

THE SELECTION OF A MODE OF URBAN TRANSPORTATION: INTEGRATING PSYCHOLOGICAL VARIABLES TO DISCRETE CHOICE MODELS

ELECCIÓN DE UN MODO DE TRANSPORTE URBANO INTEGRANDO VARIABLES PSICOLÓGICAS A MODELOS DE ELECCIÓN DISCRETA

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ABSTRACT: A study using revealed preference surveys and psychological tests was conducted. Key psychological variables of behavior involved in the choice of transportation mode in a population sample of the Metropolitan Area of the Valle de Aburrá were detected. The experiment used the random utility theory for discrete choice models and reasoned action in order to assess beliefs. This was used as a tool for analysis of the psychological variables using the sixteen personality factor questionnaire (16PF test). In addition to the revealed preference surveys, two other surveys were carried out: one with socio-economic characteristics and the other with latent indicators. This methodology allows for an integration of discrete choice models and latent variables. The integration makes the model operational and quantifies the unobservable psychological variables. The most relevant result obtained was that anxiety affects the choice of urban transportation mode and shows that physiological alterations, as well as problems in perception and beliefs, can affect the decision-making process.

KEY WORDS: mode choice, psychological variables, psychology of transportation

RESUMEN: Aplicando encuestas de preferencias reveladas y cuestionarios psicológicos se realizó un estudio detectando variables psicológicas claves de la conducta que intervienen en la elección de un modo de transporte en un grupo de habitantes del Área Metropolitana del Valle de Aburrá. Se tuvo en cuenta la teoría de la utilidad aleatoria para los modelos de elección discreta y la acción razonada para evaluar las creencias y se utilizó como herramienta de análisis de las variables psicológicas el cuestionario de factor de personalidad (16PF). Además de las encuestas de preferencias reveladas, se aplicaron otras dos encuestas: una de categorías socioeconómicas, y otra con indicadores latentes. Esta metodología permite una integración de modelos de elección discreta y de variables latentes, que lo hace operativo y cuantifica las variables psicológicas inobservables. El resultado más relevante que se obtuvo fue que la ansiedad incide en la elección de un modo de transporte urbano y se muestra que una alteración fisiológica, problemas en la percepción, y las creencias pueden afectar el proceso de toma de decisiones.

PALABRAS CLAVE: elección modal, variables psicológicas, psicología del transporte

1. INTRODUCTION

The urban transportation system is one of the cornerstones of the social and economic development of a city. Its proper functioning largely depends on daily activities that must be performed. The system creates mobility in regions like the *Valle de Aburrá*, with increasing populations and all the consequences for mobility that this increase brings, phenomena such as pollution, accidents, and traffic congestion [1].

Transportation engineers provide part of the solution to the problems caused by the growth of cities, in terms of population, motorization, and economic development. Urban growth involves a steady increase in transportation demand that is greater than the supply, often due to economic and political decisions. In these cases, it is necessary to use models to simulate events or scenarios to make the decision-making process faster and to produce reliable results for the decision-maker.

Modal choice is very important for individuals in society, and is often influenced by supply, economic issues, or personal aspects. Discrete choice models based on a random utility theory are stochastic processes. The probability of obtaining a particular response is a function of a set of explanatory variables such as socioeconomic characteristics and the relative attractiveness of each option. The predictive results of these models applied to transportation can be improved if brought together with the understanding of psychological processes.

The basis of discrete choice econometric models is neoclassical economic theory. Neoclassical economists were those who formalized, during the second half of the nineteenth and the early twentieth centuries, the economic models of partial equilibrium and general equilibrium, models that have survived up to the present. The models presently assume an absolute human rationality. This rationality maximizes benefits and minimizes costs. However, it can easily be seen that perfect rationality is very difficult to achieve in humans, so models must take into account their behavior on a daily basis, using those which are psychological, social, and economic variables, which might influence their decisions. Understanding social norms, attitudes, intentions, perceptions, and the overall psyche of the users will improve travel demand models, especially modal choice.

This article is composed of five sections. Section 2 describes the theories of random utility and reasoned action. Sections 3 and 4 explain the tests carried out and the most relevant results, and Section 5 presents the conclusions and key findings of the research.

2. THEORETICAL FRAMEWORK

A model is the simplified representation of reality using a mathematical system. It takes the most representative variables of a system and evaluates their influence by testing several alternatives. It allows knowing the characteristics of the system, substantially increases the number of alternatives to be evaluated, and optimizes the design of solutions [2].

