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Research and improvement of keep-right-except-to-pass traffic rules

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ABSTRACT

This paper studies the performance of keep-right traffic rule in most countries. It points out the inadequacies of the traffic rule, puts forward an improved one. And also it considers the impact if the transportation is fully controlled by intelligent system. Applying AHP (Analytic Hierarchy Process) and fuzzy comprehensive evaluation method, weighing three main factors as traffic operation, human factors and safety, and nine sub-factors like vehicle speed, traffic flow and accident rate, we establishes a fuzzy comprehensive evaluation system. According to the linear model of Green shield, we establish a linear relationship between vehicle speed and vehicle density. Through simulation, we compared the traffic conditions between the current traffic rule and improved one, and the conclusion is arrived that the improved traffic rule can promote the smoothness of traffic both in heavy and light traffic.

KEYWORDS

AHP;
Fuzzy comprehensive evaluation;
The traffic rule;
Simulation system.

INTRODUCTION

In most countries people should obey the keep-right-except-to-pass rule. When overtaking, the driver would move left one lane to overtake, and then return to the original lane. Does the conventional rule perform well? Can it effectively promote the traffic flow? In this paper, a mathematical model is established to analyze the performance of traffic rules in heavy and light traffic. The model combines the features of AHP and fuzzy comprehensive evaluation, weighs the factors like traffic flow, traffic safety, vehicle speed and others. This paper also establishes a relationship between traffic flow, vehicle speed and vehicle density, points out that when the vehicle density is large, the traffic rules can not effectively promote the smooth traffic, and proposes an improved traffic rule which can effectively solve the problem. What's more, this paper discusses the modifications and adjustments the strategies needed in countries of keep-left driving. Finally, it discusses the impact which will bring to the results of model analysis when the transportation is completely controlled by the intelligent system.

ASSESSING THE PERFORMANCE OF TRAFFIC RULE BY AHP AND FUZZY COMPREHENSIVE EVALUATION MODEL

Introduction of Methods

This approach integrates the dual advantages of fuzzy and AHP[1], applies the fuzzy principle on the basis of fuzzy theory, which quantifies some ill-defined factors. It can evaluate the decision of multiple rules scientifically and systematically. This paper studies the traffic performance of lane rules both on right and left, divides the evaluation system into a hierarchical structure, and determines the weight of each index by applying AHP; then makes fuzzy comprehensive evaluation hierarchically. Finally the overall results of the evaluation will be drawn.

Comprehensive evaluation model of traffic performance for keep-right-except-to-pass rule

Build an evaluation system as shown in Figure 1. Target layer is the performance of traffic rule. Main criteria layer includes human factors, traffic operating state and safety performance.

Parameters and evaluation criteria

Traffic operating state

Traffic operating state mainly consists of 4 parameters, i.e. overall speed, traffic flow, traffic density and rate of mixed vehicles. Explanations and evaluation criteria of these parameters are as follows:

- Overall Speed, Traffic Density and Traffic Flow

Overall speed means the average speed of vehicles in a certain section of a road. Calculation formula is as follows:

$$V_S = 60 \cdot S \cdot N / \sum_{j=1}^{N} t_j \qquad (1)$$

In this formula, N—the number of some kind of vehicles

t_j − The running time (minutes) of a vehicle in one way trip

Traffic flow means vehicles which passed through a certain section of road in unit time (Q)

Traffic density: $K = \dfrac{Q}{V_s}$

- Rate of Mixed Vehicles

The rate of mixed vehicles is indicated by the proportion of heavy vehicles in traffic. Heavy vehicles mainly include large trucks and containers. TABLE 1 is the proposed evaluation criteria of traffic parameters.

Safety includes safety facilities and the rate of accident occurrence

Safety facilities are collective name of lighting equipments, rails, stanchions, signs and markings to ensure the safety of vehicles and passengers.

