Evaluation method of handling and stability performance of special vehicle with large inertia based on the combination method of rank correlation coefficient

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Keywords: special vehicle, handling and stability performance, rank correlation coefficient, road test

Abstract. Considering the actual structure of special vehicles and security factors, three road test for special vehicle's handling and stability and eight index were used in this paper. The subjective weighting method and the objective weighting were respectively used to evaluate the special vehicle's handling and stability based on the experiments' results. The combination method of rank correlation coefficient was used to fuse the subjective and objective results. The final result can reflect the subjective feel and the objective truth.

Introduction

Handling and stability is one of the most important properties for vehicle's safety, which will directly influence the operation state of special vehicle. So it's significant to evaluate the handling and stability for ensuring safety and improving execution efficiency of special vehicle [1]. Special vehicle has the characteristics of big volume, high center of mass and narrow field of view. Considering the special structure, the evaluation method of common vehicle cannot be used in special vehicle. Referring to the evaluation standard of common vehicle, this paper chooses three experiments and pick up eight index to evaluate the handling and stability of special vehicle. The road tests were performed to get original data of evaluated index. The subjective and objective weighting were respectively used to assign the weight of each index. The combination method of rank correlation coefficient was used to fuse the subjective and objective result, the final weight of each index was obtained, making contribution to the reasonable evaluation of special vehicle's handling and stability.

Subjective weighting

The driver made a subjective judgment on the vehicle's handling and stability, the quantized judgment was the basis of subjective weighting. Referring to the application of analytic hierarchy process on vehicle, this paper describe evaluation index as three hierarchies, including target hierarchy, rule hierarchy and project hierarchy. Target hierarchy refers to the handling and stability of special vehicle. Rule hierarchy includes three aspects, stability analysis, steering performance

and returnability. Project hierarchy is to describe each index visualized. The hierarchies can be shown as table 1.

Table1 Hierarchies of handling and stability evaluation

target hierarchy	rule hierarchy	project hierarchy
handling and stability	stability ZE_1	FN_1 mobility FN_2 understeer gradient FN_3 vehicle box inclination pitch
	steering performance ZE_2	FN_4 executive ability FN_5 anti-jamming ability FN_6 delayed response
	returnability ZE_3	FN_7 swing magnitude after loosing the steering wheel FN_8 swing time after loosing the steering wheel

FN_1、FN_2、FN_3 respectively correspond to the lateral acceleration a_n, the understeer gradient U and the vehicle box inclination pitch K_f. FN_4、FN_5、FN_6 respectively correspond to resonant frequency f, resonant peak level D_f and phase lag angle a_f. FN_7、FN_8 respectively correspond to the absolute value and the total variance of the residue yaw rate after loosing the steering wheel 3s, Δr and E_r.The judgment matrix was structured based on the proportion between different factors in the same hierarchy. This paper quoted 1~9 ratio scale method, shown as table 2.

Table2 1~9 ratio scale method

scale	meaning
1	same important between two factors
3	one is a little bit more important than another
5	one is obviously more important than another
7	one is strongly more important than another
9	one is extremely more important than another
2,4,6,8	the median of the above-mentioned border judgment
reciprocal	b_{ij} is the judgment between i and j, then $b_{ji} = 1/b_{ij}$ is the judgment between j and i

Three experienced drivers of special vehicle were selected to construct the judgment matrix according to the steps of subjective evaluation. Examine the consistency by contrasting the average-consensus index table. The result of one of the drivers was shown as table 3 to table 6.

Table3 Judgment of one of the drivers on rule hierarchy

index	ZE_1	ZE_2	ZE_3
ZE_1	1	5	6
ZE_2	1/5	1	3
ZE_3	1/6	1/3	1
weight	0.71	0.20	0.09
consistency	CR=0.096<0.1		

Table4 Judgment of one of the drivers on stability

index	FN_1	FN_2	FN_3
FN_1	1	3	3
FN_2	1/3	1	1
FN_3	1/3	1	1
weight	0.6	0.2	0.2
consistency	CR=0<0.1		

Table5 Judgment of one of the drivers on steering performance

index	FN_4	FN_6	FN_5
FN_4	1	3	5
FN_6	1/3	1	2
FN_5	1/5	1/2	1
weight	0.65	0.23	0.12
consistency	CR=0<0.1		

Table6 Judgment of one of the drivers on returnability

index	FN_7	FN_8
FN_7	1	2
FN_8	1/2	1
weight	0.67	0.33
consistency	n<3 , CR<0.1	

In table5, exchange the order of FN_5 and FN_6 to get satisfied consistency. According to the above steps, the judgment of other two drivers were obtained, the average of them three was the subjective result, shown as table 7.

