefer to compare this result with two other methods, namely a compensatory standard model and non-compensatory models both named decision rules. It is easy to think about Attribute Non-Attendance (ANA) when speaking about non-compensatory decision rules. Indeed, our framework allows us to make Monte-Carlo simulations to test ANA. Hole (2011) found *"that a substantial share of respondents ignored one or more of the attributes when making their choices."* The difference between ANA and non-compensatory decision rules is that in ANA, from the whole set of attribute, we define one attribute (or more) with a zero coefficient and see how predictive the results are. On the other hand, in non-compensatory decision rules, we look for the threshold level of each attribute from which ANA happens. In her paper, Lagarde (2013) uses latent classes where each class represents a specific non-attendance decision rule. Nevertheless, in our paper, each class represents a specific non-compensatory decision rule.

5. Decision rules

As explained in the introductory part, we believe that non-compensatory models are better suited to explain modal choice. Here we focus on the different decision rules that can be used to choose a transportation mode. As already said above, a **decision rule** is an intellectual process used by

individuals to make a choice among different alternatives. This process can be applied to attributes (processing by attribute) requiring individuals to search for information about this attribute for each of the alternatives considered. The term "**threshold**" is pivotal in non-compensatory decision rules. It was introduced by Georgescu-Roegen (1936 & 1958), through the theory of consumer behavior, who suggested that "*a choice will be considered only when the positive range or threshold of insensitivity is overcome*" (Gensch & Javalgi, 1987, p870). Decision rules can be divided into two parts: on the one hand the compensatory approach, and on the other hand the satisfying approaches (or the non-compensatory models).

The compensatory linear (standard) approach means that an unfavorable position on a criterion may be compensated by a favorable position on another criterion. "*It is a rule where the deterministic portion of the utility of the offering must exceed a threshold value to be acceptable: (I(Vj > ϒ) = 1) where V_j denotes the deterministic portion of utility of choice alternative i and ϒ is the parameter to be estimated."* (Gilbride & Allenby, 2004, p393).
The choice is based on the maximization of a utility function.

As we already argued above, we believe that mode choice can be better explained through non-compensatory decision rules.

In the satisfying approach, *"the choice is based not on the maximization of a utility function, but on reaching a minimum satisfaction level"* (Gensch & Javalgi, 1987, p872). Four non-compensatory decision rules can be distinguished:

A **Conjunctive process "***requires the rejection of any alternative which failed to meet any one minimum criterion of acceptability*" (Forester, 1979, p21). In other words, "*a conjunctive rule is formed by multiplying indicator functions across the attributes (m) of an offering:*

$$\prod_m I\left(x_{jm} > \Upsilon_m\right) = 1$$

where x_{jm} is the level of attribute m for choice alternative j. The cutoff value, Υ_m, is the smallest level of the attribute that needs to be present for the decision maker to consider the offering (=1). If the cutoff value is smaller than all levels of the attribute, then the attribute is not used to screen (=0)" (Gilbride & Allenby, 2004, p393).
Conjunctive-choice processes have been identified by Foerster (1979) as potential screening rules in the field of transportation. For example, when an individual needs to go to work and asks for no more than 30 minutes trip (it refers to *temporal accessibility*), no more than 2 euros (it refers to *financial accessibility*) and in a very safe transportation mode (it refers to *security*), if one of the transportation mode in the choice set either lasts more than 30 min or costs more than 2 euros or is not safe enough, this transportation mode is not chosen by the individual. It means there is a minimum acceptable level for each attribute.

In our case, we believe that individuals have a psychological limit about the number of attributes taken into account in their mode choice. It means that individuals have an even stronger psychological limit about the number of acceptability thresholds. Nevertheless, we can expect a cluster of individuals using this decision rule. This cluster would mainly be composed by mobility experts or more generally, by the most demanding individuals.
Using this rule, an alternative is acceptable if and only if it meets the level (w_i) of all criteria (x_i). See the following graph as an example of a conjunctive rule.

