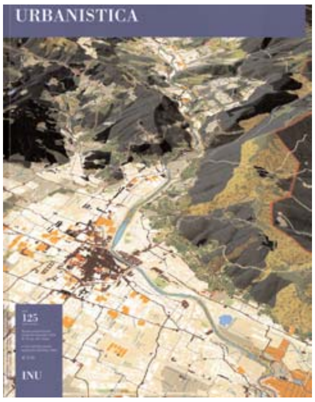

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The Prospect Theory and the prediction of traveler behaviour

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During recent years there has been an evolution of the instruments used in transport planning, related to the necessity of the development of efficient instruments for transport demand prediction, in order to provide a wellargued basis for transport planning and infrastructure projects. In this field, it is particularly important to develop powerful tools for the understanding of human behaviour, which can provide correct information about the choice behaviour of transport system users, which creates the demand for transport services among the population. In this work, we propose the use of a behavioral model for the prediction of transportation demand, based on the axioms of Prospect Theory. This approach seems particularly useful in the prediction of human choice behaviour when choice options are affected by variability.

The proposed methodology has been developed on the basis of traditional behavioral models used in transportation demand prediction, with which it shares the main structure, although it presents a new approach to the understanding of human behaviour in daily choice processes, according to modern psychological studies on economic behaviour.

Behavioral models used in transport planning so far have mainly been based on the hypothesis of rational behaviour of the human being, who tries to maximize his personal utility (as a homo œconomicus), thus choosing the option that gives him the greatest benefits with minimal costs. The best-known behavioral theories are based on this hypothesis, such as the Expected Utility Theory (Von Neumann, Morgenstern 1944), whose greatest quality is the simplicity with which it associates to each option, in a probabilistic approach, a utility value given by:

$$EU = ?i\ pi\ u(xi)$$

which is a function of the utilities u(xi) and the probabilities pi of the possible results xi of the option. In transport planning, the Random Utility Theory is also widespread. It asserts that the utility Uji associated by the user i to the option j is a random variable given by the sum of a System Utility Vji, a linear function of the attribute values, and of a random error term eji:

$$Uji = Vji + eji.$$

The probability distribution associated to the random term of utility defines the different behavioral models belonging to the group of the Random Utility Models. For these models, the probability of choosing an option j is equal to the probability that the perceived utility of the option j is higher than those of all the other options belonging to the choice set. Models of this type have been very useful in transport planning since they could provide quite robust information about choice processes involved in the use of transport systems. On the other hand, the rising complexity of modern transport systems and the importance of the topic of a correct transport demand prediction, usually the first step in a long process of planning which involves expensive infrastructures which have a great impact on the landscape, make it necessary to improve the prediction instruments, in order to support planners in the best way. The development of more powerful tools is also related to the nature of the attributes treated, which are not easy to define in a deterministic way and often present a large variability. For many transport problems, particularly in urban areas, the characteristics of the alternatives are highly varied and uncertain, due to many causes which can not always be perfectly recognized, such as traffic congestion, road accidents or weather conditions (Bonsall 2003).

Consequently, it is extremely important to develop instruments that can interpret the way in which such uncertainty affects traveler behaviour.

Several objections have been moved in the past to traditional behavioural theories. For instance, the Allais Paradox (1953) shows an inversion of preferences predicted by the Expected Utility Theory, connected to the certainty effect: decision-makers seem to prefer the alternatives that present certain effects in comparison with alternatives whose effects are only probable. Some other ways in which behavioral theories are violated have been highlighted (Kahneman, Tversky, 1979); the way in which the alternatives are framed affects the choice process according to the framing effect, showing risk-seeking or risk-averse behaviour depending on the situation (Tversky, Kahneman 1981). Starting from these considerations, Kahneman and Tversky (1979) proposed a new behavioral theory, the Prospect Theory, as an instrument for predicting human behaviour in situations involving risk or uncertainty. The main element of this theory is the hypothesis that the choice is made by the decision-makers valuing each alternative in terms of loss or gain, analysing the change that the alternative brings to the status quo. The evaluation of an alternative depends on a decision weight function, which weights probability values simulating the human perception of such probabilities. The value function, concave in the region of gains and convex in the region of losses, is deeper in the domain of losses: $|v(-x)|>v(x)$, thus assuming a graph of typical S-form. The argument of the function, the result x, is the change perceived by travelers. This is valued in terms of difference from a reference point.

