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An unsupervised three-way decisions framework of overload preference based on adjusted weight multi-attribute decision-making model

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Abstract

In the process of traffic control, law-enforcement officials are required to accurately evaluate the potential probability of freight-driver’s overloading behavior. This study establishes a model of overloading preference assessment on the basis of freight-driver’s individual variation. With indexes selecting, the equal-weight and AHP-based adjusted weight decision-making model are used respectively to evaluate freight-driver’s overload preference. Synthesizing the results from two models, we present a three-way decisions model to make judgment.

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Keywords: Overload preference; multi-attribute decision-making model; three-way decisions

1. Introduction

E-commerce enterprises flourish with the arrival of the age of big data and the improvement of Internet plus model. Internet economics thrive but logistics transportation are not well coordinated with it. Ma Yun said logistics transportation is the Achilles’ heel on Double 11 Shopping Carnival. The more prosperous the Internet economics is, the more obvious the deficiency of logistics transportation will be. Faced with the excessively high cost and thin profit, freight-drivers are looking for a new way to raise their income. Consequently, overloading becomes a

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widespread phenomenon among transportation industry. Freight-drivers' choices of overloading mirror their psychological preferences to a certain extent. Government has enacted laws to restrain freight-driver's behaviors and some drivers are profoundly aware of the damage of overloading. However, freight-drivers are still likely to overload after weighting all the factors. This performance is defined as overloading preference of freight-drivers. How to judge freight-driver's preference is significant to freight-drivers themselves as well as the country. On one hand, discerning overload behaviors beforehand is conducive to reduce traffic accidents. On the other hand, it is contributed to lower the cost of highway maintenance and standardize the order of transportation industry.

At present stage, literatures concerning overloading still remain on theoretical level and few researchers on the perspectives of freight-driver overload preference. Jiang (2010) analyzes the game theory between road management departments and transportation enterprises ground on the game theoretical model theory, and introduces market reputation model to clarify that self-discipline management is a new way to control overload transportation. Wang (2013) explores the practical effect of penalty of overload. Yin (2008) applies utility function of transporters to analyze and compare the expected effects of diverse transporters. Study about evaluation of the level of investment risk preferences focus on investment field, few on logistics transportation area. Liu (2011) establishes an evaluation system on the level of personal investment risk preferences. Zhou (2002) puts forward an evaluation system of venture enterprise's credit level by using Fuzzy Comprehensive Evaluation.

Current study focus on the index system relatively, and few methods study the judgment method. This study constructs an index system of overloading preference to prejudge freight-driver's behavior. We introduce a three-way decisions model based on multiple attribute decision-making to make a more objective scientific judgment.

2. Index system of freight-driver's overloading preference

The index system is established from two aspects: indexes selection and the structural relationship among them. Based on the external factors and internal factors that influence freight-driver's overload behaviors, this study refers to relevant literatures and considers about the science, pertinence, independence and comprehensiveness to determine 13 indexes. Index System of Evaluation of Freight-Driver's Overload Preference is displayed below:

Gender(x_1): the gender of freight-drivers. Driving experience(x_2): the years of driving. Marital status(x_3): single or married and the marital satisfaction. Income satisfaction(x_4): the degree of income satisfaction. Risk preference(x_5): attitude when facing uncertain risk. Risk neutral attitude and cognition(x_6): attitude toward overload and cognition toward the hazards of overload. Unhealthy lifestyle(x_7): negative living habits such as smoking and excessive drinking. Driving habits(x_8): personal daily driving habits such as wearing safety belt. Frequency of overload fine(x_9): times of penalty causing by overload. Law enforcement(x_{10}): inspection frequency toward overload. Amount of penalty(x_{11}): the size of a fine for overloading. Overload behaviors of counterparts(x_{12}): other freight-driver's overload behaviors. Attitude of people around them(x_{13}): the attitude of their friends and family toward overloading.

3. Modeling step

3.1. Judgment of overload preference based on equal-weight multi-attribute decision

Equal-weight multi-attribute decision is a common multi-attribute decision method. When the decision makers are uncertain about the problems they are facing, setting equal weight to every index can avoid a blind and subjective decision and objectively represent the general level of each sample. Suppose it contains m samples and n indexes in the data. Sample i scores C_{ij} on the index j. Thus the general score of sample i is:

$$W_i = \sum_{j=1}^{n} C_{ij} \tag{1}$$

In the decision of binomial distribution, the results have two and only two alternative values. Therefore, once a general score comes out, a judgment value should be set as a standard for decisions making. Calculate an average score of all the general scores from different samples and name it "the Judgment Value V". Compare all sample scores with value *A* and then make a decision. If the sample score is higher than value *V*, we consume that this driver is prone to overload. The value *V* can be calculated by this equation:

$$V = \frac{1}{mn}\sum_{i=1}^{m} W_i \qquad (2)$$

The algorithm process is shown as follows:

Step1: Establish index system from the present literatures.