The relationship between accident rate[2] and standard deviation of velocity

$$y = 9.853e^{0.055\sigma} \qquad (2)$$

TABLE 2 and TABLE 3 indicate the proposed evaluation grade.

Human factors include driving states, driving errors and driving skills. They are judged by people's daily

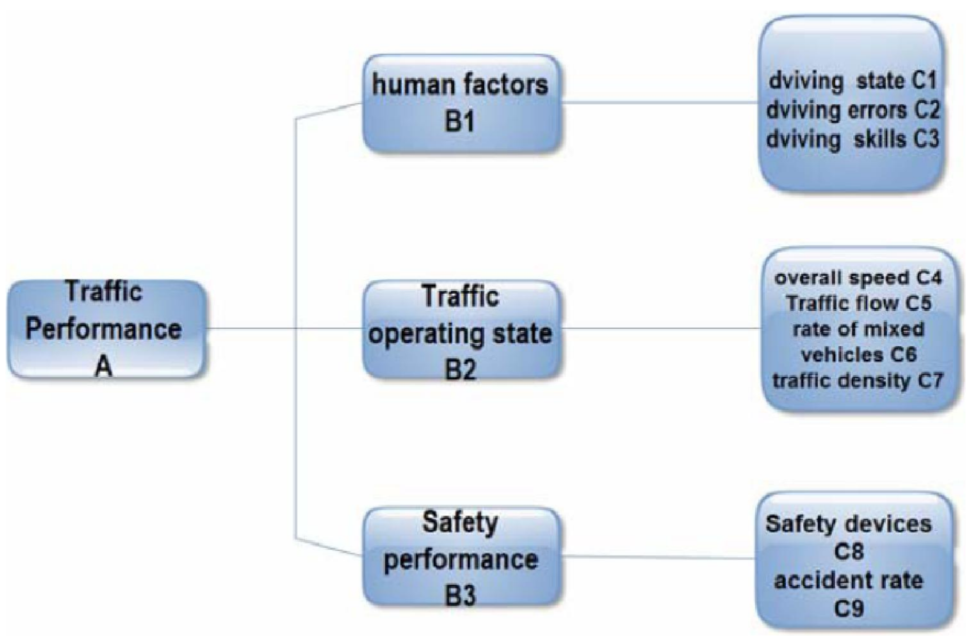

Figure 1: The evaluation system of traffic performance

TABLE 1 : Proposed criteria of parameter of traffic operation

grade	I	II	III	IV	V
Overall speed (V)	>80	>75	>70	>65	>60
Traffic flow (Q)	<25000	<35000	<45000	<55000	<65000
Traffic density (K)	<12	<20	<30	<45	<60
Rate of Mixed vehicles	<10	<15	<20	<25	<30

TABLE 2 : Evaluation grade of safety facilities

grade	I	II	III	IV	V
criteria	To be well-equipped, reasonable,aesthetic, economic and practical	To be basically and reasonably installed, economic and practical	To be basically and reasonably equipped, Structure-reliable	To be unreasonably equipped	To be badly equipped

TABLE 3 : Evaluation grade of accident rate

grade	I	II	III	IV	V
Accident rate (R)	<10	<20	<30	<40	<50

experience.

Each parameter values in different traffic operating states

The definition condition of heavy traffic and light traffic:

When $Q/C \geq 1$, it is considered as heavy traffic; when $0 < Q/C < 1$, the traffic is considered light.

Q stands for traffic flow; C stands for traffic capacity.

Through access to relevant literature, the relationship between the values of the parameters is obtained as follows:

$$\begin{cases} \mathbf{V_S} = \mathbf{V_i} / [\mathbf{1} + (\mathbf{Q}/\mathbf{C})^{\beta}] \\ \beta = \alpha_2 + \alpha_3 (\mathbf{Q}/\mathbf{C})^{\mathbf{3}} \\ \mathbf{V_S} = \mathbf{KQ} \end{cases} \quad (3)$$

In Formula:

V_S - speed in certain section

V_i – Velocity designed

$\beta, \alpha_1, \alpha_2$, α_3 - correction coefficient

Each parameter values in different states are shown in TABLE 4.

