第 30 卷第 7 期
2013 年 7 月

控 制 理 论 与 应 用
Control Theory & Applications

Vol. 30 No. 7
Jul. 2013

DOI: 10.7641/CTA.2013.11194

基于前景理论的实时路径选择模型

吴 磊, 杨立才†

(山东大学 控制科学与工程学院, 山东 济南 250061)

摘要: 动态路径诱导是解决交通拥堵问题行之有效的手段. 传统动态路径诱导系统中的路径选择模型依托期望效用理论, 实践表明这种以确定性的理论解决具有不确定性的交通问题的模型与出行者的实际行为之间存在明显的背离. 针对交通状况的复杂性、时变性、不确定性, 本文建立一种基于前景理论的路径选择模型, 该模型考虑了由于出行者的主观能动性而导致的非完全理性化的交通行为特征, 能够准确地描述不确定性交通条件下出行者的决策过程. 通过仿真实验对比基于前景理论与基于期望效用理论的路径选择模型给出的最优路径, 结果表明前景理论在描述出行者的路径选择行为时能够在一定程度上克服期望效用理论的不足, 可以较准确地刻画出行者在不确定性条件下的路径选择决策行为, 更接近于出行者的实际行为模式.

关键词: 前景理论; 价值函数; 路径选择模型; 动态路径诱导

中图分类号: TP273 **文献标识码**: A

Prospect theory-based route choice model in dynamic route guidance system

WU Lei, YANG Li-cai†

(School of Control Science and Engineering, Shandong University, Jinan Shandong 250061, China)

Abstract: Dynamic route guidance system (DRGS) is one of the most efficient solutions to the traffic jam. The traditional route choice models of DRGS are based on expected utility theory (EUT), which solves the uncertain traffic problems with certain method. It is proved that the sorts of these models are contrary to the individual's actual behavior. To deal with the complexity, time variance, and uncertainty of traffic condition, this paper presents a route choice model based on prospect theory (PT). The proposed model takes the incomplete rationality of traffic behavior led by the traveler's subjective initiative into account. The introduction of PT to DRGS can accurately describe the decision-making process under uncertainty. An experiment is given to compare the performance of the PT-based model with that of the EUT-based model. The results show that the prospect-theory-based model precisely describes the route choice decision making behavior. In a way, the proposed model, which gives a more realistic and reliable route that individual usually takes, overcomes the shortcomings of EUT in the description of route choice behavior.

Key words: prospect theory; value function; route choice model; dynamic route guidance system

1 Introduction

Dynamic route guidance system (DRGS), as an important part of intelligent transportation system (ITS), is an efficient method for solving urban traffic congestion, improving transportation efficiency, and reducing air pollution. Traditional DRGS establishes its route choice model based on the expected utility theory (EUT), without any consideration of traveler's subjective initiative in decision making during route choice process. The EUT-based models usually evaluate the alternative routes by expected utility maximization on condition that the current traffic condition is certain objectively or the future traffic condition can be predicted. Many assumptions are made to make these models workable: 1) All road information is completely known; 2) All the travelers are perfectly rational; 3) All the travelers seek for utility maximization. But the traffic condition is complicated and uncertain, and the travelers cannot adequately perceive the current or future traffic condition. Therefore, the hypothesis of perfect rationality violates the reality, and the EUT-based route choice model is proved to be inconsistent with traveler's real decision making behavior[1], such as the famous Allais and Ellsberg Paradox.

Researchers try to find an alternative theory of EUT to explain the decision making behavior under uncertainty. The most famous alternative, which is based on Simon's Bounded Rationality, is the prospect theory (PT) proposed by Kahneman and Tversky in 1979. The PT has been suc-

Received 21 September 2011; revised 31 May 2012.

†Corresponding author. E-mail: yanglc@sdu.edu.cn; Tel.: +86 0531−88392024.