There have been many applications of the theory, also in the implemented version called Cumulative Prospect Theory (Tversky, Kahneman 1992): confirmations of the predictions of the theory have been found in the analysis of decision-makers' behaviour in different economic and financial fields (Camerer 1998), confirming the way in which decision-makers face alternatives involving some risks (Harbaugh et al. 2002). Fewer experiences are reported regarding applications of the theory to non-economic contexts: people behaviour in risky contexts has been investigated in medicine and, only recently, in association with transport accidents (De Blaeij, van Vuuren 2001). Even more recent are the applications to choice behaviour prediction in transport planning, with the realization of Prospect Theory analysis on the way in which travelers deal with the uncertainty about travel times (Avineri, Prashker 2002), and of comparisons between choice predictions given by a Random Utility Models and those resulting from the application of CPT models (Avineri 2003; Avineri, Prashker 2003).

In this work, we propose a model based on the axioms of the Cumulative Prospect Theory, which is designed for the prediction of the choices by public transport system users, with the aim of giving a realistic representation of the choice processes in condition of high variability. The proposed methodology represents the first application of Prospect Theory to those contexts in which decisions are made after analyzing more than one attribute of the alternatives. This represents a new theme in Prospect Theory research, implicating the development of a careful calibration phase. The context chosen for this application recreates a typical choice situation for transport systems users in many large cities: the choice between two different bus lines, based on the analysis of the expected travel times of the lines. The results of the application of the model are compared with choices directly expressed by the users in a experimental survey, and with the probabilities of choice given by a Logit Model hereafter referred to as RUT Model.

The CPT Model

The CPT Model has been based on the structure of a Logit-Random Utility Model, in which the utilities of the alternatives are framed with a Cumulative Prospect Theory approach (Tversky, Kahneman 1992). The alternatives are described with the use of probabilistic prospects, reporting all the possible values of the attributes in association with their probabilities. At first, a reference point, which represents the local conditions in which the user take the decision, was defined. Then, for each alternative of the choice set we can calculate a Cumulative Weighted Value, with the expression:

CWV = V(f+) + V(f-)

where V(f+) represents the value associated with gains, which represent positive changes for the user, while V(f-) is the value associated by the model with losses. The previous functions, V(f+) and V(f-), may be written in relation to the results of the probabilistic prospects, in the form:

V(f+) = ?0n ?i+ vi(xi),
V(f-) = ?-m 0 ?i- vi(xi),

where xi are the results of the prospect for - m ? i ? n. The value function, which follows the described properties, is represented by:

V(x) = xa if x ? 0,
V(x) = - l(- xß) if x < 0.

The function is deeper in the domain of losses, as an effect of the parameter l >1, showing a loss-averse behaviour on the part of travelers. The decreasing marginal utility is given by the parameters a, b < 1. Decision weights are defined by the expressions:

?n+ = w+ (pn),
?-m- = w- (p-m),
?i+ = w+ (pi +…+ pn) - w+ (pi+1 +…+ pn)
0 ? i ? n-1,
?i- = w- (p-m +…+ pi) - w- (p-m +…+ pi-1)
1- m ? i ? 0.

Where w+ and w- are strictly increasing functions, defined in the probability values [0, 1], and limited in [0, 1], which satisfy:

w+ (0) = w- (0) = 0,
w+ (1) = w- (1) = 1.

The weighting functions, referring to positive or negative results w+ and w- are defined as follows:

w+ (p) = pg / [pg + (1 - p)g]1/g,
w- (p) = pd / [pd + (1 - p)d]1/d.

Weighting functions are not probabilities: thus the sum of complementary events is not necessarily equal to 1, usually being smaller than 1, as evidence of the certainty effect: the difference to the unity represents the added value given by decision-makers to a reliable risk-less event.

