

文章编号:1671-1637(2012)03-0067-06

## 后悔理论视角下的出行选择行为

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**摘要:**应用随机后悔最小化理论与随机效用最大化理论, 分别建立 RRM-MNL 模型和 RUM-MNL 模型研究了出行方式选择行为。在模型参数、拟合优度方面对 2 个模型进行了比较, 应用直接弹性分析了在交通管理措施评价方面的区别, 并通过城际出行方式中的飞机、火车、长途汽车、小汽车 4 种出行方式数据进行实际验证。分析结果表明: 相比于 RUM-MNL 模型, RRM-MNL 模型能够描述在多属性方案选择过程中的部分补偿性决策行为和折衷效应, 能更真实地反映实际出行行为选择过程; 等待时间、出行时间和出行费用对飞机、火车和长途汽车 3 种出行方式的选择概率都具有弹性; 在 RRM-MNL 模型中, 等待时间对 3 种方式的弹性值分别较 RUM-MNL 模型的低 7.30%、13.14% 和 7.70%。可见, 对于同一属性变量, 出行者具有不同的选择偏好, 会表现出不同的选择行为。

**关键词:** 交通规划; 出行方式; 随机后悔最小化; 随机效用最大化; 部分补偿性决策; 折衷效应; 直接弹性

**中图分类号:** U491.1      **文献标志码:** A

## Travel choice behavior based on regret theory view

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**Abstract:** Based on random regret minimization (RRM) theory and random utility maximization (RUM) theory, RRM-MNL model and RUM-MNL model were set up to research the choice behaviors of travel modes respectively. Aiming at RRM-MNL model and RUM-MNL model, the parameters and the goodnesses of fit were compared, their difference on the evaluation of traffic management measures was analyzed through direct elasticity, and practical verification was carried out based on four travel data such as aircraft, train, coach and car during intercity travel. Analysis result shows that compared with RUM-MNL model, in RRM-MNL model, the partial compensatory decision-making behavior and compromise effect during the choice process of multi-attribute method are described better, and the choice process of travel behavior can be reflected more really. The choice probabilities of wait time, travel time and travel cost on three travel methods such as aircraft, train and coach have significant elasticities. In RRM-MNL model, the elasticities of wait time for aircraft, train and coach all are lower than those in RUM-MNL

**Receipt**      **Date:** 2011-12-22

**Research Projects:** National Natural Science Foundation of China (51008190, 50878129); Research Foundation of Selecting and Training Outstanding Young Teachers in Shanghai Universities (sdj10009); Research Foundation of Shanghai Dianji University (10C201); Key Subject Construction Project of Shanghai Dianji University (10XKJ01)

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model, and reduce by 7.30%, 13.14% and 7.70% respectively. So, for the same attribute variable, while the traveler has different choice preferences, the different choice behaviors will be displayed. 4 tabs, 4 figs, 15 refs.

**Key words:** traffic planning; travel mode; random regret minimization; random utility maximization; partial compensatory decision-making; compromise effect; direct elasticity

## 0 Introduction

Discrete choice model based on random utility maximization (RUM) theory is the leading paradigm in travel behavior analysis. But, more and more researchers are continuously challenging the truth of behavior assumption by practical test, and it requires the improvements from two aspects such as fully compensatory decision-making process and the sensitivity of choice set composition in the model. Based on the discrete attribute of travel choice, Arentze et al introduced the method of parametric action decision-making tree to the study of discrete choice behavior through a combination of logit model and decision-making tree method, and refused the fully compensatory decision-making assumption of classical RUM model<sup>[1]</sup>. Bell used regret concept to explain phenomena where RUM theory is not obeyed in practical choice situation, and also questioned the assumption of fully compensatory during the decision-making process<sup>[2]</sup>. Zhang et al reformed the multinomial logit (MNL) model and nested logit (NL) model from the angles of relative utility and relative interest, and the independence of irrelevant alternatives (IIA) property of MNL model was avoided<sup>[3]</sup>. Gilbride et al analyzed the screening rule of decision-making process, and found that the schemes which satisfied screening rule could compose preparation choice set, and entered the decision-making process while RUM theory was obeyed. While the schemes that not satisfied screening rule could be deleted directly, and the final result was not effected<sup>[4]</sup>. However, these new models discussed above often are complicated, the parameters are difficult to estimate and understand, and adversely affects the application in the practice of travel behavior forecast and traffic management<sup>[5-6]</sup>. Leong et al analyzed travel choice data, and found that