This paper was supported by the Shandong Provincial Natural Science Fund (No. ZR2010FM036) and the Graduate Autonomous Innovation Fund of Shandong University (No. yzc10127).

cessfully used in evaluation and policy of financial risk and electronic commerce. Considering similarities between economics and transportation, researchers at home and abroad employ the PT to solve transportation issues. Researches indicate that PT deals with the imperfect behaviors led by the traveler's subjective initiative, and is consistent with traveler's route choice behavior under uncertainty, that is, PT is suitable for route choice issue[2]. At present, plenty of researchers establish the route choice model based on prospect theory. Katsikopoulos et al.[3] found that travelers tend to risk aversion in the route choice experiment when the average value of a group of travel times is below the reference travel time. But the travelers tend to risk seeking when the average value is above the reference. Bogers et al.[4] found the similar phenomenon that travelers tend to risk aversion when they can freely choose the route between an uncertain short one and a stable long one, that is, most travelers choose the long route. Satoshi Fujii[5] and GAO[6] used prospect theory to analyze traveler's departure time choice in uncertain transportation network. Avineri[7–10] used cumulative prospect theory to discuss the passenger's behavior model. Jou[11] and Senbil[12] studied the applicability of reference point of prospect theory in the traveler's departure time choice model. ZHAO et al.[13] analyzed the route choice process using priori traffic information, and established the route choice model based on PT for commuters. YANG et al.[14] improved the value function of the route choice model based on PT for commuters.

These route choice models are mostly for commuters. Due to the periodicity and definiteness of arrival time, models for commuters are quite different from route choice models of DRGS in reference point selection, value function establishment, and model basis. Especially, the reference point of models for commuters is definite, that is the check-in moment, and these models provide the optimal deviation of objective function to the reference. But the models of DRGS give the optimal cumulative value of objective function, with no definite reference. Hence, this paper presents a prospect theory-based route choice model, and gives an experiment for comparison with EUT, which provides a new method to DRGS. The experimental results show that the prospect theory-based model provides a more reasonable and realistic route than the EUT-based model does. The proposed model can precisely describe the traveler's decision making process under uncertainty.

2 Prospect theory

Prospect theory is about individual's actual decision making behavior under uncertainty[15]. Its core idea is that decision makers make a decision depending on the wealth change rather than the final value, which is consistent with the decision making principles. Therefore, the PT has been proven to be a good alternative approach of EUT. PT solves a problem from the standpoint of gain and loss. It regards that individuals' treatments to gain and loss are asymmetric. Facing to the gain, individuals tend to risk aversion, while facing to the loss, individuals tend to risk seeking. Evaluation of the gain and loss is based on a selected reference point.

Prospect theory divides the individual's decision making process into two stages, which are the editing phase and the evaluation phase. The basic function of the editing phase is to organize and analyze all kinds of probabilities and to simplify the different results for the sake of the follow-up evaluation and selection subsequently. In the evaluation phase, decision makers should estimate the results from the editing phase, and choose the scheme with the maximum prospect value as a future implementation plan.

In the editing phase, there are two functions to describe the individual's decision making behavior, which are the value function $v(x)$ and weighting probability function $w(p)$ respectively. The definition of the value function is relative to the selection of the reference point. In the PT, the expression of the editable prospect value of an event under uncertainty is $U(x)$, which is the product of $v(x)$ and $w(p)$. The value function gives each probable result a value $v(x)$, which measures the value deviated to the reference point, namely the gain and loss. The weighting probability function $w(p)$ is related to the probability of the occurrence of each event, which does not measure the probability, but the impact of prospect attractiveness of the event. The weighting probability function is a probability evaluation function.

An uncertain event

$$w(p) = P(x_1, p_1; x_2, p_2; \cdots; x_n, p_n)$$

means that the probability of the appearance of result x_i is p_i, and $p_1 + p_2 + \cdots + p_n = 1$. According to PT, the prospect value expression of the event is as follows:

$$\begin{aligned} &U(x_1, p_1; x_2, p_2; \cdots; x_n, p_n) = \\ &v(x_1) \cdot w(p_1) + v(x_2) \cdot w(p_2) + \cdots + \\ &v(x_n) \cdot w(p_n) = \\ &\sum v(x_i) \cdot w(p_i). \end{aligned} \tag{1}$$

3 Model establishment

The cores of the PT-based route choice model are the selection of the reference point, the value function, and the weighting probability function. Before the establishment of the dynamic route guidance model based on prospect theory, some necessary definitions are given as follows:

T_{ij}^k: the travel time of road section (i, j) at the present moment k;

T_{ij}^m: the minimum travel time of road section (i, j);

T_{ij}^r: the reference point of road section (i, j);

$V(\cdot)$: the value function;