Step 2: Decision making model.

Model 1: Decision making model by equal weights.

Calculate Expectation → Calculate average score *A* → Compare sample scores with *A* decisions.

Model 2: Decision making model by adjusted weights.

Calculate index importance by fuzzy methos → Select index by importance → Adjusted weights by AHP → Calculate expectation → Calculate average score *A* → Compare sample scores with *A* decisions.

Step 3: Evaluate the results by three way decisions

Compare results between two weight models and make decision → Pay more attention to uncertain samples and manage overload samples.

In the case of decision-making on overload preference, it requires 13 index scores from freight-drivers to judge if they will overload or not. Under the circumstance, we suppose: 1. One has no prior knowledge. 2. Law-enforcing department has no evident preference on any index (believing that the weight of each index should be equal). 3. The probability that drivers overload is always 1/2. 4. Take no consideration on the experience of law-enforcement officials. Under these hypotheses, the behavior of law-enforcing department on judging the appearance of overload can be regarded as the Bernoulli trials. When the number of sample is big enough, the probability that drivers overload will be around 50%, and probability that drivers do not will be nearly 50% as well.

Calculate general scores of 141 samples in this case with the equal weight. Then figure out average value which equals 2.27, and compare every sample score with value. Samples with a score higher than 2.27 as overload cases and those lower as the opposite. There are 73 overload cases and 68 non-overload cases in total. And the ratio between the two groups is nearly 1:1.

3.2. Multi-attribute transfer weight decision-making theory model

The adjusted-weight multi-attribute decision is another multi-target decision method. When the decision makers are familiar with index data, they would adjust the weights repeatedly through combining subjective and objective information. And then select the best decision-making solution after comparing each index combination.

The multi-attribute adjusted weight decision-making method has a wide range of applications, such as engineering design, economy, management etc. With adjusted-weight multi-attribute decision, the possibility of overload can be expressed in a score represented by equation (3).

The higher score S means that the person is more tend to choose overload. In the model, the weight will represent relative importance of each index while the value of index represents the importance degree. Actually, few of the indexes have significant influence on the judgment of overload. Therefore, filter the indexes which are not reach standard after considering the assessment of related persons generally.

$$S = \beta_1 x_1 + \beta_2 x_2 + \Lambda + \beta_m x_m \qquad (3)$$

3.2.1. Establishment of index system U and the remark set W

According to the index system above, define set U contains n indexes, all of which are in the same layer. Define remark set *W* has *m* alternative values $W = \{x_1,\ x_2,\ \mathrm{L}\ x_s\}$ and from x_1 to x_s each value represents a degree of importance, from the most unimportant to the most important.

3.2.2. Analysis of index membership degree

To further analyze the importance of *n* indexes and select significant indexes, we interview *t* experts about their comment and score the importance of indexes. 5 represents the most important while 1 represents the most insignificant. Based on the questionnaire feedback, we can analyze the membership degree of indexes.

Membership degree originates from fuzzy mathematics. There is lots of fuzzy phenomenon in social economic life and their definitions are vague. Thus these can't be described by classical set theory. Some elements may more or less belong to a certain set, rather than simply true or totally false. Degree of membership reflects the possibility that an element belongs to a set. There is no doubt that drivers' overload preference is a fuzzy concept. Thus, the index system of drivers' overload preference can be regarded as a fuzzy set and every index as an element to analyze the membership degree.

Given $y_1, y_2, \ldots y_t$ are scores of *t* experts on index *i*. According to direct statistical method, the degree of membership $U(x_i)$ is

$$U(x_i) = \frac{1}{5t}\sum_{i=1}^{m} y_i \tag{4}$$

A higher value of $U(x_i)$ indicates a high percentage that this element will belong to this set and a more important part that this element play. Therefore, elements with high membership degree can be accepted to the index system. Otherwise, elements will be excluded.

Sort the membership degree in descending order. Finally *n* indexes were selected which will have significant influence on the behavior of overload.

3.2.3. The calculation of coefficient weight

Determine weights of indexes with AHP. AHP is a decision-making method proposed by American operations researcher Thomas L. Saaty in 1970s. AHP requires consulting experts in order to determine proper weights. AHP always goes with the following steps:

STEP 1: With specific rules, experts are asked to compare all indexes in pairs, and rank them in the order of importance individually. With the score given, there comes out the straight reciprocal matrix *A*.