The values of the parameter a, b, l, g, d suggested by Tversky and Kahneman (1992) are 0.88; 0.88; 2.25; 0.61 and 0.69. These values were used in this work.

Both waiting functions tend to over-estimate the events which have a low probability of happening. This phenomenon of overestimation of low probability events has been confirmed in many experimental studies, in marketing, financial and economic fields (Edwards 1996). Non-linear weighting functions, in addition to the S-shaped value function, are responsible for risk-seeking behavior showed by decision-makers in some situations, and risk-averse in others.

The system utility of the alternatives can be expressed in relation to CWVs of the alternatives attributes, as linear combinations in the b-coefficients:

V1 = ba CWV1a + bb CWV1b,
V2 = ba CWV2a + bb CWV2b,

while probabilities of choosing the alternatives are:

p1 = 1 / {1 + e[(V2-V1) / q]}
p2 = 1 - p1

The coefficients ba and bb referring to waiting time and time spent on board, were determined in the phase of calibration of the model.

The choice context

The described CPT model was applied to a choice context in which public transport system users have a chance to choose between two different bus lines for a city trip. The different location of bus stops forces the users to make a preventive choice of bus line, based on the comparison of waiting times and times on board for both lines. All the other attributes of the alternatives, such as travel costs, comfort, or the pedestrian distance to reach the bus stops are assumed to be equivalent for both alternatives, so irrelevant in this choice process. The context was selected for the importance of analysing the effect of the attributes variability on choices in public transport systems, which usually involve great variability in their characteristics, especially in bus services, as an effect of sharing the route with private vehicles. This variability represents one of the main reasons for travelers' disaffection with the use of public transport services. Thus, the development of a model that could predict people's reaction to uncertainty regarding travel times may be very useful. It can assist planners to estimate the users' reaction, in terms of transport demand, to actions and policies that reduce travel times and their variability, conferring priority on public transport. The choice context was geographically set in the city of Bari.

The results of the survey

The choice context was proposed to a group of 60 potential travelers in a stated preferences survey, in which the participants had to choose one of the two proposed alternatives. The participants in the experimental survey were recruited from among the student population of the Polytechnic of Bari; participation in the experiment was voluntary; no payment was made the participants.

The calibration methodology is based on the maximum likelihood method. To apply this methodology, a database of experimental observations is needed. This could be done with a Rp (revealed preferences) or Sp (stated preferences) survey. The Sp survey, used in this work, allows us to control the experiment, planning the scenarios, which form the full factorial plan. In the experiment, the scenarios were created using a Partial Factorial Plan, assuming two possible levels for the attributes, waiting time and time spent on the bus, and imaging two different dispersion levels as a further attribute of the alternative. The number of possible scenarios was limited to 25= 32 using a defining relation that reduced the dimension of the full factorial plan, without decreasing the quality of collected information. The scenarios were divided into groups to limit to nine the number of scenarios proposed to each participant; there being 60 participants in the survey, total collected preferences in the experiment were 540. All the sheets distributed to the participants were filled in, without leaving any empty spaces.

Choice predictions

To apply the CPT Model to this specific context, reference points were fixed. A time of 10 minutes was set as the reference point for waiting time, while 25 minutes was that for time spent on the bus, according to the ordinary conditions (Tversky, Kahneman 1992) locally found in the city.
The application of the model gives the Cumulative Weighted Values for each attribute of the alternatives: CWV1a = -2.41, CWV1b = -1.94,
CWV2a = -1.11, CWV2b = -0.99.
The calibration procedure is based on the Maximum Likelihood Method. Computing phase was assisted by the use of commercial software. The whole 240 experimental observations data-base was split into two parts: 75% was used as an acquisition database for the software, while the remaining 25% of observations were used to validate the model. The calibration yields coefficient values of ba = +0.3101 and bb = +0.1426.
Applying the CPT Model to the experimental context, choice probabilities are P1 = 36.9% and P2 = 63.1%.
In the RUT Model application, system utility assumes the expression:

$$Vj= baTaj+ bbTbj$$

depending on the averages of the two attributes. The coefficients b for this model have been determined with a methodology analogous to that of the CPT Model, using a database of the same dimension (240 experimental observations), split into 75% for calibration and 25% for validation.
The application of the described methodology finds ba = - 0,4295 and bb = - 0,3336.
Applying the RUT Model to the choice context, choice probabilities are P1 = 64.4% and P2 = 35.6%.
The experimental survey among the 60 participants, showed that the majority of the potential users expressed a preference for Line 2, with a percentage rate of 58.3%; the remaining 41.7% considered Line 1 better.
According to more than the half of the survey participants, CPT Model assigned a bigger value of choice probability to the alternative which presents less variability in the definition of its attributes.

The reference point

Differently from what has been seen in classical theories, in Prospect Theory alternatives are judged in terms of gain or losses as a variation from a reference point (Edwards 1996), sharing this property with other modern behavioral approaches (Munro, Sugden 2003). The determination of the most adequate reference point represents a crucial operation. This should be done simultaneously with the experimental survey.
The relationships between reference point value and CPT predictions are not easily found. The definition of the reference point directly affects the evaluation of the alternatives in terms of gains or losses. Decision-makers show risk-aversion when the choice is taken under positive external conditions, while more risk-seeking behavior is shown under negative external conditions (Neilson 2002). As a result, a shift of the reference point leads to consequences which are not easily predictable, owing to the non-linear functions of utility that are involved (Schmidt 2003; Avineri, Prashker 2003). A sensibility analysis was conducted on the CPT Model, with the aim of investigating changes in the model predictions varying the reference point used to determine the CWVs. A large variability in the probabilities associated with the alternatives was found, sometimes causing phenomena of inversion of the preference for some values of the reference point. Choice probabilities depending on the different reference points used for the two attributes are shown in the graphs.
In a three-dimensional diagram model predictions are drawn depending on the possible values of time used as a reference point for the two attributes, giving evidence to the values of the reference point for which choice probability of Line 1 is higher than 50%.

Conclusions

The proposed CPT Model represents a new type of behavioral model used for transport user choice prediction. The development of this methodology does not entail a rejection of the rational behavior conception; rather, it should be judged as an integration of it, based on the Cumulative Prospect Theory, in agreement with modern studies of cognitive psychology, that accept the results of economic theories as a quite good, even if incomplete and not very realistic, approximation of real behaviour, highlighting the importance of certain other aspects which guide individual choices (Guala, Motterlini 2003). The main originality of this work is in the implementation of a choice model, based on CPT, in which choice prediction is obtained from the analysis of two attributes for each alternative, while all previous experiments were based on the evaluation of only one attribute to formulate a monoparametric utility for each choice option.
The development of a methodology that allows us to predict choice behaviour as dependent on the variability of more than one attribute of the alternatives, starts new processes in understanding complex behaviour, in those situations that involve conditions of great variability, risk or uncertainty.
The application to the proposed context has enabled us to focus on the effects of attributes variability on choices made by the transport system users, finding correspondences between CPT Model predictions and the real behaviour stated by users in the survey.
Decision-makers are seen to prefer reliable alternatives, even if accompanied by higher averages of the alternatives attributes: this is the well-known certainty effect explained by Kahneman and Tversky's Prospect Theory. For this reason, the majority of users

say they prefer the alternative that comports higher travel times but that is rather regular and reliable, and not affected by risks. The sensitivity analysis confirms the great importance of choosing the most appropriate reference point. This operation makes the model strictly related to local settings, guaranteeing a good simulation of real human behaviour (Zhang et al. 2004). The results dependence on local conditions may be useful to judge the effects of the realization of new transport infrastructures on local communities. The reference point may be used in the analysis of the answer that such interventions have on specific social-economical components of the population. For instance, we might set different reference points for waiting times depending on users' age, or different reference points for transportation costs depending on family income. Future developments of this work will analyse high variability scenarios in relation to the choice processes involved in applied contexts of transport planning.

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