We can take a case study in China Xilin freeway for example, analyze each parameter value in different operating status. The results are calculated as shown in TABLE 5.

Referring to the above data, evaluation is carried out according to experience and evaluation criteria.

The index weight and evaluation results in light traffic

The index weight

$A = (0.24, 0.39, 0.37)$

$A_1 = (0.4404, 0.2070, 0.2681, 0.0845)$

$A_2 = (0.25, 0.75)$

$A_3 = (0.1667, 0.3333, 0.5000)$

The comprehensive evaluation results can be obtained through the calculation process in 4.21.

$$R = \begin{bmatrix} 0.3521 & 0.4348 & 0.1522 & 0.0277 & 0.0304 \\ 0.3141 & 0.5397 & 0.1462 & 0 & 0 \\ 0.0652 & 0.5249 & 0.4099 & 0 & 0 \end{bmatrix}$$

$$D = A \cdot R = (0.2311.0.5090, 0.2452, 0.0066, 0.0073)$$

After normalization, according to maximum membership principle:

$$D = \max(0.2313, 0.5094, 0.2454, 0.066, 0.0073) = 0.5094$$

It can be seen that the keep-right traffic rule is in a better grade performance in light traffic.

The weight of each index and evaluation results in heavy traffic

The same method in 4.4 can be used to get the comprehensive evaluation of the results in heavy traffic.

TABLE 4 : Speed - flow general model parameter table of freeway

Type of Freeway	Speed designed Vs/km*h-1	Traffic capacity （C）	a1	a2	a3
Freeway	120	2200	0.93	1.88	4.85
	100	2200	0.95	1.88	4.86
	80	2000	1	1.88	4.9
	60	1800	1.2	1.88	4.88

TABLE 5 : Each operating parameter values for Xilin Freeway

Parameter	traffic flow (pcu/d)	Overall speed (km/h)	Traffic density (pcu/km/ln)	Rate of Mixed Vehicle (%)	Accident rate per 100 million vehicle kilometers
In Light traffic	36574	65.4	20.7	22	11
In heavy state	56529.6	35	67.3	22	9.853

$$R = \begin{bmatrix} 0.2521 & 0.3348 & 0.2522 & 0.1277 & 0.0332 \\ 0.0506 & 0.1020 & 0.0012 & 0 & 0 \\ 0.3178 & 0.2355 & 0.4467 & 0 & 0 \end{bmatrix}$$

$$D = A \cdot R = (0.1978, 0.0273, 0.2263, 0.0306, 0.007)$$

$$D = \max(0.1978, 0.2073, 0.2263, 0.0306, 0.007) = 0.2263$$

It can be seen that the traffic rule of driving on the right performs medium in congested state.

Considering the traffic flow, traffic safety, vehicle speed limits and other factors, and seen from the above AHP and fuzzy comprehensive evaluation model analysis, the keep-left-except-to-pass rule is good in light traffic and it is medium in heavy traffic. The performance can be improved.

TRAFFIC FLOW MODEL OF KEEP-RIGHT RULE

Model of traffic flow

According to Greenshield linear model, a relationship formula between speed V and vehicle density K can be gained under the keep-right rule:

$$V = V_f - \frac{V_f}{K_j} K = V_f (1 - \frac{K}{K_j}) \quad (4)$$

where V_f is the average speed of vehicles when the vehicle density tends to be zero; K_j is the maximum traffic density on freeway. Based on (3) and (4), the relationship between traffic flow (Q) and vehicle density (K) can be gained:

$$Q = KV = K \cdot V_f (1 - \frac{K}{K_j}) = V_f (K - \frac{K^2}{K_j}) \quad (5)$$