$W(P(\cdot))$: the weighting function of probability $P(\cdot)$, short for weighting probability function;

$U(\cdot)$: the prospect value function,

$$\max U(\cdot) = \sum V(\cdot)W(\cdot).$$

3.1 Reference point selection

In the prospect theory, the calculation of prospect value mainly relies on the reference point to distinguish gain and loss. Theoretically, there is a definite speed limitation on urban road. Due to this speed limitation, each road section has a minimum travel time T_{ij}^m, that is

$T_{ij}^m = \mathrm{Leng}_{ij}/v_{\max}$, where Leng_{ij} is the length of road section (i, j). Because of the influences, such as traffic condition, driving preference, intersection delay and so on, the travel time of road section (i, j) is longer than T_{ij}^m. The reference point is relative to the travel time, so it is in the range $[T_{ij}^m, +\infty)$.

So far, there is no literature on the selection of reference point of route choice model in DRGS. "The urban traffic management and evaluation index system" published by the Chinese Ministry of Public Security in 2008 provided the grading schedule of the traffic state evaluation index listed in Table 1, that is, the peak hour average speed of trunk road. From the point of view of traditional resident habits, the traffic states are divided into three grades: unobstructed, slow, and congested. Based on the data listed in Table 1, the traffic states can be described as follows:

- Unobstructed. The average speed of vehicles is over 30 km/h, including the average speed over Grade 1;
- Slow. The average speed is between 19 km/h and 30 km/h, including the average speed among Grade 1 to Grade 3;
- Congested. The average speed is under 19 km/h, including the average speed among Grade 4 and Grade 5.

Table 1 Grading schedule of peak hour average speed of trunk road in built up area

km/h

Evaluation grade	1	2	3	4	5
Super-huge & Class A	$[25, 30]$	$[22, 25]$	$[19, 22]$	$[16, 19]$	$[0, 16]$
Class B	$[28, 33]$	$[25, 28]$	$[22, 25]$	$[19, 22]$	$[0, 19]$
Class C & D	$[30, 35]$	$[27, 30]$	$[24, 27]$	$[21, 24]$	$[0, 21]$
Index	$[90, 100]$	$[80, 90]$	$[70, 80]$	$[60, 70]$	$[0, 60]$

The travel time T_{ij}^k depends on the velocity, so the selection of the reference point refers to the evaluation rules of unobstructed road and congested road. As the speed limitation of urban trunk road is generally 60 km/h, the relation between the travel time T_{ij}^k and minimum travel time T_{ij}^m is as follows:

$$\frac{T_{ij}^k}{T_{ij}^m} = \frac{\mathrm{Leng}_{ij}/v}{\mathrm{Leng}_{ij}/v_{\max}} = \frac{v_{\max}}{v} = \frac{60}{v}. \tag{2}$$

From equation (2), the travel time can be described as $T_{ij}^k = T_{ij}^m * (60/v)$. Generally speaking, when traffic jam occurs, the travel time is increasing rapidly. This causes severe influence to traffic flow, while the condition of slow traffic flow is not evident. Hence, set the speed of the separation between the slow and congested road (v=19 km/h) as the speed of the reference point, so that the reference point T_{ij}^r is approximate to three times T_{ij}^m. The reference point divides the travel time of each road section into two regions. The region whose value is above the reference point tends to loss, while the region whose value is below tends to gain.

The " The urban traffic management and evaluation index system" only offers the grade partition of trunk road. According to the limiting velocity of each kind of roads, the principle of zooming in proportion is adopted to divide the traffic grades of express way, collector road, and local road respectively.

Table 2 lists the partition of traffic grade of all sorts of urban roads. From equation (2), the reference points of all the other roads can be acquired in the same way.

Table 2 Partition of traffic grade

km/h

Traffic state	Express way speed limit: 80	Trunk road speed limit: 60	Collector road speed limit: 40	Local road speed limit: 30
Unobstructed	$V > 40$	$V > 30$	$V > 20$	$V > 15$
Slow	$25 < V < 40$	$19 < V < 30$	$12 < V < 20$	$10 < V < 15$
Congested	$V < 25$	$V < 19$	$V < 12$	$V < 10$

3.2 Value function definition

The original pattern[16] of value function proposed by Kahneman and Tervsky can well satisfy the decision maker's risk preference characteristics:

$$v(x) = \begin{cases} x^{\alpha}, & x < T_{\mathrm{w}}, \\ -\lambda(-x)^{\alpha}, & x \geqslant T_{\mathrm{w}}. \end{cases} \tag{3}$$

Avineri[1–4], and ZHAO[13] applied equation (3) into traffic field as the route choice model for commuters. In equation (3), x indicates the difference between the predicted arrival time and reference point, and T_{w} indicates the commuting time, that is, the reference point.