travelers adjusted their decision-making rules according to different travel circumstances<sup>[7-8]</sup>. Jou et al prohibited the fully compensatory decision-making assumption, and found that modeling researches on the choice behaviors with different decision-making rules were hot spots in travel choice behavior field<sup>[9-10]</sup>. Based on random regret theory, Chorus et al defined the regret value from attribute level and scheme level, proposed the new modeling method of discrete choice model by using random regret minimization (RRM) theory, and analyzed the RRM-based multinomial logit (RRM-MNL) model emphatically. The RRM-MNL model was similar to MNL model in specification and estimation, and the IIA property was overcome while the form of choice probability was succinct<sup>[11]</sup>. In RRM-MNL model, the partial compensatory decision-making process can be described, and the sensitivity on choice set structure can display the composition effect of customer choice behavior.

In the view of the limitations of RUM-MNL model and the advantages of RRM-MNL model in travel behavior modeling, the RRM-MNL model is selected to analyze travel choice behavior. The model structure, compromise effect and partial compensatory decision-making characteristic are analyzed, and model parameters and the goodnesses of fit are compared between RRM-MNL model and RUM-MNL model. The model application in traffic management is discussed by using direct elasticity, and the effectiveness of travel behavior analysis is verified through intercity travel data.

## 1 RRM-MNL model

### 1.1 Model structure

A decision-making maker  $n$  faces a set of methods  $I$ , each method  $i$  ( $i=1,2,\dots,I$ ) can be described in the terms of  $M$  attributes  $x_{nim}$  ( $m=1,2,\dots,M$ ).

Based on RRM theory, when choosing one from the set of methods  $I$ , the decision-making maker aims to minimize the random regret. The random regret value  $R_{rni}$  is composed of a deterministic term  $R_{ni}$  and an independent and identically distributed random error  $\epsilon_{ni}$

$$R_{rni} = R_{ni} + \epsilon_{ni} \quad (1)$$

The deterministic term  $R_{ni}$  is the sum of all attribute regret values obtained by comparing method  $i$  another method  $j$  ( $j \neq i$ )

$$R_{ni} = \sum_I \sum_{m=1}^M R_{nijm} = \sum_I \sum_{m=1}^M \ln \left\{ 1 + \exp[\beta_m (x_{njm} - x_{nim})] \right\} \quad (2)$$

where  $R_{nijm}$  is attribute regret value determined by the comparing results of attribute  $m$  for method  $i$  and method  $j$ ;  $x_{nim}$  and  $x_{njm}$  are the values of attribute  $m$  for method  $i$  and method  $j$  respectively;  $\beta_m$  is corresponding parameter.

Eq. (2) implies that attribute regret value  $R_{nijm}$  is close to zero when method  $j$  performs much worse than method  $i$  in the terms of attribute  $m$ , and there is a linear function of attribute difference value when method  $j$  performs better in the terms of attribute  $m$ . In this situation, parameter  $\beta_m$  approximates the slope of  $R_{nijm}$ , and it is shown in Fig. 1.

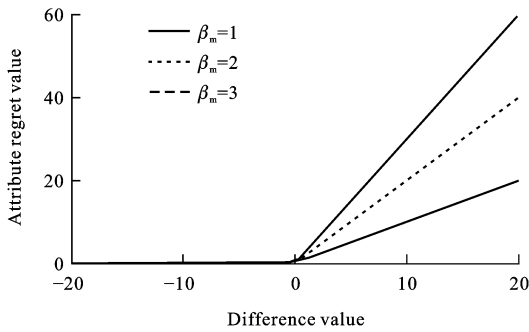


Fig. 1 Attribute regret values

The random regret value  $R_{rni}$  is equivalent to its opposite number. Assuming the random error  $\epsilon_{ni}$  obeys the distribution of Gumbel  $(0, 1)$ , the probability of decision-making maker  $n$  choosing method  $i$  ( $P_{ni}$ ) can be described as<sup>[11]</sup>

