ANALYSIS OF PERFORMANCE CORRELATION OF SUBJECTIVE AND OBJECTIVE EVALUATION OF TIRE AND VEHICLE

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ABSTRACT

In the initial stage of tire and vehicle development, ordinary drivers demanded only the basic performances including price and economic values, etc. However, performances that ordinary drivers are demanding are continuously increasing due to diversified information sharing and technology advancements with particular focus on the steering and safety features of the vehicle. Methods of evaluating the performances of tire and vehicle can be divided largely into subjective evaluation and objective evaluation. Both of these methods have their respective strengths and weaknesses. In order to supplement their weaknesses and to maximize their synergic effects, various relevant companies are conducting a diverse range of performance correlation researches. In this study, correlation research methods that had been used frequently in the past were reviewed and new analytic method capable of quantitatively indicate the differences in the subjective evaluation results and performance levels is presented.

Key words: Four parameter, Subjective test, Objective test, Performance correlation, Target setting.


1. INTRODUCTION

Steering and safety performance evaluation method for tire and vehicle can be generally divided into 2 methods. First is the subjective evaluation that evaluates performance by skilled sensibility evaluator while the second is the objective evaluation that objectively evaluates the quantitative performance characteristic values by using a diverse range of measurement equipment. Although companies utilize both evaluation methods, they continue
to rely more heavily on the results of subjective evaluation by skilled evaluators until now. As illustrated by the high dependency, subjective evaluation plays an important role in performance development. However, it has the weaknesses of being quite limited in expressing the characteristics quantitatively and fluctuation in the results depending on the conditions of the evaluator.[1] Recently, objective performance evaluation are being utilized actively in order to supplement such weaknesses of subjective evaluation and to pursue analysis of quantitative level as well as to deduce the direction of development. Furthermore, methods of improving the research and development are being sought through research on correlation between each of these evaluations. In this study, correlation research methods of subjective and objective evaluations that had been conducted thus far are reviewed and new analytic method capable of quantitatively expressing the differences in the levels of subjective evaluation results and performances is presented.

2. CORRELATION ANALYSIS

2.1. Subjective Evaluation

In subjective evaluation, performance evaluation is fundamentally conducted on the basis of SAE Recommended Practice, J1441 – Subjective Rating Scale for Vehicle Handling. Rating system that represents performances is given in the Table 1 below. Moreover, weighted value of performance is set and modified in accordance with the characteristics or concepts of the vehicle and tire. Although the detailed items of performance evaluation differ slightly between companies, key performances evaluation items (steering and stability, etc.) are the same in general. All the evaluations are made by skilled evaluator and comments are made on the aspects that are not expressed in terms of rating for utilization in performance comparison and analysis.[7]

Table 1 Subjective Rating Scale for Vehicle Handling, SAE J1141 [7]

<table>
<thead>
<tr>
<th>Rating</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Poor</td>
<td>1</td>
</tr>
<tr>
<td>Poor</td>
<td>2</td>
</tr>
<tr>
<td>Fair</td>
<td>3</td>
</tr>
<tr>
<td>Good</td>
<td>4</td>
</tr>
<tr>
<td>Excellent</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>7</td>
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<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2 Four Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1</td>
<td>Steady state gain of yaw velocity response</td>
</tr>
<tr>
<td>fn</td>
<td>Natural frequency of yaw velocity response</td>
</tr>
<tr>
<td>ξ</td>
<td>Damping of yaw velocity response</td>
</tr>
<tr>
<td>φ</td>
<td>Phase delay at 1Hz of lateral acceleration response</td>
</tr>
</tbody>
</table>

For performance and characteristic analysis, values of 4 parameters are applied to each of the axes of the rhombus-shaped graph as illustrated in Fig. 1. Rhombic domain ex-pressed by this graph illustrated the performances of vehicles at a glance and was design to illustrate that the vehicle performances have been improved if the area of the rhombus increases. Moreover,
each parameter can be explained with sensitivity of circling, convergence of circling, ease of circling and controllability of tracking.[6]

![Figure 1 Example of rhombus plot [5]](image-url)

Delivery function equation that presumed the each momentum and transverse acceleration as the secondary system can be expresses as follows. It is possible to obtain natural frequency, attenuation coefficient, steady-state gain and transverse response lag value through the delivery function of the system expressed by the equations (1) and (2). [5]

\[
\frac{\psi}{\delta_H} = a_1 \frac{1+\tau_r s}{1+2c_1 \frac{s}{\omega_n} + \frac{s^2}{\omega_n^2}}
\]

(1)

\[
\frac{a_V}{\delta_H} = a_3 \frac{1+b_1 s + b_2 s^2}{1+2c_1 \frac{s}{\omega_n} + \frac{s^2}{\omega_n^2}}
\]

(2)