The first step in travel demand modeling is trip generation, which seeks to explain the trips produced and attracted, based on socioeconomic variables. The

next step is to distribute the trips according to a specific criterion that generally uses a mathematical model (gravity model), calibrated to replicate trip distribution according to impedance (cost), and to determine the future origin-destination matrices from the base year. At this point, a new element comes into play: the transportation modes and modal split through them, which are linked to characteristics such as comfort, service level, cost, travel time, etc. In this step, the psychological variables have to be considered, since these are very important to the user's behavior. After this stage, the traffic is assigned to the road network. Here the number of passengers that will travel every hour, in one direction and in a certain mode of transportation is estimated [1].

2.1 Econometric discrete choice models

Discrete choice models arise as stochastic models in which the probability of obtaining a particular response is a function of a set of explanatory variables. These models are based on the random utility theory. The implicit assumption that must be borne in mind is to use cross sectional data.

In general terms, discrete choice models are based on the theory that "The probability that individuals choose a given option is a function of their socioeconomic characteristics and the relative attractiveness of this option." [3]. It must also take into account psychological variables, which play an important role in the process of selection of the various modes of transport. We also need to know the behavior of a group of individuals in aggregate form, such as the market demand for goods or services. However, information is usually collected at the individual level, as in the case of revealed preference techniques. Therefore, it is necessary to introduce the basics of modeling individual choices that are described below.

The microeconomic analysis of consumer behavior is based on the fundamental assumption that the rational consumer will always choose the combination of alternatives that is most useful for him. However, psychological variables such as attitude, social norms, and anxiety will also influence transportation mode choice. Consequently, these variables need to be included in the analysis.

There is a set of feasible alternatives for the set of all combinations that consumers can choose. Then, if $p = (p_1, p_2, \dots, p_k)$ is the vector of prices of all goods X , and there is available income I of the consumer q , the set of all possible combinations is given by Eq. (1):

$$A(q) = \{x \in X: p \cdot x \leq I\} \quad (1)$$

Thus, the problem facing the consumer to maximize the utility can be expressed as Eq. (2):

$$\text{Max } U(x) \text{ s.t. } p \cdot x \leq I \quad x \in X \quad (2)$$

To solve this problem, the random utility theory [4] was used, which states, as mentioned before, that individuals belonging to a certain homogeneous population Q , act rationally and have perfect information. There must be a set $A = \{A_1, A_2, A_3\}$ of alternatives available, which must meet three characteristics: first, they must be mutually exclusive from the perspective of the decision maker, and making an alternative choice does not necessarily imply any of the others; second, the set must be exhaustive, where all possible alternatives should be included and the individual must choose one; and third, the number of alternatives must be finite; otherwise discrete choice models cannot be applied. The set of alternatives available to an individual q is $A(q)$, and will have an associated set of attributes $x \in X$.

Each alternative $A_i \in A$ has an associated utility U_{iq} for individual q . The modeler, being an observer, has incomplete information on all the factors considered by individuals when making their choice; therefore, it is assumed that this utility can be represented by two components:

- I. A deterministic part, called *systematic* or *representative* utility V_{iq} which is a function of the measured attributes X . Typically, a linear additive function is used in parameters $V_{iq} = \sum \theta_{ikq} X_{ikq}$, where X_{ikq} represents the attribute value k of alternative A_i for individual q .
- II. A random part ε_{iq} that reflects the idiosyncrasies and preferences of each individual, as well as errors of measurement and observation by the modeler. It is generally assumed that the errors ε are random variables with zero mean and a probability distribution to be specified [5]. Thus, the utility function is depicted by Eq. (3):

$$U_{iq} = V_{iq} + \varepsilon_{iq} \quad (3)$$

Individual q chooses the most useful alternative, i.e., choose A_i if, and only if, Eq. (4) is satisfied:

$$U_{iq} \geq U_{jq} \quad \forall A_j \in A(q) \quad (4)$$

For more information about utility functions, refer to Ortúzar and Willumsen [6].