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2j} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nj} & \cdots & a_{nn} \end{pmatrix} \tag{5}$$

In the matrix, a_{ij} represents the relative importance between index *i* and index *j*.

Each row is a series of scores from one expert, and each line represents all the scores of one index. Due to the importance score between two indexes is relative, there is one basic rule:

$$a_{ij} = \frac{1}{a_{ji}}, i, j = 1,2,\cdots n \tag{6}$$

STEP 2: Use MATLAB to calculate the eigenvalue of maximum and its corresponding eigenvector of matrix *A*. Then normalize the eigenvector. And there comes out the weights of relative importance between indexes in two neighboring layers.

STEP 3: Figure out consistency index CI according to single hierarchical arrangement.

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{7}$$

λ_{max} is the maximum eigenvalue of the straight reciprocal matrix. The value of *CI* represents the consistency of matrix. If *CI* is equal to 0, the straight reciprocal matrix is consistent. And the larger number of *CI* represents a higher degree of inconsistence.

STEP 4: Figure out the average value of λ_{max}. The elements of Matrix *A* above the main diagonal are selected from {1/9, 1/8, ..., 1/2, 1, 2, ..., 8, 9} randomly. Fill the elements below the main diagonal with their corresponding reciprocal and calculate consistency index values. Repeat procedure above for 5000 times and average the results. The result value is *RI*, called random consistency index. And RI is the average value of λ_{max}. Usually, *RI* value can reference the Table 1 below. In the Table 1, *n* represents the numbers of index, *RI* is the average value of λ_{max}. For instance, if we pick out 7 indexes, the *RI* value ought to be 1.32.

STEP 5: Check consistency of the straight reciprocal matrix. The consistency ratio *CR* can be calculated with the following equation (8). If *CR* is less than 0.1, then we can believe that the matrix has a satisfying consistency.

$$CR = \frac{CI}{RI} \tag{8}$$

Table 1. Random consistent value.

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

3.2.4. Index variable distribution

Each index could be regarded as a variable and the possible values for all variables are -1, 0 and 1. Value 1 means that an index has positive influence on overload while -1 for negative influence. Value 0 indicates that the influence is not clear. In the questionnaire survey, only when the expert thinks an index has influence on overload, the influence degree of this index would be accepted. Otherwise, their choices are invalid. The probability of each index variable can be defined as

$$p_k = p(c_{m1} = k) = \frac{a}{b}, k = -1,0,1 \tag{9}$$

In the equation above, *a* means the number of people who think the index will intensify overload (or restrain overload or not clear). *b* means the total number of people except those who think this index has no influence. For each index variable, we have Table 2, where the expected value of each index $E(X_i) = \sum_{k=-1}^{3} k \cdot p_k = p_1 - p_{-1}$.

Table 2. The probability of each index variable.

Value(k)	-1	0	1
Probability(p_k)	p^{-1}	P^0	P^1

3.2.5. Results

Table 3. Result of equal-weight & adjusted weight.

Equal weight \ Adjusted-Weight	Overload	Non-overload	Total
Overload	57	16	73
Non-overload	16	52	68
Total	73	68	141

The expected score could be a boundary between overload and non-overload. If the score higher than the expected score, it means that the probability of overload is quite high, otherwise the probability of overload is quite low. According to the probability theory, the expected score is the sum of expectation values of all indexes. $E(S) = \beta_1 E(X_1) + \beta_2 E(X_2) + \cdots + \beta_m E(X_m)$. The sample mean A of 141 samples is approximately 0.555923.

Comparing each score of sample with *A* , we get 73 overload cases and 68 non-overload cases.

3.2.6. Three-Way Decisions Theory

Three-way decisions theory is an extension of the traditional two-way decisions theory [9, 10]. In the traditional two-way decisions, only acceptance and rejection are considered. But in real life, the decision problems people faced with often have the characters of uncertainty, incompleteness and inaccuracy, and all these cause that people can't make a decision of acceptance or rejection immediately. Three-way decisions theory added a disclaimer choice on the basis of the traditional two-way decisions theory. Namely, people will use the disclaimer option when they can't make a decision immediately on account of the lack of information, and it also can be regarded as deferment. People can make decision until they obtain sufficient information through further observation.

This study applies equal-weight and adjusted-weight decisions to judge driver's behavior. The judgment is obvious: if two results are "overload", the final judgment is "overload"; if two results are "non-overload", the final result is "non-overload". If two results are contradictory, we use a disclaimer choice and delay to make decision.

