A Cumulative Prospect Theory Approach to Traveller Behaviour Prediction

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Synopsis

Transport systems in Urban Areas are day by day becoming more complex. The rising complexity of these systems, combined with the congestion of most European city centres, creates not easily predictable choice behaviour of travellers. Frequently, transport system users are required to deal with a great variability of the alternative attributes; travellers' choices are consequently influenced. Even greater is the influence this variability has on commuters.

Several approaches has been developed to predict travel choice behaviour. Nowadays, most part of them are still based on the hypotheses of the Random Utility Theory; despite that, the observation of real choices among transportation system users highlights a non-linear choice behaviour, which is not possible to explain with Random Utility Models. Thus, more powerful tools are required by planners to evaluate choice behaviours of travellers, to guide the design of new transport infrastructures and services. With this aim, some other choice models, based, e.g., on Fuzzy Inference, have been developed.

In this work, we discuss the opportunities offered in this field by Kahneman & Tversky's Cumulative Prospect Theory. This theory, especially designed to predict choice behaviours in conditions of uncertainty and risk, was first applied to monetary choice problems, such as lotteries with money prizes; more recently, it has been also applied to other research fields. At the moment, few experiences are reported on the application of the theory in transportation planning: Prospect Theory Approaches have sometimes been proposed to forecast travel choice behaviour in those choice contexts that involve high variability, uncertainty and risk. The aim of this work is to analyse how Cumulative Prospect Theory may be useful in the understanding of the way travellers behave in daily choice processes. For this purpose, a literature review of past experiments is provided. Furthermore, we report the results of an application of CPT to set up a choice model for the prediction of traveller behaviour in a medium size city. Unlike previous experiences in this field (Avineri et al.), the proposed methodology enables us to implement a modelization of Prospect Theory for the prediction of people choice based on the analysis of more than one attribute of the alternatives. The effects of the variability of the alternative attributes on travellers' behaviour are investigated in connection with the analysis of the transport system of the city of Bari. The research focuses on the effect of congestion on travel choices between different public transport lines: how congestion influences the use of the lines? The different paths followed by the lines are examined in relation to the effects of traffic conditions; travellers are seen to behave in a risk adverse way, trying to avoid risks of delays. A detailed analysis on the way local conditions affect choices is made, with reference to the dependence of choices on past habits of the commuters (reference point from which the choice is made).

A Cumulative Prospect Theory Approach to Traveller Behaviour Prediction

Choice behaviour prediction is currently seen as an interesting theme in many research areas. The understanding of how human behaves in daily context is investigated in different fields: most part of behavioral approaches derives from econometric studies. They were at first developed in order to predict choice behaviour in all contexts in which the alternatives are proposed to decision-makers in terms of monetary outcomes. Similar importance is nowadays attributed to choice behaviour prediction in non-monetary choice contexts. In transportation planning, the correct estimation of the transport demand implies the knowledge of the way in which travellers behave in choice context. In this field, a great importance is assumed by the implementation of behavioral models that might be able to deal with complex choice contexts as those in which travelers make their travel decisions in modern society.

The choice theories that have been developed are mainly based on some basic assumptions on human behaviour. First of all, in many choice processes, the total number of feasible alternatives (universal set) is quite high. Realistically, the decision-maker can consider only a limited number (choice set) of these, also owing to the time and cost involved in seeking information about all alternatives.

In the evaluation of the alternatives that belong to the choice set, the decision-maker is assumed to show a rational behaviour: he tries to maximize his personal utility (as a *homo oeconomicus*) 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). According to this theory, choices are based on an Expected Utility value that is associated to each choice option. The Expected Utility is simply defined in a probabilistic way:

$$EU = \Sigma_i \, p_i \, u(x_i).$$

The EU is a function of the utilities $u(x_i)$ associated to the possible outcomes x_i of the option and of the probabilities p_i associated to those outcomes; decision-makers are assumed to select the alternative with the maximum EU value. Due to the simplicity of this probabilistic approach, Expected Utility Theory is worldwide widespread as an easy way to predict choice behaviour with a quite good degree of approximation.