$$P_{ni} = \frac{\exp(-R_{ni})}{\sum_{j=1}^I \exp(-R_{nj})} \quad (3)$$

From Eq. (2) and Eq. (3), in RRM-MNL

model, the ratio of the choice probabilities of methods  $i$  and  $j$  depends on the performances of two methods relative to one another as well as relative to another method  $k$  ( $k \neq i, j$ ) in the choice set, which overcomes the IIA limitation of RUM-MNL model<sup>[12]</sup>.

When the decision-making maker  $n$  uses RUM as the decision-making rule, the choice probability of method  $i$  can be expressed as follow

$$P_{ni} = \frac{\exp\left(\sum_{m=1}^M \gamma_m x_{nim}\right)}{\sum_{j=1}^I \exp\left(\sum_{m=1}^M \gamma_m x_{njm}\right)} \quad (4)$$

where  $\gamma_m$  is model parameter.

## 1.2 Model attribute

### 1.2.1 Compromise effect

In RRM-MNL model, the methods with middle values on all attributes are more popular than those with a poor performance on some attributes and a strong performance on the others, which is called compromise effect common in customer choice behavior<sup>[13-14]</sup>, and it is shown in Fig. 2. A choice situation has three methods A, B and C, each method defines in the terms of two attributes that are equally important, which means  $\beta_1 = \beta_2$ , and  $\Delta$  is a non-negative increment. The attribute values are  $\{1, 3\}$ ,  $\{2+\Delta, 2-\Delta\}$  and  $\{3, 1\}$  for methods A, B and C respectively. When  $\Delta = 0$ , the choice probability of method B ( $P_B$ ) is larger than those of methods A and C ( $P_A$  and  $P_C$ ), and method B becomes a compromise method.

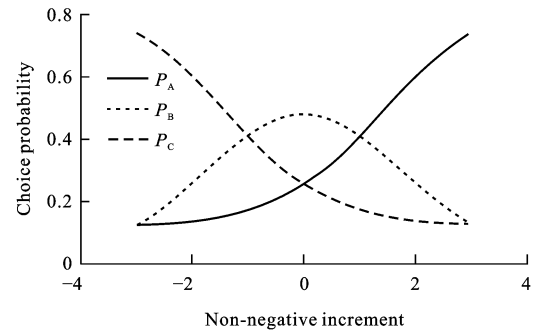


Fig. 2 Compromise effects

### 1.2.2 Partial compensatory decision-making

Assuming attributes  $l$  and  $m$  are equally important to the decision-making maker, and have the same influence coefficient, which is  $a$  in RUM-MNL model and is  $b$  in RRM-MNL model. The linear

additivity of utility function in RUM-MNL model determines that the change method caused by one unit decreasing in attribute  $l$  can be fully compensated by one unit increasing in attribute  $m$ . Therefore, the parameter  $\gamma_m$  in RRM-MNL model can measure the contribution of attribute  $m$  on choice probability.

In RRM-MNL model, there is an attribute difference between two methods. While there is a decrease in the choice probability of attribute  $l$ , the influence on choice probability is not only made up by attribute  $m$  but also depended on attributes  $l$  and  $m$ , which demonstrates the partial compensatory decision-making process. Assuming method  $i$  is better than any other method  $j$  on attribute  $l$ , but is worse on attribute  $m$ . It is obvious that for attribute regret value, the increasing value of attribute  $l$  is much smaller than the decreasing value of attribute  $m$ . Therefore, the parameter  $\beta_m$  in RRM-MNL model can only partly measure the contribution of attribute  $m$  on choice probability. So, the parameters in RRM-MNL model and RUM-MNL model are different obviously. In order to describe the difference of choice decision-making behaviors in the two models, the direct elasticity of attribute variable on choice probability  $E_{x_{nm}}^{P_{ni}}$  is analyzed