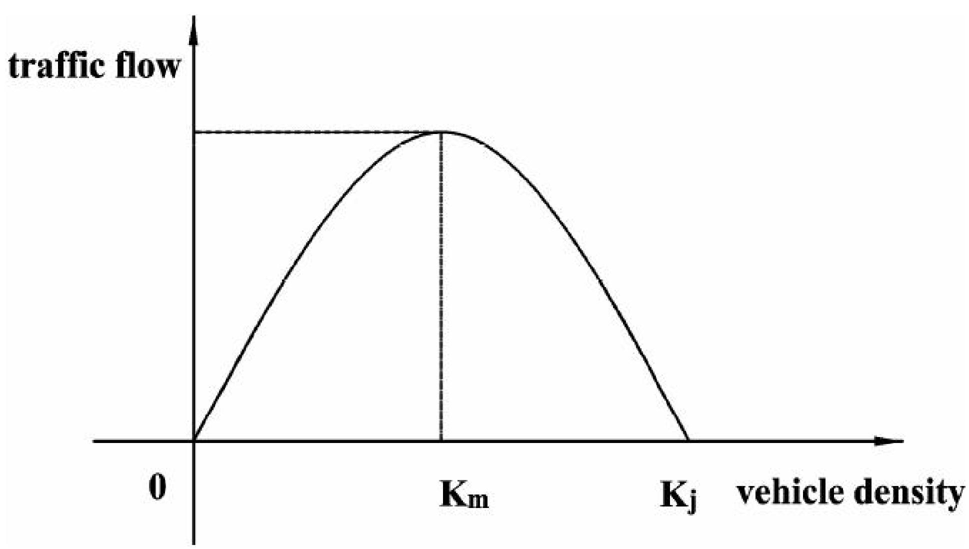

Figure 2 : Q-K

Which is illustrated in Figure 2.

From above, we can see that when traffic density $K < K_m$, traffic flow will increase gradually and the traffic go smoothly;

When traffic density $K = K_j / 2 = K_m$, the traffic flow becomes the largest, and the traffic is on the critical state of being light and heavy;

When $K > K_m$, the traffic flow decreases as the traffic density increases, which causes heavy traffic.

Therefore, it is not effective for the keep-right rule to promote traffic flow when the traffic density is big.

In fact, take a three-lane freeway for instance; we suppose that all drivers fully obey the keep-right-except-to-pass rule. All vehicles run on right-most lanes, and they are not allowed to run on the overtaking lane except that they pass other vehicles.

In this case they move one lane to the left, pass, and return to their former travel lane, which leads to the unreasonable use of these two lanes.

On one hand, the right-most lanes, which are low speed lanes, easily cause traffic jam or accidents; on the other hand, the usage rate of left-most lanes are low, which are high-speed lanes. All of the above cause a low traffic flow, and block traffic to some extent.