Choice predictions given by the Random Utility Theory (Ben Akiva and Lerman, 1985), highly widespread in transport planning, are based on the hypothesis of rational behaviour, too. This theory asserts that the utility U_j^i associated by the user i to the option j is a random variable, given by the sum of a systematic utility V_j^i, which is a linear function of the attribute values, and of a random error term ε_j^i:

$$U_j^i = V_j^i + \varepsilon_j.$$

Several sources of randomness of utility lead to the introduction of the random residual ε_j^i such as (Cascetta, 2001): measurement errors in evaluating the attributes involved in systematic utility, unobserved attributes difficult to evaluate, taste variation among different users or errors in the evaluation of the attributes by the decision-maker.

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.

Choice models belonging to this type have been commonly used in transport planning to predict traveller behaviour. However, the rising complexity of transportation systems and the need of well argued predictions in complex choice contexts are leading to implement traveller choice models. Nowadays, the interest is mainly focused on the implementation of methodologies that can simulate the way in which travellers face the uncertainty and the variability involved in the choice process. Hereafter, a possible approach to do this is presented.

THE IMPLEMENTATION OF CHOICE MODELS

Many observations have been moved on the basic assumptions of the behavioral theories that have been reported. The hypothesis of Rational Behaviour was criticized, too: in 1955 Simon developed another approach called "bounded rational". According to this approach, the user shows limited capacities to seek and process information; his decisions are consequently affected by this limited information acquisition.

Some authors criticized the probabilistic approaches that have been presented so far. Probability measures were considered not adequate to satisfactorily describe human processes of perceptions. For this reason, different approaches to the understanding of human behaviour were proposed through the use of Fuzzy Logic. Fuzzy logic is regarded to be a useful mathematical approach to modeling traffic and transportation processes affected by ambiguity, uncertainty and variability (Teodorovic, 1999). Many experiments have been conducted, indeed, in this field: fuzzy measures are regarded to provide a more realistic description of human perceptions, in relation to the vagueness of the description of attributes. The alternative attributes are described through the use of fuzzy sets, where the membership function represents the spread of human perception for that attribute (Akiyama and Yamanishi, 1993). In such models, choice predictions are based on the comparison of the utility value of the alternatives expressed in dependence of possibility measures instead of probability values (Dell'Orco and Kikuchi, 2004).

Several further objections have been moved on probabilistic behavioral theories. The Expected Utility Theory was criticized as a result of experimental observations, which were in contrast with its predictions: the same difference in the probability of winning between two lotteries may produce different preferences. For instance, the Allais Paradox (Allais, 1953) shows an inversion of the preferences predicted by the Expected Utility Theory, which can be connected to what psychologists call the *certainty effect*: decision-makers seem to prefer the alternatives that present certain effects in comparison with alternatives whose effects are only probable.

Tversky & Kahneman (1981) discussed some other ways in which behavioral theories are violated. They showed how the same strategy to stop an epidemic (the *Asian Disease*) was differently appreciated in terms of people choice depending on the way this strategy was described in terms of saved lives or in terms of deaths. This effects, the *framing effect*, implies that the perceived utility of a choice option is influenced by the way it is framed, in terms of gains or losses for the decision maker. 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.

The Cumulative Prospect Theory

Starting from these considerations, Kahneman & 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, analyzing the change that the alternative brings to the status quo (represented by the *reference point*). The value function is worth zero for the attribute value assumed as the reference point. In comparison with this value all the other possible values of the attribute are coded as gains or losses. 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-shaped form. The argument of the function, the result x, is the change perceived by travelers, valued in terms of difference from the reference point.
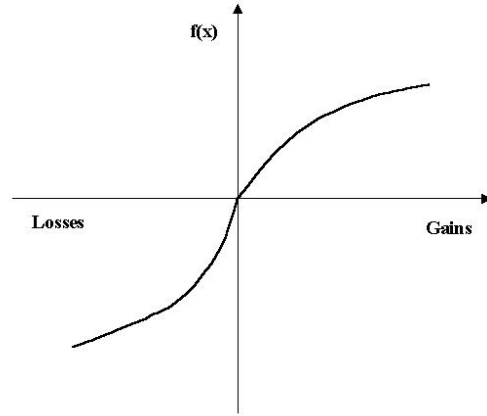
Figure 1: The Value Function

The evaluation of the alternative depends on a decision weight function, which weights probability values simulating the human perception of such probabilities. According to the implemented version of the theory, the *Cumulative* Prospect Theory (Tversky & Kahneman, 1992), a Cumulative Weighted Value can be associated to every available alternative. The decision-maker is expected to choose the alternative that presents the highest CWV.