2.1.1 Multinomial Logit Model (MNL)

The MNL is the model used in this investigation and it is the discrete choice model most widely used. The model is obtained from assuming that the error terms in Eq. (3) are independently and identically distributed (i.i.d.), Gumbel distributed. Thus, the probability that an individual q chooses alternative i is given by Eq. (5):

$$P_{iq} = \frac{\exp(\mu \cdot V_{iq})}{\sum_{A_j \in A(q)} \exp(\mu \cdot V_{jq})} \quad (5)$$

where μ is a scaling factor related to the variance of the error term, $\mu = \pi / (\sqrt{6}\sigma)$.

2.1.2 Substitution Patterns

The MNL, with its assumption of i.i.d. errors, has the property of independence of irrelevant alternatives (IIA), which is expressed as Eq. (6):

$$P_{iq} / P_{jq} = \exp\{\mu(V_{iq} - V_{jq})\} \quad (6)$$

If two alternatives have any non-zero probability of being chosen, the ratio between the probabilities of choice of these is not affected by the absence or presence of any additional alternative in the set of available alternatives. This property makes the model fail if some alternatives are correlated, which is not considered by the model, such as the odds ratio between two alternatives remains constant, and is independent of the changes occurred in a third one.

This fact may be expressed in terms of cross-elasticities of the probabilities of the model. If we consider a change to an attribute of alternative j , we would like to know the effect of this change in the probability of all remaining alternatives. Now the elasticity of P_{iq} with respect to an attribute of alternative j is given by Eq. (7):

$$E_{X_{jkq}}^{P_{iq}} = -\theta_{jk} X_{jkq} P_{jq} \quad \forall i \neq j \quad (7) \quad \setminus s$$

where the elasticity of P_{iq} with respect to an attribute of alternative j is given by Eq. (10):

$E_{X_{jkq}}^{P_{iq}}$ is the value of attribute k of alternative j for individual q , and θ_{jk} is the coefficient (if the variable is incorporated into the utility representative in a non-linear form, then it corresponds to the derivative of V_{jq} with respect to X_{jkq}). This cross elasticity is the same for all i (the index i does not appear in the expression), which tells us that an improvement in the attributes of an alternative reduces the likelihood of all other alternatives in the same proportion. This pattern of substitution is a demonstration of ownership of IIA. The proportional substitution may be realistic in some choice situations, where the use of the MNL is appropriate.

2.2 Psychological variables

When considering the involvement of a human being, at least three fundamental aspects of his/her conduct have to be taken into account: the intention, the opportunity, and psychological variables (personality, emotions, neurophysiological characteristics, etc.). The *intention* arises from the interaction of attitude and social norm, which depends on behavioral and normative beliefs, respectively. The *opportunity* is closely related to socio-economic variables that are external to the individual, and *psychological variables* include the study of anxiety.

The econometric discrete choice models relate primarily to the *opportunity*. In this investigation, the anxiety variable is measured directly in the individual through the use of psychometrics (16PF test) [7], which provide a great contribution to discrete choice models because, to the best knowledge of the authors, there are no reports in the literature of such work including discrete choice models.

One of the most important physiological variables is anxiety. Anxiety can be observed from the physiological, cognitive, and behavioral perspective [8]:

- *Physiological perspective*: Physiological responses of preparation, to be active in attacking or fleeing. These include muscle tension and fast heart beats.

The person turns cold and pale with a fear of staying quiet and going unnoticed.

- *Cognitive perspective*: Cognitive responses are prepared. These include attention to possible threats and action planning.
- *Behavioral perspective*: Behavioral responses for problem solving, adjustment to and acceptance of the situation, or problem avoidance.

Anxiety can occur chronically, as a personality trait present during almost the entire life of the individual (generalized anxiety disorder, GAD). Episodes that give rise to fear of impending death, or fear of going crazy are called anxiety attacks (or panic attacks).

2.2.1 Characteristics of generalized anxiety disorder

- Constant state of hyper-vigilance and autonomic nervous system hyperactivity manifested by sweating, palpitations, stomach discomfort, shortness of breath, a dry mouth and a constant state of motor tension.
- It is related to chronic situations of stress, apprehension, worry, and difficulty with attention and concentration. It occurs more often in women than in men.
- Muscular stress manifested by headaches, an inability to relax, restlessness, and difficulty sleeping.

2.2.2 Characteristics of panic disorder

The symptoms are shortness of breath, dizziness, loss of consciousness, tremors, sweating, nausea, flushing, chills, pain, fear of going crazy or losing control, and numbness; then panic disorder can lead to alcohol and drug dependence.

All these disorders can affect the decision of individuals to drive. Accordingly, in some cases, they prefer to use public transport.