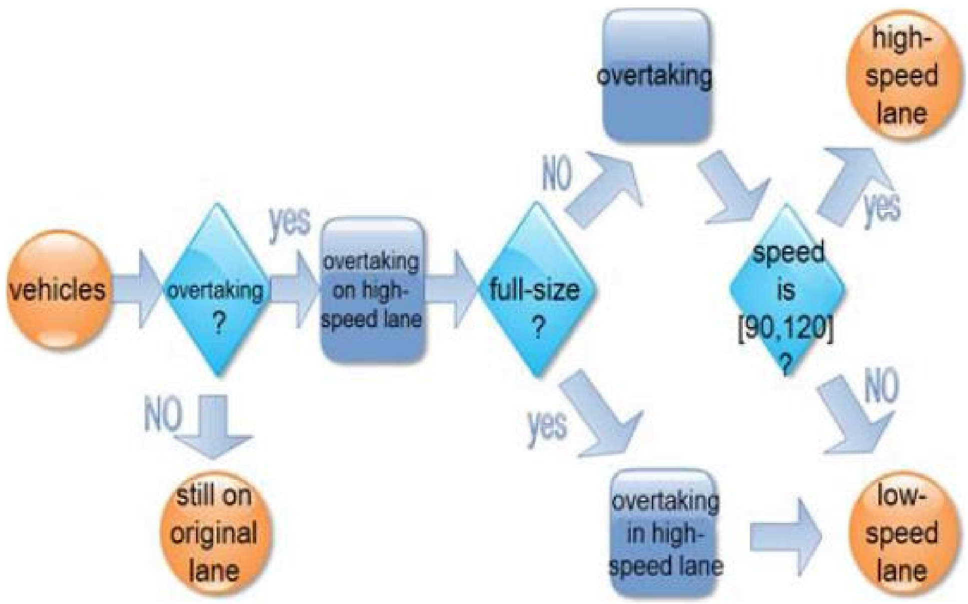

Figure 3 : The Improved Model of Keep-right Rule on High-speed Lane

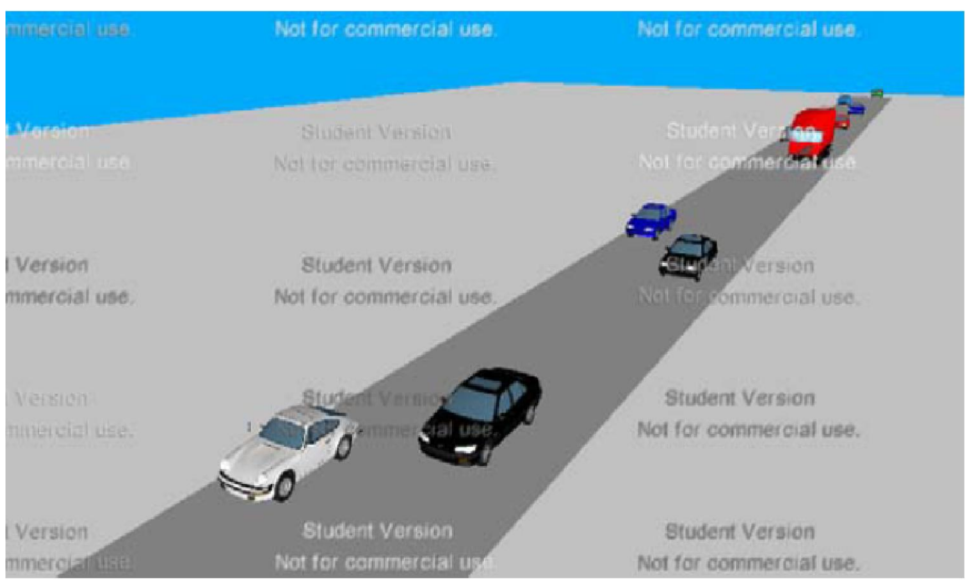

Figure 4 : Simulation icon

The improved model of keep-right rule

We propose an improved model after considering the safety and improving the utilization ratio of high speed lane to avoid cars congesting, small and mid-sized cars are allowed to run and overtake on high-speed lane. However, the full-size vehicles can overtake but can not run on the high speed lane. All vehicles are available to the low-speed lane. When the full-size vehicles overtake, they must return to their former travel lane. By contrast, the small or mid-sized cars can choose to run either on high-speed lane or slow-speed lane according to its speed. The improved rule can be illustrated as the following

We conducted a simulation about the previous keep-right traffic rule and improved one through the software Vissim. Supposing that the proportion of the numbers of full-size cars, mid-size cars and small cars are 1:2:2, its simulation diagram is as follows:

In the simulation, we count out the operation of the vehicles in the two traffic rules in 30 minutes as shown below:

From the Figure 5 and Figure 6 above, compared with former traffic rules, the traffic flow will increase by 8.26% in the state of light traffic, and 13.193% in heavy