The alternatives are described with the use of probabilistic prospects, in which all the possible values of the attributes are reported in association with their probabilities. Having defined a reference point, the CWV is calculated as follows:

$$CWV = V(f^{+}) + V(f^{-}),$$

depending on the two terms, respectively associated to gains, $V(f^{+})$, and to losses, $V(f^{-})$. The previous functions, $V(f^{+})$ and $V(f^{-})$, may be written in relation to the results of the probabilistic prospects:

$$V(f^{+}) = \Sigma_{0}^{n} \; \pi_{i}^{+} \; v_{i}(x_{i}),$$

$$V(f^{-}) = \Sigma_{-m}^{0} \; \pi_{i}^{-} \; v_{i}(x_{i}),$$

where x_{i} are the results of the prospect for $-m \leq i \leq n$.

The value function, which follows the described properties, is represented by:

$$v(x) = x^{\alpha} \qquad\qquad \text{if } x \geq 0,$$

$$v(x) = -\lambda \, (-x^{\beta}) \qquad\qquad \text{if } x < 0.$$

The value function depends on the parameters α, β and λ. Experimental observations on people choices usually show a decreasing marginal utility; this condition implies that α, β < 1. The common loss-averse behaviour of the decision-makers causes the value function to be deeper in the domain of losses. As a consequence the parameter λ is expected to be bigger than 1. On the basis of similar experimental observations, Tversky & Kahneman (1992) suggested for *α, β, λ* the values 0.88; 0.88; 2.25.

Decision weights are defined by the expressions:

$$\pi_{n}^{+} = w^{+} \, (p_{n}),$$

$$\pi_{-m}^{-} = w^{-} \, (p_{-m}),$$

$$\pi_{i}^{+} = w^{+} \, (p_{i} + ... + p_{n}) - w^{+} \, (p_{i+1} + ... + p_{n}) \qquad\qquad 0 \leq i \leq n-1,$$

$$\pi_{i}^{-} = w^{-} \, (p_{-m} + ... + p_{i}) - w^{-} \, (p_{-m} + ... + p_{i-1}) \qquad 1-m \leq i \leq 0.$$

w^{+} and w^{-} are strictly increasing functions, defined in the probability values [0, 1], and limited in [0, 1]. They satisfy the properties

$$w^{+} \, (0) = w^{-} \, (0) = 0,$$

$$w^{+} \, (1) = w^{-} \, (1) = 1.$$

The weighting functions, referring to positive or negative results (w^{+} and w^{-}) are defined as follows:

$$w^{+} \, (p) = p^{\gamma} / (p^{\gamma} + (1-p)^{\gamma})^{1/\gamma},$$

$$w^{-}(p) = p^{\delta} / (p^{\delta} + (1-p)^{\delta})^{1/\delta}.$$

Weighting functions are not probabilities: the sum of complementary events is not necessarily equal to 1, but it is usually smaller, 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 weighting functions are expressed in dependence of the parameters γ and δ. The use of the weighting function allows simulating the way in which people perceive the probability values. Kahneman and Tversky (1992) suggested the values γ = 0.61 and δ = 0.69; these values were found out through a process of linear regression on the experimental data obtained in an appropriate survey. Different assumptions on the parameter values would involve different way in which probabilities can be weighted. In Figure 2, different shapes of the weighting function are proposed, depending on the parameter values that have been used. In the figure, the weighting function for gains is painted for values of the γ parameter varying between 0.40 and 0.80. For all values, the weighting function shows the property of overestimating low probabilities, while high probability values are substantially underestimated. These properties of CPT weighting function may result useful in the prediction of people choice to better predict human behaviour in particular conditions. Even if the applications of Prospect Theory that have been proposed so far have always used the parameter values suggested by Kahneman and Tversky, different parameter values could be found out, for instance, in order to simulate choice behaviour in some specific settings. As reported in figure 2, low values of the parameter make the function deeper in the region of high probabilities, with a more extreme trend in the underestimation of high and medium probability values. On the contrary, high values of the parameter give a more softened trend. The diagonal, to which it is associated γ =1, represents the neutral trend: in this case, probabilities are not weighted at all. In figure 2, the weighting function for gains that adopts Kahneman & Tversky's value of γ is drawn in bold.
Weighting function for losses appears very similar to the previous; it is reported in figure 3.
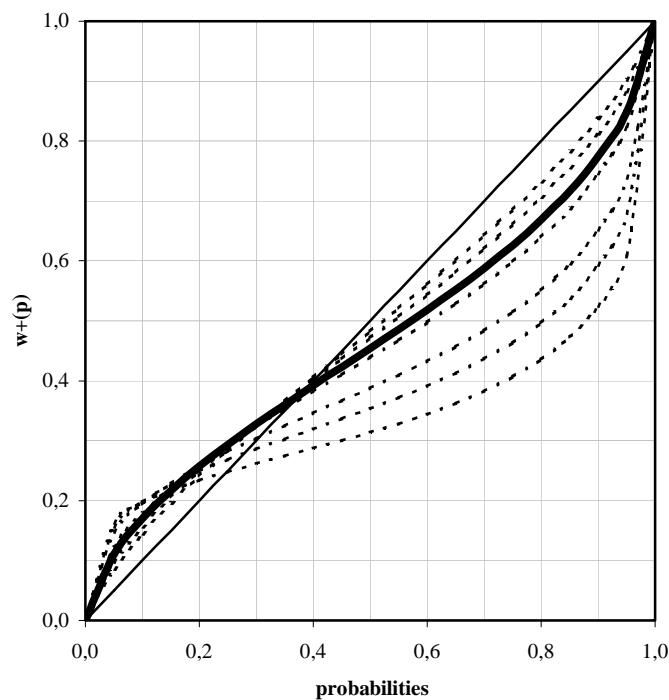

Figure 2: The weighting function for gains in dependence on parameter γ
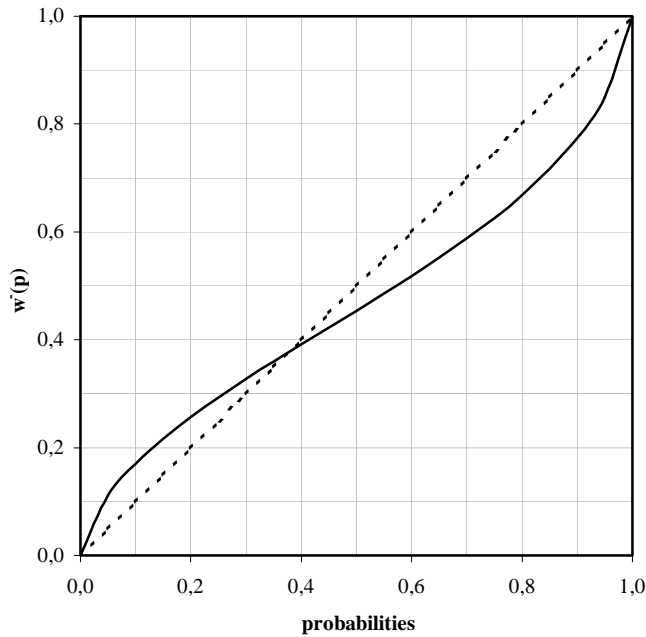
Figure 3: The weighting function for losses

Both waiting functions tend to overestimate the events that have a low probability of happening. This phenomenon of overestimation of low probability events, predicted by the theory, has been confirmed in many experimental studies, in marketing, financial and economic fields (Edwards, 1996). The 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.