$$E_{x_{nm}}^{P_{ni}} = \frac{\partial P_{ni}}{P_{ni}} \bigg/ \frac{\partial x_{nm}}{x_{nm}} = \frac{\partial \ln(P_{ni})}{\partial x_{nm}} x_{nm} \quad (5)$$

$$R_{ni} = \sum_{j=1}^I \sum_{m=1}^M \ln \left\{ 1 + \exp[\beta_m (x_{njm} - x_{nim})] \right\} - M \ln(2) \quad (6)$$

$$\ln(P_{ni}) = -R_{ni} - \left[ \ln \sum_{j=1}^I \exp(-R_{nj}) \right] \quad (7)$$

$$\begin{aligned} \frac{\partial \ln(P_{ni})}{\partial x_{nm}} &= -\frac{\partial R_{ni}}{\partial x_{nm}} - \frac{\partial \left\{ \ln \left[ \sum_{j=1}^I \exp(-R_{nj}) \right] \right\}}{\partial x_{nm}} = \\ &= -\frac{\partial R_{ni}}{\partial x_{nm}} - \frac{\sum_{j=1}^I \partial [\exp(-R_{nj})] / \partial x_{nm}}{\sum_{j=1}^I \exp(-R_{nj})} = \\ &= -\frac{\partial R_{ni}}{\partial x_{nm}} - \frac{\sum_{j=1}^I \exp(-R_{nj}) \partial (-R_{nj}) / \partial x_{nm}}{\sum_{j=1}^I \exp(-R_{nj})} = \\ &= -\frac{\partial R_{ni}}{\partial x_{nm}} - \sum_{j=1}^I P_{nj} \frac{\partial (-R_{nj})}{\partial x_{nm}} = \end{aligned}$$

$$\sum_{j=1}^I P_{nj} \frac{\partial R_{nj}}{\partial x_{nm}} - \frac{\partial R_{ni}}{\partial x_{nm}} \quad (8)$$

Eqs. (5)-(7) can result in

$$\begin{aligned} E_{x_{nm}}^{P_{ni}} &= \sum_{j=1}^I P_{nj} \frac{\partial R_{nj}}{\partial x_{nm}} + P_{ni} \frac{\partial R_{ni}}{\partial x_{nm}} - \frac{\partial R_{ni}}{\partial x_{nm}} = \\ &= \beta_m \sum_{j=1}^I P_{nj} q_1 + (P_{ni} - 1) \frac{\partial R_{ni}}{\partial x_{nm}} = \\ &= \beta_m \sum_{j=1}^I P_{nj} q_1 - \beta_m (P_{ni} - 1) \sum_{j=1}^I q_2 = \\ &= \beta_m \left[ \sum_{j=1}^I P_{nj} q_1 + (1 - P_{ni}) \sum_{j=1}^I q_2 \right] \quad (9) \end{aligned}$$

$$q_1 = \frac{\exp[\beta_m (x_{njm} - x_{nim})]}{1 + \exp[\beta_m (x_{njm} - x_{nim})]} \quad (10)$$

$$q_2 = -\beta_m \sum_{j=1}^I \frac{\exp[\beta_m (x_{nlm} - x_{nim})]}{1 + \exp[\beta_m (x_{nlm} - x_{nim})]}$$

## 2 Calculation result analysis

The data from an intercity travel mode choice survey (business travel is excluded) are used to investigate the difference between RRM-MNL model and RUM-MNL model. There are 210 travelers, and there are four traffic methods, such as aircraft, train, coach and car. The mode splits of sample are shown in Tab. 1. The model variables of RRM-MNL model are defined in Tab. 2.