4. Application examples analysis

4.1. Equal weight

Calculate average scores W_i of 141 samples in the case with the equal weight. Then compare every sample score with value *A*, which equals 2.227.

$W_A = (3+3+3+1+2+2+2+2+3+1+2+3+3)/13 = 2.308 > 2.227,$ thus A is overload.

$W_B = (3+2+2+1+1+1+2+1+1+2+2+1+2)/13 = 1.615 < 2.227,$ thus *B* is non-overload.

Similarly, the score of *C* is 1.615<2.227, so we believe he is non-overload.

4.2. Adjusted weight

Step1: Calculate the degree of membership matrix of indexes.

Count the number of selected people of each remark and present in percentage. For instance, 17 people think gender influence very little on overloading, 50 think little influence, 59 have no idea, 12 think have a big influence, and 3 think have very great influence. Thus the degree of membership is (0.121, 0.355, 0.418, 0.085, 0.021)

Similarly, calculate other indexes and make up matrix *R*.

Step 2: Calculate the degree of membership of indexes.

According to statistical method, 13 indexes are presented with the degree of membership *U(X)*.

The value of *U(X)*, which is over 0.8, means the index play a very important part in the set. Select indexes which the value of membership is over 0.8. They are law-enforcement x_{10}, amount of penalty x_{11}, attitude and cognition x_6, frequency of overload fine x_9, risk preference x_5, income satisfaction x_4 and driving habits x_8. These indexes have satisfying effects on explaining overload.

Step 3: Calculate weights with AHP.

Compare 7 indexes and construct the straight reciprocal matrix *A* by scoring indexes. Calculate the maximum eigen value and its eigenvectors based on matrix *A*. λ_{max}=7.137. Then test the consistency of *A*.

$$CR = \frac{CI}{RI} = 0.052$$

. So the straight reciprocal matrix *A* is in good consistency. Figure out the weights of 7 indexes after normalizing the eigenvectors.

Table 4. Weights of indexes.

Index	Law enforcement x_{10}	amount of penalty x_{11}	attitude and cognition x_6	frequency of overload fine x_9	risk preference x_5	income satisfaction x_4	driving habits x_8
Weight	0.160	0.254	0.062	0.174	0.097	0.190	0.064

Step 4: Calculation of expected value and distribution of indexes

Assign opposite values to 2 attributes in order to work out the influence of different sides. 1 represents this index has positive effect on overload preference, 0 represents that is has no effect and -1 represents negative effect. For instance, 0.240 of all the interviewees shows that enhancing law enforcement efforts will stimulate overloading. 0.062 represents no effect and 0.698 indicates that it will restrain overloading. The other 6 indexes can be calculated in the same way.

According to the formula $E(X_i)=\sum_{k=-1}^{3} k\cdot p_k = p_1 - p_{-1}$, the expected value of 7 indexes will come out. Then average all the indexes expected value and we can easily have the average expected score:

Average expected score=（0.457+0.603+0.852+(-0.106)+0.957+0.776+0.866）/7 =0.556

Step 5: Calculate individual score

Table 5. Result of individual score.

Sample \ Result	Score by equal weight	Judgement 1	Score by adjusted weight	Judgement 2	Judgement 3
A	2.308	Overload	0.652	Overload	Overload
B	1.615	Non-overload	0.172	Non-overload	Non-overload
C	1.615	Non-overload	1	Overload	Hesitancy

Organize data of 7 indexes from 3 drivers, shown below: $A=(\ 1,\ 1,\ 1,\ 1,-1,\ 1,\ 1)$, $B=(-1,-1,\ 1,\ 1,\ 1,\ 1,\ 1)$, $C=(\ 1,\ 1,\ 1,\ 1,\ 1,\ 1,\ 1)$. Then we calculate their scores as follows:

EA=0.160*1+0.254*1+0.062*1+0.174*1+0.097*(-1)+0.190*1+0.064*1=0.652> 0.556, overload

EB=0.160*(-1)+0.254*(-1)+0.062*1+0.174*1+0.097*1+0.190*1+0.064*1=0.172< 0.556, non-overload

The expected score of C is 1, and is judged to be overload.

The judgement 1 is based on the score of equal-weight, judgement 2 is based on score of adjusted-weight, and judgement 3 is based on judgement 1 and judgement 2.

5. Conclusions

In the area of traffic control, the judgment on overloading is a complicated but important process. Different drivers have various driving behaviors and mental activities. Whether officials can accurately figure out overload drivers and execute specific measures to determine the effectiveness of overload treatment. This paper selects proper indexes from freight-drivers and weights using AHP method and eventually makes a judgment on whether overload or not. Applying three-way decision to evaluate the results and make a final decision.

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