In order to obtain the 4 parameters, Road Vehicle – Lateral transient response test methods – open-loop test method of KS R ISO 7401 is used mostly. Evaluation is carried out by categorizing it largely into temporal domain evaluation and frequency domain evaluation. Detailed evaluation conditions such as vehicle velocity, transverse acceleration (steering angle) and steering cycle can be evaluated by modifying them within the application range within the regulation in accordance with the discretion of the tester. 4-factor evaluation method is characterized by simply analysis and enables ease of assessment of the vehicle and tire performances at a glance. In addition, it shows high correlation for some of the evaluation conditions. However, there are several issues as follows that need to be supplemented in order to apply it to all conditions. First, the range of objective results differs depending on the vehicle or tire, or the evaluation equipment used. This signifies that the same range of results cannot be applied to all the evaluation conditions and that range of results for each of the evaluations has to be set newly every time. In order to supplement this problem, there is a need to newly define the range of results in accordance with the characteristics of vehicle, tire and measurement equipment. Second, high level of generalization works is being conducted to simply express the performance characteristic. Broad range of approach method of expressing the steering and handling characteristic with 4 factors made distinction of the detailed performance characteristics difficult. In order to supplement this problem, it is necessary to execute additional analysis by separately selecting performance factor that complies with the evaluation purpose or analysis needs to be executed by adding various performance factors other than the currently used 4 factors.
2.3. Statistical analysis through setting of performance factors

Statistical analysis method through setting of performance factors sets the vehicle movement factors that can represent the subjective evaluation items among various data that can be obtained through objective evaluation, and align them with the subjective evaluation items through statistical approach method. Key factors are set on the basis of the research results of each company as well as by utilizing the existing ISO evaluation standards. Statistical analysis method used most frequently as the correlation analysis method of the objective performance factors and subjective evaluation results can be categorized largely into 2 types as follows.

2.3.1. Regression analysis

Regression analysis is an analytic method of estimating the relationship between the variables statistically by using parameter model. It is use mostly when confirming the effects of independent variables on the dependent variables. As such, simple regression analysis method used for analysis of the relationship between a single dependent variable and a single independent variable, and multiple regression analysis method used for analysis of the relationship between a single dependent variable and numerous independent variables are used. Once the regression model has been presumed, appropriateness of the model is analysed. Representative appropriateness indices including R square \[8\], Residual Analysis \[9\] and Hypothesis \[10\] etc. Simple regression analysis and multiple regression analysis can be expressed by the following equations (3) and (4), respectively. \[10\]

\[
y_i = f_i + \mu = \beta_0 + \beta_1 x_1 + \mu
\]  

\[
Y_i = \beta_0 + [x_1 \cdots x_{np}] \begin{bmatrix} \beta_1 \\ \vdots \\ \beta_{np} \end{bmatrix} + \mu_i
\]  

Presumption that dependent variable is independent under the characteristics of regression analysis is used. Occasionally, when the variables have strong correlation, there is no existence of inverse matrix, thereby generating situations in which it is not possible to obtain parameter with the above equation. In such case, it is possible to compute the reverse matrix and solve the problem by utilizing eigenvector after having used eigen value decomposition or singular value decomposition. This is referred to as the principal component regression analysis. \[11\]

2.3.2. Neural network

Neural network is a learning algorithm composed of inter-connected artificial neurons by mimicking the format of operation of biological nervous system fundamentally. It is equipped with non-linear problem solving capability and is distinguished into input layer, hidden layer and output layer as illustrates in Fig. 2 below.\[12\] Fundamentally, it solve the problem of finding the right answer, and weighted value and threshold to minimize errors on the basis of the methodology of regression analysis and supervised learning. It is where majority of algorithm problems of neural network occur.
Given the characteristics of artificial neural network, it is not possible to mathematically analyse or prove the detailed mechanism of executing analysis without consistently progressing learning since it is in black-box format. In addition, it has low efficiency because extensive manual handling is needed in refining the data.

3. TARGET SETTING

Evaluation of applicability was carried out by using the 4-factor analysis method and statistical analysis method that have been used in the past.

3.1. Experiment

3.1.1. Test condition

Information on vehicles, tires and test conditions used in this research are given in the Tables 3&4. Also, Fig 3&4 shows two examples of the steering wheel angle input.

Table 3 Information on vehicles and tires evaluated

<table>
<thead>
<tr>
<th>Test Vehicle</th>
<th>Test Tire</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>C segment</td>
<td>205/55R16 / 10set</td>
<td>SM</td>
</tr>
<tr>
<td>D segment</td>
<td>225/50R17 / 10set</td>
<td>SM</td>
</tr>
<tr>
<td>J segment</td>
<td>215/65R17 / 10set</td>
<td>SM</td>
</tr>
</tbody>
</table>

Table 4 Information on vehicles and tires evaluated

<table>
<thead>
<tr>
<th>Test</th>
<th>Standard</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective</td>
<td>SAE J1141</td>
<td></td>
</tr>
</tbody>
</table>
| Objective | ISO 7401
ISO 13674-1 |           |

Also, Fig 3&4 shows two examples of the steering wheel angle input.

Figure 3, 4 Frequency response : ISO 7401, On center weave : ISO 13674-1
All evaluations were executed through highly skilled driver in preparation for the improvement of repetitive reproducibility and safety accident of the test. In the sample result about the objective handling test below, we can derive vehicle characteristics from the result, quantifying the performance as well.