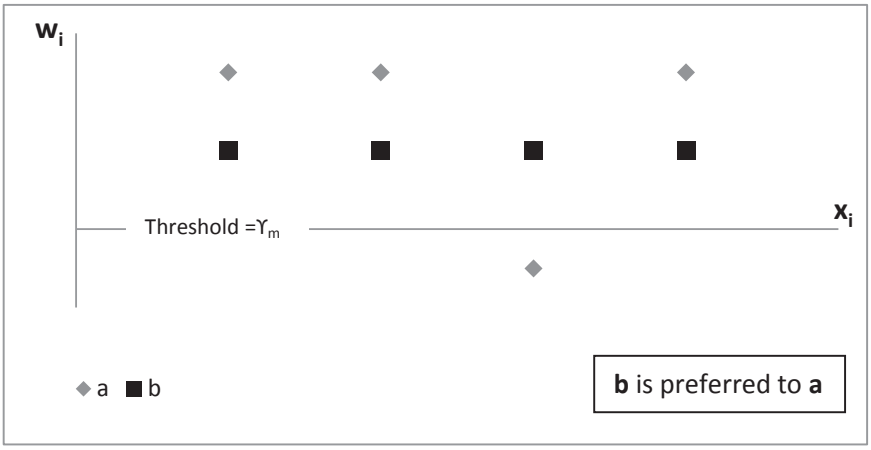


Figure 5: Conjunctive rule

Inspired by Foerster, 1979, p21

A **Disjunctive process** "*is a decision rule where at least one of the attribute levels is acceptable*: $\sum_m I(x_{jm} > \Upsilon_m) \geq 1$"(Gilbride & Allenby, 2004, p393).
For example, if an individual needs to go to work and wants to have a profitable time (it refers to *temporal productivity*) during the trip, he does not ask for an active transportation mode and maybe choose Public Transports. Even if Public Transports are dirty, noisy, slow and costly, the individual does not choose the personal car or the bike. If there is no alternative that meets this threshold, it can be compensated by another attribute which is over the threshold. For example, if there is no passive transportation mode, the individual can compensate by a free trip (it refers to *financial accessibility*). This compensation aspect is different from compensatory model. Indeed, in compensatory model, the compensable attributes need to serve the same purpose (in standard economy in general, the common purpose of any variables is the utility, expressed in euros) while in a disjunctive model, they tend to do so. In this example, temporal productivity and financial accessibility both imply less cost.
In our case, we believe that in general, individuals have more than one acceptability threshold. Nevertheless, we can expect a cluster of individuals using this decision rule. This cluster would be mainly composed by the least demanding individuals and/or the most flexible ones.

Using, this rule, an alternative is acceptable if it meets the level (w_i) of at least one criterion (x_i). See the following graph as an example of a disjunctive rule:

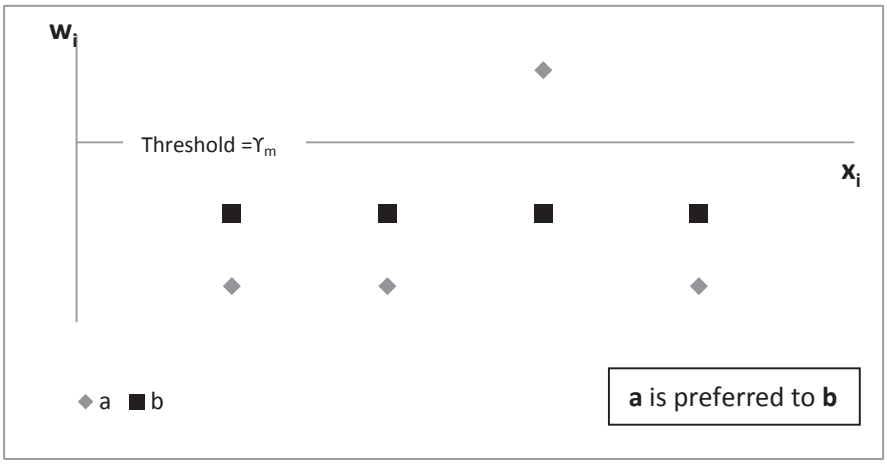


Figure 6: Disjunctive rule

Inspired by Foerster, 1979, p22

In a **Subset conjunctive process**, *"a profile must have S features above a threshold. Subset conjunctive generalizes both disjunctive (S = 1) and conjunctive (S = number of features). As defined and applied, any S of the features need to be above the threshold"* (Hauser & al., 2009, p11). For example, if S=2, in our case, an individual will choose the alternative which is above a minimum threshold for the two attributes included in S.

In our case, as already said above, we believe that in general individuals have more than one acceptability threshold. It means that we can expect different clusters (meaning different value for S with different attributes' thresholds) of individuals using this decision rule. These clusters would be composed by the majority of the population and defined by the number of acceptability thresholds taken into account and the corresponding attributes.

A **Lexicographic process** "*involves the sequential process in which alternatives are first compared in terms of the attribute values on only the most important attribute, and the alternative with the highest value is selected. If two or more alternatives are tied for the same attribute value, the next most important attribute is considered, and so forth*" (Gensch & Javalgi, 1987, p873):

$$I(x_{j1} > x_{i1} > \Upsilon_m) \geq 1$$

where x_{jm} is the level of attribute m for choice alternative j. The cutoff value, Υ_m, is the smallest level of the attribute that needs to be present for the decision maker to consider the offering and $j \neq i$.