Table7 Final results obtained by subjective method

	FN_1	FN_2	FN_3	FN_4	FN_5	FN_6	FN_7	FN_8
driver1	0.43	0.14	0.14	0.13	0.02	0.05	0.06	0.03
driver 2	0.42	0.10	0.16	0.15	0.03	0.05	0.03	0.06
driver 3	0.43	0.12	0.14	0.15	0.03	0.04	0.06	0.03
average	0.43	0.12	0.14	0.14	0.03	0.05	0.05	0.04

Objective weighting

Objective weighting is a statistic method of getting the weight depending on the testing data of indexes. Considering the excessive test projects and evaluation indexes of vehicles, the high

security requirement and high difficulty of road test, this paper used three different objective weighting methods to get index weight, which could obtain as much information as possible with less indexes and could ensure the accuracy and credibility of the evaluation, the methods were variation coefficient method, entropy method, correlation coefficient method respectively.

To meet the needs of analysis, eight road test of the special vehicle were performed. The results were shown as table8, the first and the last were virtual vehicles, of which the data were the lower and upper limit of corresponding index in the nation standard.

Table8 Results of road test

	a_n / (m / s^2)	U / ((o)/(m/s^2))	K_f / ((o)/(m/s^2))	f /(Hz)	D_f /(dB)	a_f / (o)	Δr /((o) / s)	E_r /(s)
con01	3	1.2	1.4	0.3	5	100	6	0.9
con02	3.9	0.31	0.29	3.9	1.6	89.9	0.50	0.63
con03	4.5	0.08	0.33	3.6	3.17	76.2	1.95	0.61
con04	6.32	0.32	0.31	2.86	2.9	93.1	3.19	0.85
con05	5.24	0.06	0.28	1.46	3.23	95.6	1.81	0.59
con06	5.7	0.19	0.34	1.37	3.9	87.5	4.77	1.97
con07	3.34	0.45	0.29	1.46	5.77	88.6	2.40	0.28
con08	4.45	0.22	0.41	2.54	3.9	96.8	2.41	0.29
con09	3.26	0.38	0.22	3.13	6.67	77.3	1.82	0.61
con10	6	0.5	0.7	0.5	2	60	0	0.45

The *variation coefficient method* assigned the weight of each index according to the variation degree of observed value on all evaluated objects. The basic idea of this method is the variation degree affects the final evaluation result directly, the normalized value of variation coefficient is generally considered as the weighting coefficient, which can reflect the discriminability of index. Referring to the reference[6][7], the weighting coefficient can be calculated, shown as table 9.

Table9 Results obtained by variation coefficient method

	a_n	U	K_f	f_F	D_f	a_f	Δr	E_r
Weighting coefficient w_{j1}	0.06	0.21	0.13	0.14	0.10	0.03	0.17	0.16

As shown in table 9, the weighting of understeer gradient and the vehicle box inclination pitch were bigger than that of other indexes, the weighting of the lateral acceleration and phase lag angle were smaller. The result was basically credible and can reflect the relationship between different indexes.

Through considering the real condition of special vehicle and consulting experts, the importance of index variation was emphasized. In order to highlight the importance of the variation degree on the evaluation result, the *entropy method* was selected as the auxiliary of the *variation method*. The *entropy method* assigned the weight of each index according to the amount of information each index delivering. The more information the index delivers, the smaller the uncertainty and the entropy is. The result of the *entropy method* can be calculated, shown as table 10.