2.3 Theory of Reasoned Action

The theory of reasoned action [9] deals with the ability to predict probabilistically the intention that the subject

has of making a specific decision. The prediction could be based on the identification of his particular beliefs, own attitudes, and the role of social pressure in his life; i.e., as the result of the interrelationship between beliefs, attitudes, and intentions.

To decide what action to take in a particular situation, people consider their beliefs and their belief behavioral rules. The former originate their attitudes toward a behavior defined, whereas normative beliefs determine subjective norms. These two factors, one of a personal nature (attitudes) and the other of social origin (subjective norms), can indicate the intention that an individual has to perform a certain behavior in the future. As has been documented [9], similar variation may exist between the weight given to these two factors and the final behavior of individuals.

Finally, attitude is a predisposition valuation of the subject, which can lead to a feeling toward a particular object and that, in response, causes the subject to move. Attitudes are the result of social learning, but it can also originate in the subject's beliefs. What leads a person to act in one way rather than another is, as a first factor, the resultant compromise between the behavioral beliefs and the evaluation aspects predominant in these beliefs. The second factor is seen as resulting from beliefs, since the person develops his/her own rules based on subjective beliefs about which individuals or specific groups influence his/her actions [9]. As mentioned previously, the actions taken by an individual depend on attitude and anxiety.

3. CASE STUDY

A study to find out more about the beliefs of people when commuting in different modes of transportation was conducted in the Metropolitan Area of the *Valle de Aburrá*. A semi-structured survey was conducted in order to obtain as much information as possible about the conduct of such people.

Additionally, the sixteen personality factor questionnaire (16PF) [7] was carried out to assess psychological factors, together with a survey on socio-economic conditions [10]. The 16PF is probably the most-widely used system for categorizing and defining personality. It is a multiple-choice personality questionnaire which was developed over several decades of research by

Raymond B. Cattell. The 16PF contains 187 multiple-choice items which are written at a fifth-grade reading level, and the administration of the test takes from 35–50 minutes. The item content typically sounds non-threatening and asks simple questions about daily behavior, interests, and opinions. There are 16 different scales that measure: warmth, reasoning, emotional stability, dominance, liveliness, rule-consciousness, social boldness, sensitivity, vigilance, abstractedness, privateness, apprehension, openness to change, self-reliance, perfectionism, and tension. The factors are further grouped together into global factors: self-control, anxiety, extraversion, independence, and tough-mindedness.

The sample tested was composed of 123 individuals who took the entire group of tests. They chose between car and bus for when they go to work or school. The 16PF test was conducted over the whole sample chosen. In the following sections, the features and the outstanding results of the various tests performed are reported.

3.1 Socioeconomic survey

This survey asked about marital status, age, sex, type of housing, municipality, social stratum, occupation, vehicles owned, if they have access to a vehicle at any time as a driver, or if they have a carpool or free taxi service. Of the 123 people tested, 62 were men (50.4%) and 61 were women (49.6%).

3.2 Personality test (16PF)

The second-order factors of personality were calculated from the typical decatypes scores, obtained from the first-order factors. These factors are:

QI: low–high anxiety (set–anxiety)

QII: introversion–extraversion (invia–exvia)

QIII: little–many controlled socialization

QIV: passivity–independence

4. ANALYSES OF RESULTS

The MNL model was used, taking into account the variables: attitude, social norm, anxiety, sex and carpool. The best model after completing the ranking

is presented in Table 1. The car is represented by the letter (a) and bus by the letter (b).

Table 1. MNL model results

Car = a	MNL
Bus = b	--
Constant (a)	2.36 (1.16)
Attitude (a,b)	-0.510 (-2.10)
Anxiety (b)	0.838 (2.24)
Social Norm (a,b)	-0.541 (-2.07)
Sex (b)	-0.739 (-0.85)
Carpool (a)	--
l(0)	-31.192
l(c)	-31.192
l(θ)	-21.333
ρ ²	0.316
Sample	123

It can be observed from Table 1 that the variables are statistically significant (the constant term and sex variable were not) and conceptually valid. The previous model provides mathematical formulas that best represent the situation through the utilities of the modes, as follows:

$$U_{car} = -0.510 * Att - 0.541 * S_N$$

$$U_{bus} = -0.510 Att - 0.541 * S_N + 0.838 * Anx$$

where:

Att = attitude towards the service provided by a transportation mode

S_N = social norm regarding the use of one transportation mode

Anx = anxiety present in individuals

The subjective value of intent (SVI) in the choice of a mode of transportation is: $\theta_{att} + \theta_{sn}$

where: $SVI = 0.510 + 0.541 = 1.051$

Thus:

$SV(Att) = (\theta_{Att}) / (SVI) * 100$ is the subjective value of the “attitude” regarding the “intent” of choosing a mode of transportation. In this case $SV(Att) = 48.5\%$, and

- $SV(S_N) = (\theta_{S_N}) / (SVI) * 100$ is the subjective value of “social norm” regarding the “intent” of choosing a mode of transportation. In this case $SV(S_N) = 51.5\%$

4.1 Choice behavior

According to the estimated model, it is possible to forecast the probability of choosing each of the modes that were specified in the research. The following are the market shares, taking into account average values for the attitude and social norm variables, according to the scale (1: strongly agree, 2: agree, 3: moderately agree, 4: indifferent, 5: moderately disagree, 6: disagree, 7: strongly disagree) and (1: extremely good, 2: good, 3: fairly good, 4: indifferent, 5: moderately poor, 6: bad, 7: extremely bad) and for anxiety the value of 5, since the scale of this variable is decatypes (1-10). The results are presented in Table 2.

Table 2. Mode Marketshare

Mode	Variable	Mean	Utility	Probability
Car	Attitude	4	-1.84	13.9%
	Social Norm	4		
	Anxiety	5		
Bus	Attitude	4	-0.014	86.1%
	Social Norm	4		
	Anxiety	5		

These results are consistent with those obtained by the Origin-Destination Survey of 2005 [11], where the choice of car was 13%. The model was estimated based on trips made during a weekday for work or study.

4.2 Model elasticity

As mentioned before, elasticity is the percentage change in the probability of choosing some alternative A_p from the set of alternatives A_j when varying the attributes of the alternative A_i (direct elasticity) or alternative A_j (cross elasticity), taking into account that each alternative also belongs to the choice set A_q .

The MNL cross elasticity with respect to an attribute, and changing a single point, is: $E_{piq}^{*} X_{jkq} = -\theta_{jk}^{*} X_{jk}^{*} P_{jq}$, The results are presented in Table 3.

The cross elasticity measures the responsiveness of the demand probability for a mode to a change in

the conditions of another mode. If the two modes are substitutes, the cross elasticity of demand will be positive, and if the two goods are complementary, the cross elasticity of demand will be negative.

Table 3. Crosselasticities (*point modification on Likert scale, since 4)

Description		Attributes		
		Attitude	Social Norm	Anxiety
		-0.510	-0.541	0.838
Mode	Probability	1*	1*	5
Car	13.9%		7.0%	7.5%
Bus	86.1%	43.9%	46.6%	--

Table 3 shows that the probability of choosing the bus varies by 7%, for a change of one point in the attitude towards the car, and varies by 7.5% compared to a variation of a point in the social norm to the car, while keeping the same levels of anxiety for both. The probability of choosing a car varies by 43.9% compared to a change of one point in the attitude toward the bus. It can be inferred from the Table that the bus and car are substitute goods.

Taking into account the results obtained in this research, it is observed that attitude, subjective norms (social), and anxiety influence transportation mode choice.

5. CONCLUSIONS

An anxious person tends not to use a car for transportation when he/she has the responsibility of driving. It should be noted that if a person has physiological changes because of anxiety, his minimum perception-reaction times will be affected, and these are highly necessary for the driving process.

Attitude, social norm, and anxiety affect the transportation mode choice decision. It was shown that it is possible to estimate an MNL model and determine the choice of transportation mode type using only psychological variables. The above results facilitate the planning, development, and implementation of standards, and the design of educational campaigns based on improved knowledge of the behavior of users.

The areas of the brain determined by rationality cannot operate in isolation from the areas of biological and emotional regulation. The two systems communicate and affect behavior together, and consequently, the behavior of people. The emotional system is the first force acting on the mental processes, and this, therefore, determines the course of decisions, which affect the final decision about the mode of transportation to use, as shown in this research.

The econometric model considering the psychological variables described in this paper can improve the estimation of discrete choice models, reducing the error term in the utility function. Accordingly, discrete choice models should always include a psychological latent variable that measures stress or anxiety of individuals, in order to obtain more realistic models.

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