Applications of Prospect Theory in choice prediction

Many applications of the Cumulative Prospect Theory are reported in literature: the choice predictions of the theory have been confirmed 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).

The influence of the framing effect on people choice was analyzed by Oliver (2004): in his work, the same standard gamble was presented to decision-makers in different terms, trying to determine how the framing effect affects choice. Due to the specific subject of the experiment, health and medicine, the choice seemed to be mainly affected by the loss aversion of the decision-maker behaviour.

The interest for the influence of the framing effect on choice inspired also the work of Wang and Fischbeck (2004): in this paper, the framing effect is analyzed in relation to health insurances. The researchers collected the data on people choice in dependence on the way the alternatives were framed. This was useful for setting up a methodology for the calibration of the CPT parameters that adjust to experimental observations in the best way.

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; anyway, the application of the theory to travel choice processes looks promising: the capabilities of the Prospect Theory of dealing with risk contexts can be useful in the prediction of traveller behaviour. This is directly related to the specific nature of the attributes treated; they are not easy to define in a deterministic way, often presenting 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). In these conditions, the use of CPT might result convenient.

E. Avineri performed several applications of Prospect Theory to transport context: this was performed (Avineri and Prashker, 2003) comparing a CPT approach for the prediction of route choice with a RUT model; they were applied to the choice problem between two alternatives differing only for the variance of

their attribute. The result showed that the RUT model could not recognize the effect of the variability of the alternatives, attributing the same choice probability to both choice options. On the contrary, the CPT approach could manage the effect of the different variability of the two alternatives in terms of probability of choice: the percentage of preference for the alternative with higher variance was lower.

Another application of CPT was realized in order to analyze line choice in public transport (Avineri, 2003): the CPT was applied to the attribute of waiting time; choice predictions of the CPT model were in contrast with those predicted by utility maximization.

The same violations of Expected Utility Theory observed by Kahneman and Tversky on monetary context were also confirmed through another application on traveller choice behaviour (Avineri and Prashker, 2004): the results of an experimental survey on travel behaviour highlighted the Allaix Paradox and the inflating of small probabilities.

EXPERIMENT DESCRIPTION

This work deals with transit line choice in urban area and examines two attributes through the CPT approach: on-board travel time and waiting time, whilst the other research found in literature consider only one attribute. The context chosen for this application recreates a typical choice situation for transport system 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 context was selected for the importance of analyzing 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. Many times, this variability represents one of the main reasons for travelers' disaffection with the use of public transport services. The choice context was geographically set in the city of Bari.

In the proposed choice context, the bus stops of the two lines are assumed to be localized in two different places, so that passengers are required to make a choose at the beginning of the trip between the bus stops, each of them associated with a transit line. For each alternative, two attributes are recognized as relevant to traveller choice: waiting time and on-board travel time. The two lines are run by the same operator, so it is reasonable to assume that other factors, like ticket cost or comfort are the same for the two lines and that consequently they should not affect this choice.

The different characteristics of the two lines have been reported in terms of the probabilistic prospects in Tab 1 and Tab 2. In every probabilistic prospect, the possible values of the attribute are associated to the correspondent values of probability.

Tab 1: Probabilistic Prospects for line 1

Waiting Time Line 1	4 minutes	8 minutes	12 minutes		20 minutes				
Probabilities [%]	30	35	20		15				
Time spent on board Line 1				16 minutes	20 minutes	24 minutes	28 minutes	32 minutes	36 minutes
Probabilities [%]				15	25	25	20	10	5

Tab 2: Probabilistic Prospects for line 2

Waiting Time Line 2		8 minutes	12 minutes						
Probabilities [%]		50	50						
Time spent on board Line 2					20 minutes	24 minutes	28 minutes		
Probabilities [%]					5	65	30		

The aim of this work is to discuss the advantages/disadvantages given by the use of the Cumulative Prospect Theory in the prediction of traveller preferences in uncertain contexts of choices. For this purpose,

we consider a model arising from the combination of the Cumulative Prospect Theory with a consolidated approach in transportation choice models, a Multinomial Logit. In this CPT-Model, the systematic utility of the alternatives can be expressed in relation to the CWVs of the alternative attributes, as a linear combinations in the β-coefficients:

$$V_j = \Sigma_{r=1,..,M} \, \beta_{rj} CWV_{rj}$$

where *M* is the total number of attributes. The choice probability of an alternative *j* is evaluated as

$$p[j] = exp(V_j/\theta)/\Sigma_{h=1,..,N.} exp(V_h/\theta)$$

where *N* is the total number of available alternatives. This model will be hereafter indicated as CPT-Model.