Table10 Results obtained by entropy method

	a_n	U	K_f	f	D_f	a_f	Δr	E_r
entropy H_j	0.9766	0.8653	0.9213	0.9107	0.9558	0.9861	0.8755	0.9182
weighting coefficient w_{j2}	0.04	0.23	0.13	0.15	0.07	0.02	0.21	0.14

As shown in table9 and table10, the result of *variation coefficient method* and *entropy method* was similar, strengthening the reliability of the two methods.

Both the *variation coefficient method* and *entropy method* were based on the variation degree of each index, the index weighting coefficient could not reflect the data's independence. So this paper leaded in an assigning method considering the data's independence to make up for the information loss caused by the above two methods, called *multiple correlation coefficient method.* This method assigned the weight of each index according to information's multiplicity and index's independence, the smaller the multiplicity is and the more independent the index is, the bigger the weighting coefficient is. The weighting coefficient could be calculated by this method , the result was shown in table 11.

Table11. Results obtained by multiple correlation coefficient method

	a_n	U	K_f	f	D_f	a_f	Δr	E_r
weighting coefficient w_{j3}	0.1287	0.108	0.0991	0.2066	0.1006	0.1523	0.0987	0.1059

The result of *multiple correlation coefficient method* was great different from *variation coefficient method* and *entropy method*. Through fusing different results of those three methods, the inaccuracy of each method can be lowered.

Comprehensive evaluation

Each method not only has some scientificalness and rationality but also has some limitations. The subjective weighting method relies on human's subjective feeling too much, objective weighting methods rely on data too much, one single method cannot evaluate the special vehicle's reasonably.

Considering both objective feeling and subjective reality, this paper use the combination method of rank correlation coefficient to fuse the above three methods, and get the final weighting coefficient.

Firstly, calculate the 'spearman' rank correlation coefficient, to detect the correlation degree of each weighting method. The rank correlation coefficient can be calculated:

$$r_{ik} = 1 - \frac{6\sum_{j=1}^{a}(w_{ij} - w_{kj})^2}{a(a^2 - 1)} \tag{1}$$

r_{ik} is the rank correlation coefficient of the ith and the kth weighting method. a is the

number of the index. w_{ij}, w_{kj} is the j th index of the i th and the k th weighting method. Find two methods whose rank correlation coefficient was the biggest. Compare the respective rank correlation coefficient of the two methods and other methods. The bigger of the two has the highest consistency, the rank correlation coefficient vector of the bigger one and other methods is:

$$r_D = (r_{1,} r_2, \mathbf{L}, r_k)^T \tag{2}$$

Normalize this vector; a weighting vector could be obtained:

$$w' = (w_1', w_2', \mathbf{L}, w_k')^T \tag{3}$$

Use this weighting vector to revise the weighting coefficient, the final weighting coefficient could be obtained:

$$z = w' \begin{bmatrix} w_{11} & w_{12} & \mathbf{L} & w_{1a} \\ w_{21} & w_{22} & \mathbf{L} & w_{2a} \\ \mathbf{M} & \mathbf{M} & \mathbf{L} & \mathbf{M} \\ w_{k1} & w_{k2} & \mathbf{L} & w_{ka} \end{bmatrix} \tag{4}$$

In this paper, the final coefficient is:

$$z = (0.16 \quad 0.17 \quad 0.12 \quad 0.16 \quad 0.08 \quad 0.06 \quad 0.14 \quad 0.11)$$

Above analysis show that different method could obtain different results, and there may exist high conflict between different methods. The combination method of rank correlation coefficient could solve the conflict between different weighting methods and make a reasonable judgment on the weighting of index effecting the vehicle's handling and stability.

The product of the weighting coefficient and the score of each index is the weighting score, the final evaluation score of the special vehicle could be obtained by pulsing all the weighting score.

Conclusion

Aiming at the issue of special vehicle's handling and stability evaluation, the road tests of the vehicle were performed. The analytic hierarchy process was used to obtain the subjective weighting coefficient. The *variation coefficient method*, the *entropy method* and the *multiple correlation coefficient method* were used to obtain the objective weighting coefficient. The combination method of rank correlation coefficient was used to fuse the subjective and the objective results and get the final weighting coefficient. The final result could give attention to the superiority of each weighting method and decrease the conflict between different methods.

Acknowledgements

This work was financially supported by the National Natural Science Foundation of China (51475462)

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