![Sample result: on center weave (left) frequency response (right)](image)

**Figure 5** Sample result: on center weave (left) frequency response (right)

### 3.1.2. Equipment

Equipment used in this research can be divided largely into 2 types. First, Steering robot system of ABD was used for quantitative measurement and secure repeatability & reproducibility. By using equipment, we measure steering angle, torque and set the driving condition.

Second, Inertial & GNSS system of OXTS was used to measure 3-axis velocity, acceleration, moment of vehicle motion. It is widely used GNSS-based measurement equipment mostly by vehicle related companies. With simple and easy installation, it can compute vehicle motion and characteristics.

### 3.1.3. Analysis

On the foundation of the applicability evaluation, analytic method with new format was deduced and this is referred to as Performance Target Setting. Fundamental analytic method of Target Setting is as follows.

First, setting of independent and dependent variables: Execute setting of the evaluation range including tire, vehicle and measurement equipment in order to secure the correlation of the Target Setting method. Through this, prevent the problem of fluctuation in the range of objective results in advance.

Second, vehicle and tire characteristic evaluation: Execute the subjective evaluation and objective evaluation that had been implemented in the past by utilizing ISO specifications. At the time of subjective evaluation, maximize subdivide the evaluation items and put priority on the evaluation of performance items that are close to the items of objective evaluation results.

Third, setting of key performance factors and regression analysis: Execute correlation and regression analysis in order to deduce factors that can represent subjective performance. Through this, it is possible to deduce key factors that can quantitatively express and represent the subjective evaluation results.

Fourth, illustrate and set the zones of objective performance factors: Illustrate the results of subjective evaluation and the key factors of objective evaluation obtained early on the graph. Through this, it is possible to easily analyse the quantitative performance levels and confirmation of development goals in accordance with the evaluation purpose.
3.2. Result

Execute correlation analysis in order to deduce factors that can represent subjective performance and the result in Fig. 6 below.

![Figure 6 Correlation analysis (subjective vs. objective)](image)

Each color has represents a percent about the correlate, in red more than 70%, in orange and blue 60~69%, in bright orange and bright blue 50~59%, in blank less than 50%.

![Figure 7 Target setting analysis](image)

Fig. 7 illustrates the results of execution of Target Setting for a single performance item by setting tire and vehicle as the independent variable and the dependent variable, respectively, and by utilizing correlate data that were analysed in the past.

<table>
<thead>
<tr>
<th>Steering response Subjective rating</th>
<th>C&amp;D Segment Delay Time</th>
<th>J Segment Delay Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.25</td>
<td>~ 112ms</td>
<td>~</td>
</tr>
<tr>
<td>7</td>
<td>113 ~ 115ms</td>
<td>~</td>
</tr>
<tr>
<td>6.75</td>
<td>116 ~ 119ms</td>
<td>~</td>
</tr>
<tr>
<td>6.5</td>
<td>120 ~ 124ms</td>
<td>129 ~ 132ms</td>
</tr>
<tr>
<td>6.25</td>
<td>125 ~ 131ms</td>
<td>133 ~ 137ms</td>
</tr>
<tr>
<td>6</td>
<td>132 ~</td>
<td>138 ~</td>
</tr>
</tbody>
</table>

Through this analysis, it was possible to quantitatively confirm the performance characteristics that were previously evaluated subjectively. Moreover, it was possible to assess the performance range of the subjective evaluation rating. In comparison to the 4-parameter method that can only check whether the performance of the subject has been improved or not, it can be applied to more extensive range of areas. In addition, it is deemed that the efficiency of research and development will improve since it is possible to set the quantitative-targets of performance and development direction. In addition, it is determined that extensive range of application would be possible through subdivision of various variables.
(example, analysis of vehicle performance characteristics in accordance with the changes in the key factors of tire, performance sensitivity according to the factors and deduction of subjective evaluation rating through dynamics simulation, etc.).

4. CONCLUSIONS
This study presented the performance target setting method capable of quantitatively expressing the differences in the subjective evaluation results and performance levels by reviewing the correlation analysis method, which had been utilized thus far, and by executing applicability evaluation. Advantages of 4-factor analysis method and statistical analysis method were evenly applied to the Target Setting method. As such, it has the following strengths.

First, it is possible to quantify subjective evaluation. As such, it is now possible to supplement the outcomes of subjective evaluation that were doubtful in the past through quantification as well as to assist understanding of performance characteristics.

Second, it is possible to set the quantitative target of performance and development direction. Therefore, there no longer is the need to set abstract development goals and it is possible to enhance the efficiency of research and development through analysis of more accurate and quantified performance levels.

Third, there is greater possibility of expansion and application. It is determined that it can be applied to more diversified range of researches through subdivision of various parameters or variables that not only compare the simple performance characteristics but also modify performance.

Based on the outcomes of this study, researches on the correlation between subjective evaluation and objective evaluation will be executed continuously under more diversified conditions in the future.

REFERENCES