The results of the application of the CPT-Model to the choice context that have been proposed will be compared, in terms of choice preferences, with the results arising from the application of a traditional Logit Model.

The systematic utility of the Logit Model includes the expected values of each attribute and is evaluated as:

$$V_j = \Sigma_{r=1,..,M} \, \beta_{rj} X_{rj}$$

while the probability of choice for this model is expressed in the same way as for CPT Model, in dependence on the specific systematic utility function.

In order to estimate the parameters in both models a Stated Preferences survey was designed, recognizing different scenarios through probabilistic prospects for each attribute. On this base, firstly utility functions and then choice probabilities were estimated.

The Survey
The choice context has been proposed to a group of 60 potential travelers in a *stated preferences* survey. The participants were recruited from among the student population of the Polytechnic of Bari; participation in the experiment was voluntary; no payment has been made to the participants. Interviewees were asked to imagine having to make a trip by bus, using public transport lines; from the starting point, two different lines were available to enable them to reach their destination. The origin and the destination were located respectively at the Polytechnic and in the city centre; the distance on foot was about 2.4 Km. The transit lines had different bus stops, so it was assumed that the decision-maker should choose on which line to use before they started out.

Each participant in the survey received a block of questions, in which they were asked to indicate the preference of transit line for different scenarios. The first question represented the choice between the two lines that have been described, while the following scenarios were constituted by the questions especially created to form the database for the calibration and the validation of the CPT and the Logit model.

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 $2^5 = 32$ 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 with a *block decomposition* in order 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
The results of the survey are reported in this paragraph. All the data collected in the survey consisted of 540 experimental observations. Of these 60 were preferences indicated by the students in the *reference scenario* (which was proposed to all participants), while the remaining were formed by 240 experimental observations which were useful for calibrating the CPT Model and 240 observation for calibrating the Logit Model.

At first, to use the CPT Model, a reference point was defined. According to local conditions found in the city of Bari, 10 minutes were chosen as the reference point for waiting time, while 25 minutes were chosen as the reference point for time spent on the bus.

The calibration procedure is based on the *Maximum Likelihood Method*. Computing phase was assisted in this study by the use of commercial software. The whole experimental observations database was split into two parts: 75% were used as an acquisition database for the software, while the remaining 25% were used to validate the model. The calibration yielded the values of coefficients to be inserted in the systematic utility of CPT Model:

$$V_j = +0.3101 \cdot CWV_{wait}^j + 0.1426 \cdot CWV_{board}^j.$$

The coefficients of the CPT Model are positive because the Cumulative Weighted Values express how much that alternative allows decision-makers to obtain gains in comparison with the two reference points in terms of waiting time and travel time. Statistical tests on these parameters were done. Both coefficients are statistically different from zero at the 0.05 significance level.

The application of the CPT Model gives the Cumulative Weighted Values for each attribute of the alternatives:

$$CWV_{1a}=-2.41, \qquad CWV_{1b}=-1.94, \qquad CWV_{2a}=-1.11, \qquad CWV_{2b}=-0.99.$$

After calibrating the model, its validation was performed on the 25% of experimental observations not used in the calibration phase: the percentage of correctly predicted choices was 71,67%.

Applying the CPT Model to the experimental context, choice probabilities were

$$P_1=36.9\%, \qquad P_2=63.1\%.$$

For the Logit model the results of estimation leaded to this systematic utility function:

$$V_j = -0.4295 \cdot T_{wait}^j - 0.3336 \cdot T_{board}^j.$$

The values of the coefficients correctly have negative signs; they are statistically different from zero at the 0.05 significance level, too. The validation phase, performed in the same way on the 25% of experimental data, gave a percentage of 86.67% of correctly predicted choices.