Tab. 1 Sharing ratios

Travel method	Sharing ratio/%
Aircraft (method 1)	30.10
Train (method 2)	28.62
Coach (method 3)	27.00
Car (method 4)	14.28
Total	100.00

Tab. 2 Definitions of model variables

Variable	Definition
$T_1$	Wait time(min)
$T_2$	Travel time(min)
$C_1$	Travel cost (yuan)
$C_2$	Household income (1 000 yuan)
$S_1$	Intrinsic constant of aircraft
$S_2$	Intrinsic constant of train
$S_3$	Intrinsic constant of coach

The regret functions for the four travel methods are

$$\begin{aligned} R_{n1} &= S_1 + \beta_{C_2} C_{2,n} + \sum_{i=2}^4 \left\{ \ln[1 + \exp(\beta_{T_2} (T_{2,ni} - T_{2,n1}))] + \ln[1 + \exp(\beta_{C_1} (C_{1,ni} - C_{1,n1}))] + \right. \\ &\quad \left. \ln[1 + \exp(\beta_{T_1} (T_{1,ni} - T_{1,n1}))] \right\} \quad (11) \end{aligned}$$

$$R_{n2} = S_2 + \sum_{i=1,3,4} \left\{ \ln[1 + \exp(\beta_{T_2}(T_{2,mi} - T_{2,n2}))] + \ln[1 + \exp(\beta_{C_1}(C_{1,mi} - C_{1,n2}))] + \ln[1 + \exp(\beta_{T_1}(T_{1,mi} - T_{1,n2}))] \right\} \quad (12)$$

$$R_{n3} = S_3 + \sum_{i=1,2,4} \left\{ \ln[1 + \exp(\beta_{T_2}(T_{2,mi} - T_{2,n3}))] + \ln[1 + \exp(\beta_{C_1}(C_{1,mi} - C_{1,n3}))] + \ln[1 + \exp(\beta_{T_1}(T_{1,mi} - T_{1,n3}))] \right\} \quad (13)$$

$$R_{n4} = \sum_{i=1}^3 \left\{ \ln[1 + \exp(\beta_{T_2}(T_{2,mi} - T_{2,n4}))] + \ln[1 + \exp(\beta_{C_1}(C_{1,mi} - C_{1,n4}))] + \ln[1 + \exp(\beta_{T_1}(T_{1,mi} - T_{1,n4}))] \right\} \quad (14)$$

where  $T_{1,mi}$  is the wait time of method  $i$ ;  $T_{2,mi}$  is travel time;  $C_{2,mi}$  is household income;  $C_{1,mi}$  is traveling cost;  $\beta_{C_1}$ ,  $\beta_{C_2}$ ,  $\beta_{T_1}$  and  $\beta_{T_2}$  are undetermined parameters.

The regret function of car is used as base method and the model is estimated through BIOGEME<sup>[15]</sup>. The results of RRM-MNL model and RUM-MNL model are compared in Tab.3. Regarding the values of AIC index, the goodness of fit for RRM-MNL model is better than that of RUM-MNL model.

In Tab. 3, all the intrinsic constants in RRM-MNL model are negative and the intrinsic constant of aircraft is smallest. It implies that for all the intercity travelers, when traveling by aircraft, train and coach, the regret values are negative, and the sizes of sharing ratios are aircraft, train, coach, car successively, which is in accordance with the survey result. The other results of model parameters all agree with real travel mode choice behaviors and are significant at 95% confidence level.

Tab. 3 Comparison of calculation results

Variable	Attribute	RUM-MNL model		RRM-MNL model	
		Estimate value	t-test value	Estimate value	t-test value
$S_1$	Intrinsic constant of method 1	3.926 0	3.907	-2.470 0	-8.233
$S_2$	Intrinsic constant of method 2	3.871 0	8.255	-1.948 0	-6.115
$S_3$	Intrinsic constant of method 3	3.244 0	7.077	-1.484 0	-2.103
$T_1$	Common variable	-0.095 8	-9.278	-0.036 0	-8.847
$T_2$	Common variable	-0.004 1	-4.748	-0.004 3	-6.445
$C_1$	Common variable	-0.012 8	-2.015	-0.010 6	-2.686
$C_2$	Specific variable of method 4	0.016 5	2.544	-0.018 8	-2.179
Likelihood ratio only with constant		-291.122			
Likelihood ratio of results		-162.617		-159.976	
Information Criterion(AIC)		1.682		1.590	