For example, if an individual urgently needs to go to hospital, he asks for the fastest (it refers to *temporal accessibility*) transportation mode able to bring him there. Here, the most important attribute is the temporal accessibility and the individual chooses the transportation mode with the

highest level of this attribute. He chooses the taxi. But if there are two alternatives (taxi and subway) with the same rapidity, the individual makes a tradeoff for the second most important attribute. In this example, the individual may want the less shaky transportation mode (it refers to *physical comfort)* and then choose the taxi.

In our case, we believe that in general, individuals take more than one attribute into account to choose their transportation mode. Nevertheless, we can expect two clusters of individuals using this decision rule. The first cluster would be mainly composed by the poorer individuals who would always choose the cheapest mode. The second cluster would be mainly composed by the richer individuals who would always choose either the fastest mode or the most comfortable one or the most time productive one.

See the following graph as an example of a lexicographic rule:

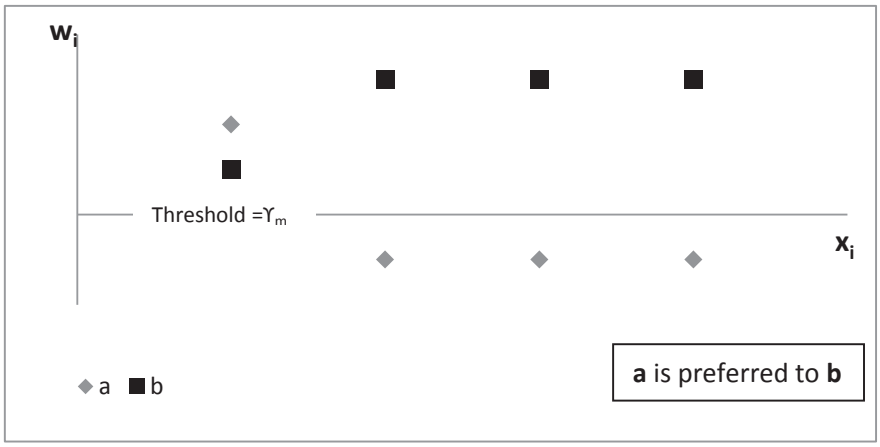


Figure 7: Lexicographic rule

Inspired by Foerster, 1979, p20

Elimination by Aspect (EBA) "*is a function of only those attributes that are not common to all the alternatives*" (Gensch & Javalgi, 1987, p874). It does not fit with our framework because we consider a common set of attributes for all transportation modes. In other words, there is no specific attribute for any transportation mode.

To support the test of non-compensatory models in our paper, Gensch & Javalgi (1987) stated that segmenting methods by model types increases predictive ability and the understanding of behavioral processes. Moreover, Levin & Jasper (1995) found that for an automobile choice, 86% of the choice processes are non-compensatory. These two findings allow us to believe that the decision processes for mode choice are not as simple as a compensatory linear process. The next question is: which decision rule for which individual? It is the reason why here we want to test every non-compensatory decision rule and then cluster individuals depending on which one they use. The main purpose is here to find the most predictive set of decision rules. To do so, we now know that we need to analyze the importance of attributes for individuals, the level of the perception of attributes for all

alternatives, the modal portfolio, the decision processes used by individuals with their corresponding thresholds and the final choice.

6. Conclusions and future research

In this contribution, we try to better explain the decision-making process of modal choice using the AHP method developed by Saaty (1977) within the behavioral framework developed by Ben-Akiva & Boccara (1987). Speaking about the AHP method, we use the relative measurement to quantify attitudes toward modal choice and the absolute measurement to quantify transportation mode perceptions. It results in hierarchy of preferences used to test different choice processes and then build clusters to improve the analysis of mobility demand structure.

The final goal of this framework is to model "shocks" with the modal shift as output. As our framework is based on the mobility demand of individuals, the only shocks we are able to model here are exogenous demand shocks (unanticipated changes in demand). Different kinds of shocks can be investigated depending on the time horizon. In a short term, we consider both attitudes and modal portfolio as fixed because of their time inertia. Alternatively, perceptions have no real inertia. Therefore, to model short term shock, such as public policy, we assume that only perceptions change. Precisely, these changes of perceptions are applied to some specific group(s) of individuals for specific attribute(s) related to specific mode(s). To determine which group(s) of individuals is(are) concerned, which attribute(s) is(are) impacted, and of which mode(s), existing research works can be used as regard to "known shocks", but for "new shocks", we will base our scenario on expert judgment.
Besides, in the mid-term or the long-term, we consider that attitudes and modal portfolio can change. Starting from foresighting scenarios, we know both the direction and the amplitude of the changes of attitudes and the new modal portfolio repartition. To go further, it is also be possible to model a new sociodemographic structure of individuals.

To sum up, the framework is very flexible and enables us to model changes in perceptions, in attitudes, in modal portfolio or even in sociodemographic structure. In other words, this framework is well fitted to understand the construction of preferences and decision processes within the modal choice. Finally, a foresighting modeling of mobility demand is also possible.

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