Applying the RUT Model to the choice context, choice probabilities are

$$P_1=64.4\%, \qquad P_2=35.6\%.$$

The experimental survey among the 60 participants showed that the majority of the potential users expressed in the reference scenario a preference for Line 2, with a percentage rate of 58.3 %; the remaining 41.7 % considered Line 1 better.

Tab 3: Experimental results and choice prediction of the models

	LINE 1	LINE 2
CPT Model	36.9%	63.1%
Logit Model	64.4%	35.6%
Experimental data	41.7%	58.3%

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
One of the relevant figures of Prospect Theory is its property of using a relative value function in the definition of the Cumulative Weighted Value. Differently from what was 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). This approach to predict human behavioral directly arises from the observation of people choice, as came out in the research conducted by Kahneman and Tversky. However, this approach is looked promising in the implementation of choice theories, as confirmed by similar studies conducted in modern research that involve the definition of a relative utility in the prediction of people choice (Munro & Sugden, 2003).

Therefore, the determination of the most adequate reference point represents a crucial operation when using a CPT approach. This operation represents a critical phase of the development of the behavioral model, since it tends to influence the trustworthiness of the results of the model application to choice predictions. Theoretically, the reference point should be set previously, at most simultaneously with the experimental survey.

The relationships between reference point value and CPT predictions are not easy to be 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). Consequently, a shift of the reference point changes the choice prediction in a not easily predictable way, owing to the non-linear functions of utility that are involved (Schmidt, 2003; Avineri & Prashker, 2003).

In this work, we have conducted a sensibility analysis to investigate the changes in CPT choice predictions at varying the reference points that have been used. This analysis has been performed on the results of the application of the proposed CPT Model to the choice context that has been previously described. Choice probabilities have been just determined for the reference point values of 10 minutes for waiting time and 25 minutes for time spent on board. In this section, the effects of a change of those reference points are presented.

Since the definition of the reference point affects the CWV shown by an attribute, the CWV of each alternative attribute has been calculated for different values of the reference point. The results have been drawn in dependence of the reference point used for each one of the two attributes. A large variability of CWVs has been found; this is not possible to be interpreted through a mathematical expression.

As for the choice predictions, these are highly influenced by CWV changes; this means a shift in the choice probability predicted by the model for the two lines. In figure 4 and figure 5, the choice probabilities predicted by the CPT model are drawn in dependence on the reference point used for the two attributes.
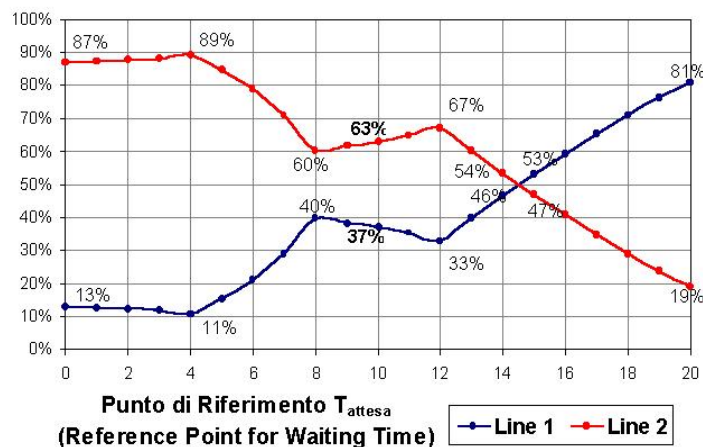