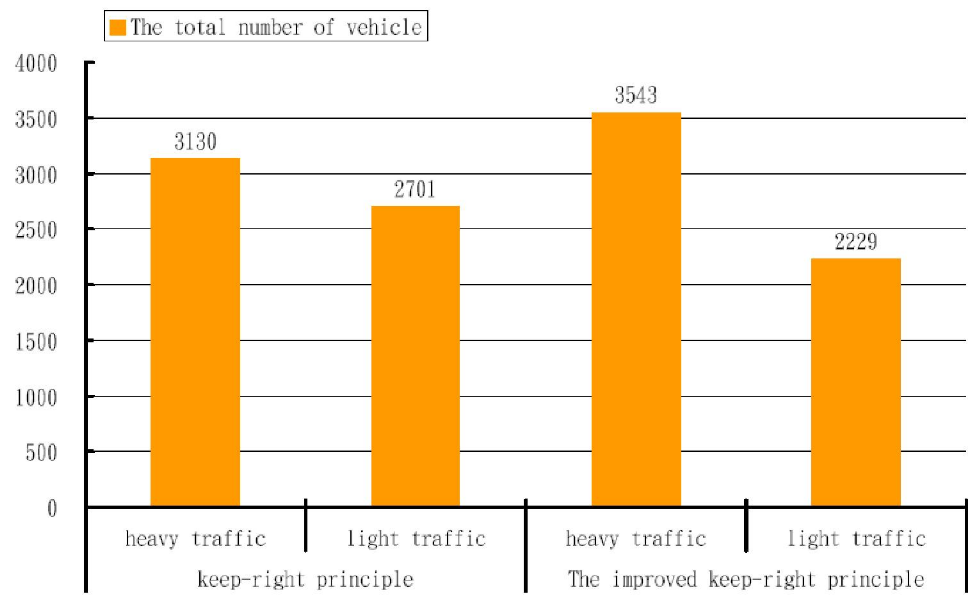

Figure 5 : The total number of vehicle

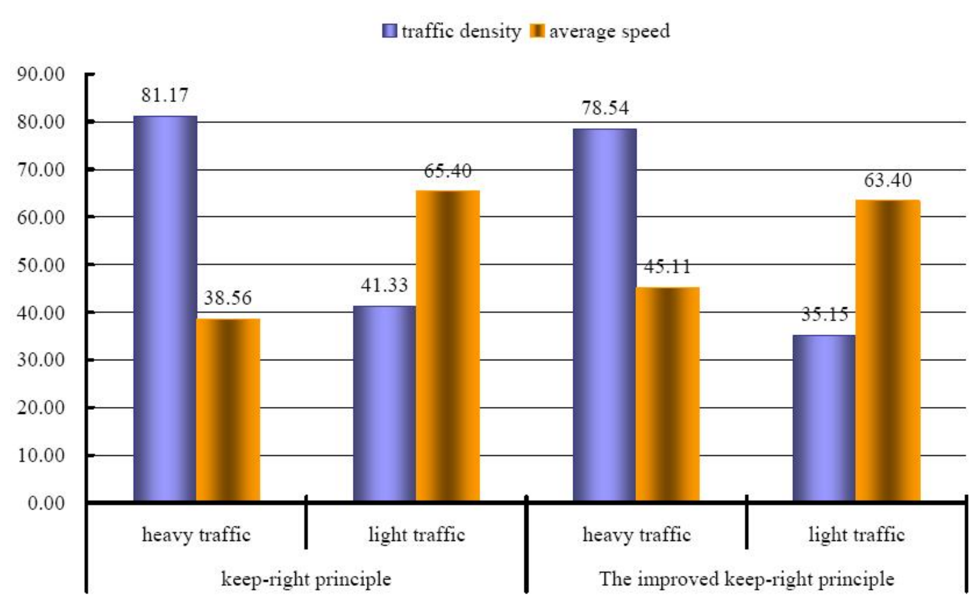

Figure 6 : The traffic density and average speed

traffic under the improved rules. Thus the keep-right improved rules effectively boost a smooth traffic.