For commuters, the route choice model should include three reference points: the acceptable earliest arrival time T_{e}, the commuting time T_{w}, and the optimal arrival time T_{p}. So, YANG[14] improved the value function for commuters in route choice model as follows:

$$v(T_{r,k}) = \begin{cases} -\alpha_1(T_{\mathrm{e}} - T_{r,k})^{\alpha_1}, & T_{r,k} \leqslant T_{\mathrm{e}}, \\ \alpha_2(T_{r,k} - T_{\mathrm{e}})^{\alpha_2}, & T_{\mathrm{e}} < T_{r,k} \leqslant T_{\mathrm{p}}, \\ \alpha_3(T_{\mathrm{w}} - T_{r,k})^{\alpha_3}, & T_{\mathrm{p}} < T_{r,k} < T_{\mathrm{w}}, \\ -\alpha_4(T_{r,k} - T_{\mathrm{w}})^{\alpha_4}, & T_{\mathrm{w}} \leqslant T_{r,k}. \end{cases} \tag{4}$$

The value functions mentioned above are all for commuters without generality. However, there is no deterministic reference point in route choice model of DRGS, and the parameter of DRGS is the travel time computed by the velocity, distance, and intersection delay etc., which is not measured by exact moment. Hence, the value function of route choice model for commuters cannot be applied in DRGS directly.

The reference point separates the region into gain and loss, but it can not describe the definite gain and loss. The value function gives the gain and loss a certain numerical value. The value function of travel time T_{ij}^k gets its max value at the minimum travel time T_{ij}^m, and its value decreases with the growth of T_{ij}^k. When T_{ij}^k reaches T_{ij}^r, its value decreases to zero. However, when T_{ij}^k goes beyond T_{ij}^r, the road section is crowded. Meanwhile, the value tends to loss with the growth of T_{ij}^k. The longer T_{ij}^k becomes, the greater the loss is, namely, the value is more negative. Theoretically, the travel time T_{ij}^k is bigger than the minimum travel time T_{ij}^m due to the speed limitation. Since there is overspeed driving occasionally in real world, the travel time T_{ij}^k is smaller than the minimum travel time T_{ij}^m at this moment, and this situation is illegal and forbidden. Although the condition that travel time is smaller than the minimum travel time exists, the value on this condition should not become bigger, but equal to the value at minimum travel time point. From all above, the value function can be constructed as equation (5), which composes of three sections. When $T_{ij}^k < T_{ij}^m$, the value function shows a constant prospect value. When $T_{ij}^m < T_{ij}^k < T_{ij}^r$, the value function shows a slowly decreased positive prospect value. When $T_{ij}^k > T_{ij}^r$, the value function shows a sharply decreased negative prospect value.

$$v(x) = \begin{cases} (x)^{-\alpha T_m}, & x \leqslant T_{ij}^m, \\ (x)^{-\alpha x}, & T_{ij}^m < x \leqslant T_{ij}^r, \\ -\lambda(-x)^{\alpha}, & x > T_{ij}^r, \end{cases} \tag{5}$$

where α is the risk attitude coefficient, and the range of α is from 0 to l. The larger α indicates, the greater the travelers tend to the risk. When α is equal to l, the traveler is risk neutral. The expression of gain is different from that of loss. The function of gain is concave, which reflects risk aversion. While the function of loss, which reflects risk seeking, is convex. The coefficient α indicates the bump degree of the value function, that is, the velocity of decrease of traveler's sensitiveness progressively. λ is the risk aversion coefficient. If $\lambda > 1$, the traveler is more sensitive to the loss, that is, the ramp of loss is steeper than that of gain, which is shown in Fig. 1. In terms of Kahneman et al. calibration[16], when $\alpha = 0.88$, and $\lambda = 2.25$, the function is consistent with the experience data.