Figure 4 Choice probabilities depending on the reference point for Waiting Time
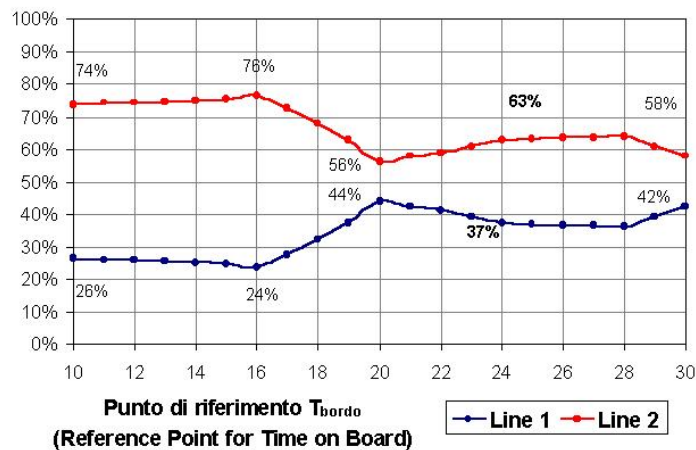
Figure 5: Choice probabilities depending on the reference point for Time Spent on Board

In the graphs, it is possible to observe how choice probabilities depend on reference point values. For both reference points, referred to the two attributes, the variability of choice probabilities is very high; in the case of the reference point used for waiting time, an inversion of preferences is also observed. This happens in correspondence of high values of the reference point: in this area of the graph, almost every value of waiting time showed in the probabilistic prospects by the two lines tends to become smaller than the reference point. In this condition, all values are seen to be gains in comparison with the reference point, and the difference between the probabilistic prospects of the two lines become not very relevant for choices. In this situation, the model tends to award a higher value of choice probability to that choice option that presents the lowest average value of the attributes (line 1). For all other values of reference point, the CPT model assigns a higher choice probability to other line, which is considered more reliable, due to the effects of the largest variability of the line 1.

CONCLUSIONS

This work aims to evaluate the capabilities of the Cumulative Prospect Theory to be applied in forecasting traveller choice behaviour. The Cumulative Prospect Theory has just been successfully used in the understanding of human behaviour in many different fields; moreover, the application of the theory to transport engineering looks promising due to its capacity of managing choice prediction in condition of uncertainty and risk. In order to test this chance, a CPT-based model has been proposed as a new type of behavioral model used for transportation user choice prediction.

In the proposed CPT model choice predictions are obtained from the analysis of two attributes for each alternative. The implementation of this model represents a main element of originality in the research on the CPT, since all previous experiments were based on the evaluation of only one attribute in the formulation of a monoparametric utility of the choice option.

The application of the proposed model to a typical choice context of urban transportation systems has permitted us to measure the possible advantages deriving from this behavioral approach. As shown by the experimental data, this approach allows us to predict choice behaviour as dependent on the variability of more than one attribute. On the contrary, it seems not particularly effective in choice prediction in those contexts in which the attribute variability is not important in the process of choice, as shown by the choice prediction given by the model in the scenarios created for calibration.

This achievement may represent an advantage connected to the use of CPT approach in the understanding complex behaviour, in those situations that involve conditions of great variability, risk or uncertainty. As confirmed by 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 alternative attributes: this is the well-known *certainty effect* explained by Kahneman & Tversky's Prospect Theory. Moreover, the majority of users assert to prefer an alternative that entails higher travel times but that is rather regular and reliable and not affected by risks.

The sensitivity analysis highlights the great importance of choosing the most appropriate reference point. This operation makes the model strictly related to local settings. In this way, it can help in providing a better simulation of real human behaviour (Zhang et al., 2004). Anyway, the result dependence on local conditions may be useful in specific situation. It can be used, for instance, to judge the effects of the realization of new transport infrastructures on local communities, measuring the impact they have on specific social-economical components of the population. For instance, different reference points for waiting times might be set depending on users' age, or different reference points for transportation costs depending on family income.

Finally, the development of *mixed models* looks promising. In such models high variability attributes are valued with a CPT procedure, while the remaining low variability attributes continue to be valued with classical methodologies based on the axioms of *Random Utility Theory*. The capabilities of such models would potentially have a great impact on transport planning activities; they would join the positive properties of models of widespread use with the advantages arising from the quality of *Cumulative Prospect Theory* of capturing additional aspects of human behaviour in those situations that involve conditions of great variability, risk or uncertainty.

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