MODEL EVALUATION AND EXPLORATION

(1) The factors with obscure boundary are quantified by applying AHP and fuzzy comprehensive evaluation which provide strong support for multi-decisions. The improved model is verified by analog simulation, which is practical and convincing.

(2) By modifying the accident rate, the impact of intelligent system on traffic has been analyzed scientifically.

(3) Some of the parameter are gained by experience, the comprehensive evaluation matrix obtained may have some deviations. Therefore, the model can be explored as follow:

We modify it by adopting grey class evaluation, establishing four whitenization weight function as in the following steps: we get $V = \{10, 8, 6, 3, 1\}$ based on evaluation criteria.

The first grey category is defined as "highest" (e=1). And design grey number as $\otimes_1 \in [10, \infty]$ the whitening weight function as f_1

$$f_1(d_{li}) = \begin{cases} d_{li}/10 & , \quad d_{li} \in [0,10] \\ 1 & , \quad d_{li} \in [10,\infty] \\ 0 & , \quad d_{li} \in [-\infty,0] \end{cases}$$

The first grey category is defined as "high" (e=2). And design grey number as $\otimes_2 \in [8,16]$ the whitening weight function as f_2

$$f_2(d_{li}) = \begin{cases} d_{li}/8 & , \quad d_{li} \in [0,8] \\ 2-d_{li}/8 & , \quad d_{li} \in [8,\infty] \\ 0 & , \quad d_{li} \notin (0,16] \end{cases}$$

The first grey category is defined as "medium" (e=3). And design grey number as $\otimes_3 \in [6,12]$ the whitening weight function as f_3

$$f_3(d_{li}) = \begin{cases} d_{li}/6 & , \quad d_{li} \in [0,6] \\ 2-d_{li}/6 & , \quad d_{li} \in [6,\infty] \\ 0 & , \quad d_{li} \notin (0,12] \end{cases}$$

The first grey category is defined as "low" (e=4). And design grey number as $\otimes_4 \in [3,6]$ the whitening weight function as f_4

$$f_4(d_{li}) = \begin{cases} 1 & , \quad d_{li} \in [0,3] \\ 6-\dfrac{d_{li}}{3} & , \quad d_{li} \in [3,6] \\ 0 & , \quad d_{li} \notin (0,6] \end{cases}$$

The first grey category is defined as "low" (e=5). And design grey number as $\otimes_5 \in [1,2]$ the whitening weight function as f_5

$$f_5(d_{li}) = \begin{cases} 1 & , \quad d_{li} \in [0,1] \\ 2-d_{li} & , \quad d_{li} \in [1,2] \\ 0 & , \quad d_{li} \notin (2,\infty] \end{cases}$$

Calculating the grey statistics and weight matrix, Calculate n_{ij}, n_i $r_{ij}(i=1,2,...,4)$, then we can get weight matrix R,

Solve the grey statistics of $\otimes_1$,

$$\begin{aligned} n_{11} &= f_1(d_{li}) + f_1(d_{li}) + f_1(d_{li}) + f_1(d_{li}) + f_1(d_{li}) \\ &= f_1(7) + f_1(6) + f_1(8) + f_1(5) + f_1(7) \end{aligned}$$

Similarly, for $\otimes_2$, we can calculate n_{12}; n_{13} for $\otimes_3$; n_{14} for $\otimes_4$. For the grey number $n_1 = n_{11} + n_{12} + n_{13} + n_{14}$, we can calculate the evaluation weight matrix:

$$r_{11} = \frac{n_{11}}{n_1}$$

Similarly, we can get r_{12}, r_{13}, r_{14}, $r_{ij}, (i = 1, 2, 3, ...19)$. Thus we can establish weight matrix R for improved comprehensive evaluation, which makes it more accurate. The fuzzy comprehensive evaluation system becomes more scientific and reasonable based on the modified weight matrix.

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