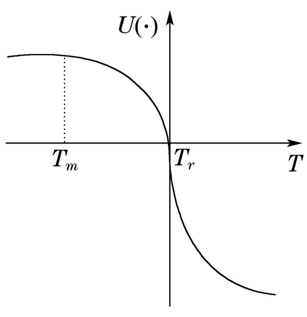

Fig. 1 Value function

3.3 Weighting probability function

The calculation of the probability in the weighting probability function is based on the subjective probability of probable results led by the event. But when the travelers make the option and decision with the empirical data or the information provided by the traffic information publishing system, they can't obtain the subjective probability of probable results led by the event due to the dynamic and uncertain traffic environment and road network condition. Therefore, the calculation of the probability is based on the traffic flow and grade of the road section shown as below:

$$P(x) = \frac{1}{\text{Grade}} \frac{1}{\frac{1}{n}\sum_{t=1}^{n} Q_{ij}^{kt}}, \tag{6}$$

where Grade is the level of the road section. Urban road networks are often divided into three levels. Level I include trunk roads and expressways. Level II are the subtrunk roads. Level III are the branch roads. Q_{ij}^{kt} indicates the traffic flow of road section (i, j) at the moment k of the day t. The traffic flow has the periodic repetitive property. The data selection is critical during the calculation of the average traffic flow. The selected traffic flows should have the similar characteristic, that is, the data at the same moment of the same working day in different weeks.

In terms of the weighting probability function proposed by Kahneman in 1992, the form of weighting probability function in the dynamic route guidance model is as follows:

When traveler faces to the gain, the $w(p)$ is as follows:

$$w^+(p) = \frac{p^\gamma}{(p^\gamma + (1-p)^\gamma)^{\frac{1}{\gamma}}}; \tag{7}$$

When traveler faces to the loss, the $w(p)$ is as follows:

$$w^-(p) = \frac{p^\delta}{(p^\delta + (1-p)^\delta)^{\frac{1}{\delta}}}, \tag{8}$$

where p is the probability of the selected road section. With extensive investigation and experimental analysis, Kahneman[16] calibrated $\gamma = 0.61$, and $\delta = 0.69$. The weighted probability function is shown in Fig. 2.

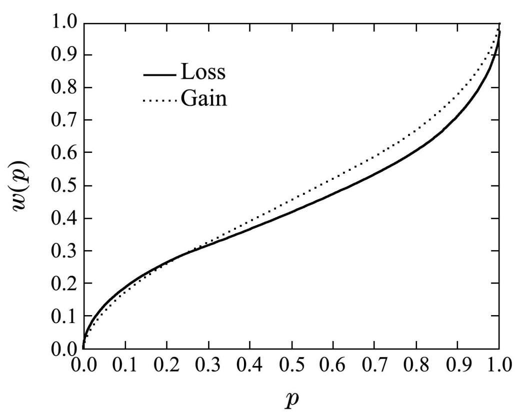

Fig. 2 Weighting probability function

3.4 Route choice model

After the acquirement of the value function and the weighting probability function in the editing phase, the prospect value of each road section can be calculated as equation (9):

$$U(T_{ij}^k) = V(T_{ij}^k) \cdot W(P(i,j)). \tag{9}$$

Travelers will choose a route with maximum prospect value by using the prospect value function. Hence, the route choice model based on prospect theory can be described as follows:

$$\max U(\cdot) = \sum V(T_{ij}^k) \cdot W(P(i,j)). \tag{10}$$

4 Experimental simulation

The main purpose of the dynamic route guidance system is to provide an optimal route between the origin and the destination. In order to verify the superiority of prospect theory to EUT in route choice model, this paper establishes both the PT-based model and the EUT-based model using Dijkstra Algorithm for route computing.

The EUT-based model is as follows:

$$\min \sum \sum T_{ij}^k. \tag{11}$$

The proposed PT-based model is as follows:

$$\max U(\cdot) = \sum V(T_{ij}^k) \cdot W(P(i,j)). \tag{12}$$

The experiment is based on a real urban road network. There are 2958 nodes and 3405 road sections in the road network. Use Dijkstra algorithm as the optimal strategy to compute the optimal route of the same origin-destination (O-D) in the two different models. The result of PT-based model is the maximum value, while the EUT-based model is the minimum value. Since the purpose of the Dijkstra algorithm is to compute the shortest path, that is, it solves the minimum issue, the prospect value of each road section in the PT-based model should multiply by minus one so as to use Dijkstra algorithm for route computing. According to plenty of tests, the two models always give different routes. From all the test results, a couple of the routes of the two different models are shown in Fig.3 and Fig.4 (in bold).