The choice probability distributions of RRM-MNL model and RUM-MNL model are shown in Figs. 3 and 4. The RRM-MNL model has a narrower range and more peak value and a smaller heterogeneity in choice probability compared to RUM-MNL model. The comparison result of variable elasticities of the two models is shown in Tab. 4, which also shows the significant differences. Taking variable  $T_1$  for case, in RRM-MNL model and RUM-MNL model, RRM-MNL model are smaller than those in RUM-MNL model, and  $T_1$  is elastic for the choice probabilities of aircraft, train and coach. The

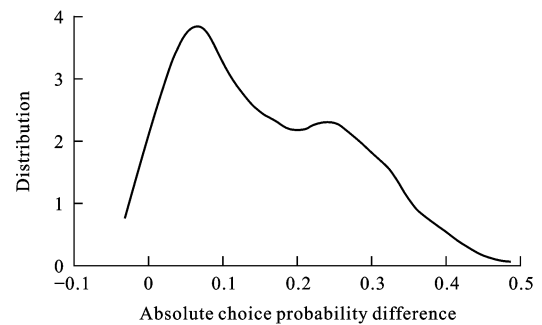


Fig. 3 Absolute choice probability difference between RUM-MNL model and RRM-MNL model

elasticities inreduce by 7.30%, 13.14% and 7.70% for aircraft, train and coach respectively. Assuming

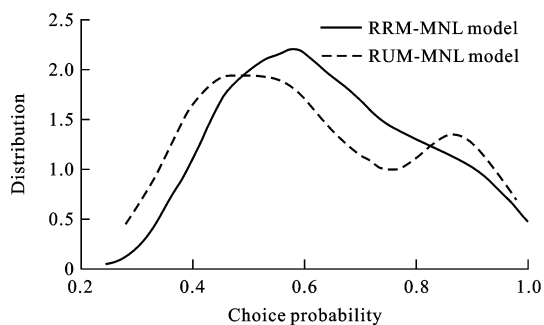


Fig. 4 Choice probability distributions of RUM-MNL model and RRM-MNL model

that when the running efficiency of coach is changed, the travel time will reduce by 5%. There are an added value of 9.26% for the choice probability of

coach in RUM-MNL model and an added value of 8.76% for the choice probability of coach in RRM-MNL model. While considering that the attributes of selected method are worse than those of other methods, travelers will reduce the behavior response strength of travel time for coach. Therefore, while forecasting travel demand and making traffic management measure, the differences of choice behaviors between RRM decision-making rule and RUM decision-making rule must be considered. The effects of other model variables on travel mode choice behavior and traffic management can be analyzed similarly.

Tab. 4 Comparison result of variable elasticities

Variable	RUM-MNL model				RRM-MNL model			
	Aircraft	Train	Coach	Car	Aircraft	Train	Coach	Car
$T_1$	-4.592	-2.656	-3.611	0.000	-4.257	-2.307	-3.333	0.000
$T_2$	-0.389	-1.852	-2.217	-1.730	-0.408	-1.752	-2.279	-1.923
$C_1$	-0.766	-0.504	-0.367	-0.205	-0.659	-0.465	-0.252	-0.195

### 3 Conclusions

Assuming that in RUM-MNL model, decision makers have complete rationality, so the RUM-MNL model has limitation in its authenticity, and is challenged by logical reasoning and practical research. Based on regret theory, the RRM-MNL model is used to analyze the choice behavior of travel mode, and the limitations of RUM-MNL model is overcome. In the proposed RRM-MNL model, partial compensatory decision-making behavior and compromise effect during the actual process can be described effectively, and the evaluation basis of making and implementing travel demand management measure can be provided. The complexity of travel decision-making behavior requirements that the choice difference of subjective decision-making rules for individual travelers must be considered in travel choice model. In the further research, the choice behavior model based on other decision-making rules can be analyzed, the analysis system of choice model should be established, in which the decision-making rule of RRM and other decision-making

rules can be combined, and the complexity of travel decision-making behavior and the heterogeneity of individual travel can be described.

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