Fig. 3 Optimal route of EUT-based route choice model

Fig. 4 Optimal route of PT-based route choice model

All the results of each route are shown in Table 3. From Table 3, it is clear that the prospect value of the optimal route provided by the Prospect Theory-based model is bigger than that provided by the Expected Utility Theory-based model. The variable of PT-based model, which differs from the single travel time variable of EUT-based model, is changed to prospect value which determined by travel time, road grade, and traffic flow so as to solve the problem that deterministic travel time cannot accurately describe both the travel behavior stochasticity and route choice probability. Moreover, the Prospect Theory adopts weighting probability function to measure the confidence coefficient of posterior information and real-time information. Hence, the PT-based model gives a more optimal route which is closer to the driver's real travel behavior, and the decision making processing is fit for the stochastic characteristics of route choice model and suitable for the description of the real traffic behavior. This reflects that the PT-based model can better deal with the non-fully rational behaviors led by the traveler's subjective initiative, and that the route provided by the PT-based model is more reliable than that provided by the EUT-based model.

Table 3 Parameters of the two optimal routes

Model	Joints	Length /km	Time cost /min	Prospect value
EUT	31	8.61058	52.34	4.6569
PT	24	8.34597	60.12	5.9496

Table 3 also lists the total joints, length, time cost of each route provided by the two different models. Generally speaking, travel time cost, which travelers regard as important traditionally, is the common index for route choice model. But the time cost is not the real travel time of a route, but a computation of present travel time or prediction of future travel time. From Table 3, although the time cost of the route provided by the EUT-based model is shorter, it only stands for a reference value, which is different from the real travel time of the route, that is, there is a deviation between the route choice model and real travel behavior. The deviation arises from the inaccurate to use of deterministic travel time as the index to evaluate the randomness of traffic behavior and route choice model, which is described in the famous Allais and Ellsberg Paradox. As a result, it is unreliable to use the single travel time to express the travel behavior stochasticity and route choice probability. Above all, although the EUT-based model is dominant in the time cost index, it doesn't state that the route provided by the EUT-based model is optimal.

However, the PT-based model is dominant in both the joint and the length indexes. Since intersection delay is a stochastic influence of travel time, and it is calculated in route computing, but the more intersections there are in the route, the greater the randomness of travel time is. Consequently, more joints means unreasonable route and decreasing reliability. The route provided by the PT-based model goes through 24 joints, which is fewer than the EUT-based model. For the most part, this model decreases the influence of the intersection delay so as to provide a more reliable route. Although the PT-based model provides a route with longer travel time, this model can both reflect the traveler's real decision making behavior in the actual travel process, and follow the desired goals. Hence, the PT-based model gives a more reasonable route than the EUT-based model, and it is consistent with the traveler's real demands and actual psychological decision making process.

The variable of the PT-based route choice model is determined by the travel time, road grade, and traffic flow synthetically, not only the travel time. It reflects the specificity that Prospect Theory deals with the imperfect behaviors led by the traveler's subjective initiative, which the Expected Utility Theory doesn't possess. As the probability weighting function of Prospect Theory can reflect the mentioned deviation between the route provided by the model and the real travel behavior, that is, the bigger the prospect value is, the smaller the deviation is, the PT-based model can provide optimal route which is closer to real travel behavior. Hence, the route provided by the PT-based model is more time reliable, so that the drivers have higher confidences to the provided routes. From the comprehensive comparison, the performance of the proposed PT-based route choice model is better than that of the EUT-based model. Considering the randomness of traffic and traveler's non-rational factors, the model can accurately describe the traveler's decision making behavior under uncertainty and complexity.

5 Conclusions

This paper presents a prospect theory-based route choice model, which eliminates the shortcomings of the utility maximization hypothesis and complete rationality hypothesis of expected utility theory. The greatest strength of prospect theory to EUT is the usage of weighting probability function. The variable of the route choice model, which no longer relies on the maximization of utility, changes into the product of prospect value and probability weighting based on traveler's psychology. Consequently, the performance of this model is more corresponding to the actual travel situation and the traveler's psychological anticipation. The experimental results show that the prospect theory-based route choice model overcomes the insufficiency of the EUT in the description of traveler's route choice behavior. The PT-based model can accurately describe traveler's route choice behavior under uncertainty, which is much closer to the actual travel routes. Meanwhile, the method using prospect theory provides a new thought for dynamic route guidance system. However, this model only uses the travel time of road section as the independent variable for prospect value computation. The integration of more parameters, such as the travel time, the distance, the fuel consumption, the environment, and so on, will be considered in the future study to obtain a more realistic multi-dimensional model.

References:

[1] AVINERI E, PRASHKER J N. Sensitivity to travel time variability: travelers' learning perspective [J]. *Transportation Research, Part C*, 2005, 13(2): 157 – 183.

[2] AVINERI E, PRASHKER J N. Violations of expected utility theory in route-choice stated-preferences: the certainty effect and inflating of small probabilities [J]. *Transportation Research Record: Journal of the Transportation Research Board*, 2004, 1894(1): 222 – 229.

[3] KATSIKOPOULOS K V, DUSE-ANTHONY Y, FISHER D L, et al. Risk attitude reversals in drivers' route choice when range of travel time is provided [J]. *Human Factors*, 2002, 44(3): 466– 473.

[4] BOGERS E A I, ZUYLEN H J. The importance of reliability in route choices in freight transport for various actors on various levels [C] //*Proceedings of European Transport Conference*. Strasbourg, France: Association for European Transport, 2004.

[5] FUJII S, KITAMURA R. Drivers' mental representation of travel time and departure time choice in uncertain traffic network conditions [J]. *Networks and Spatial Economics*, 2004, 4(3): 243 – 256.

[6] GAO S, FREJINGER E, BEN-AKIVA M. Adaptive route choices in risky traffic networks: a prospect theory approach [J]. *Transportation Research, Part C*, 2010, 18(5): 727 – 740.

[7] AVINERI E. A cumulative prospect theory approach to passengers behavior modeling: waiting time paradox revisited [J]. *Journal of Intelligent Transportation Systems*, 2004, 8(4): 195 – 204.

[8] AVINERI E. The effect of reference point on stochastic network equilibrium [J]. *Transportation Science*, 2006, 40(4): 409 – 420.

[9] AVINERI E. Incorporating fuzzy reference points into applications of travel choice modeling [J]. *Advances in Soft Computing*, 2009, 52(7): 221 – 229.

[10] AVINERI E, CHORUS C G. Editorial: recent developments in prospect theory-based travel behaviour research [J]. *European Journal of Transport and Infrastructure Research*, 2010, 10(4): 293 – 298.

[11] JOU R C, KITAMURA R, WENG M C, et al. Dynamic commuter departure time choice under uncertainty [J]. *Transportation Research, Part A*, 2008, 42(5): 774 – 783.

[12] SENBIL M, KITAMURA R. Reference points in commuter departure time choice: a prospect theoretic test of alternative decision frames [J]. *Intelligent Transportation Systems Journal*, 2004, 8(1): 19 – 31.

[13] ZHAO L, ZHANG X C. A prospect theory-based route choice model of traveler with prior information [J]. *Journal of Transportation Systems Engineering and Information Technology*, 2006, 6(2): 42 – 46.

[14] YANG Z Y, YAN G Y. Model research of route choice under real-time information based on prospect theory [J]. *Journal of Shijiazhuang Railway Institue*, 2008, 21(4): 47 – 51.

[15] KAHNEMAN D, TVERSKY A. Prospect theory: an analysis of decision under risk [J]. *Econometrica*, 1979, 47(2): 263 – 291.

[16] TVERSKY A, KAHNEMAN D. Advances in prospect theory: cumulative representation of uncertainty [J]. *Journal of Risk and Uncertainty*, 1992, 5(4): 297 – 323.

作者简介:

吴 磊 (1985–), 男, 博士研究生, 研究方向为智能交通系统、车辆自组织网络等, E-mail: wulei_control@sdu.edu.cn;

杨立才 (1962–), 男, 教授, 博士生导师, 研究方向为人工智能与智能控制、智能交通系统、生物医学工程等, E-mail: yanglc@sdu.edu.cn.