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OBJECTIVE EVALUATION OF SUBJECTIVE DRIVING IMPRESSIONS

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ABSTRACT - In the development of passenger car driving behaviour much subjective testing is involved. Although many car manufacturers have developed objective test methods and have corresponding analyses, objective parameters which correlate one to one with the subjective rating in the international rating scale (1-very bad 10-excellent) are not available.

FEV has developed objective parameters for two main interest items, steering response and secondary ride comfort. These parameters consider different analyses and correlate very well with the subjective ranking of the test drivers.

To achieve this, an investigation was put through with more than 10 different vehicles, ranging from sportscar to SUV but focused on modern mainstream European cars. The cars were subjectively assessed by more than 20 experts and laypersons and a large number of measurements has been taken.

The two parameters are developed based on a statistical regression analysis but a relation between separate sub-properties is maintained. The result is a simple measurement procedure that gives recognisable parameters and combines these to give an absolute rating for any car in the market.

The parameters deliver the reason for a good or bad behaviour as well, so that optimisation measures can be focused on the main cause.

This article deals with development of the objective parameters.

TECHNICAL PAPER –

INTRODUCTION

Subjective testing is still the most important tool in the development of steering and ride comfort attributes when it comes to developing a new chassis setting for passenger cars. Every OEM uses specific test procedures to control this development. More and more these developments are supported by objective measurements, where again the test procedures are OEM specific and are generally based on historical relations between measurement results and subjective evaluations.

FEV, as a new service provider in the field of vehicle dynamics, has seen the need for a simple, cross market evaluation tool that can give a quick rating, according to the international rating scale, of a number of the most relevant attributes of a vehicle. Coupled to the database of results of vehicles in different classes, an evaluation of the vehicle can be

given, showing the basic character, including weak and strong items. Additionally the parameters help to optimize the driving behavior of the passenger cars. The paper describes the process of elaborating the two metrics ride comfort and steering response.

THE INVESTIGATED PROPERTIES

In this first step, properties were chosen from the 2 sub attributes ride comfort and handling. Ride comfort can basically be divided in primary ride and secondary ride. Primary ride is generally associated with rigid body movements in the frequency range from 0–4 Hz, whereas secondary ride is defined as vibrations >4 Hz exposed to the driver. The item secondary ride is chosen since this relates the most to what normal customers define as ride comfort. Moreover the secondary ride does not have the contradiction of comfort and (body) control, which is well known from primary ride.

For handling the item steering response was chosen, again since this is for normal customers very much related to handling, when it comes to driving in normal (low to medium lateral acceleration) conditions.

THE CARS

For the establishment of the objective parameters 10 different cars were chosen, covering a wide range of vehicle classes, from small car, compact car to luxury limousine. Outside this range also a typical sports car and SUV were used in the tests.

Additional to these cars several cars were used to fill the FEV database and for the most of them subjective evaluations were performed (not with the complete test panel) to monitor the robustness of the achieved parameters. These results will not be discussed in this paper but have supported our conclusions.



Figure 1: The tested cars

THE TEST PANEL

Since it is known that vehicle dynamic properties are not always easy to evaluate by “normal” drivers and that during the development of these properties the tests are solely performed by

experienced test engineers, it was inevitable to involve experts in the field for the subjective tests. On the other hand, customers, not being experts are the ones that will drive and appreciate the car after it has been developed.

Therefore it was decided to involve 3 different groups of evaluators.

1. FEV vehicle dynamic experts (5)
2. FEV vehicle engineers (4)
3. Average customers (partly engineers) (12)

In processing the results of the subjective evaluation, these groups were partly treated separately and depending on the correlation between the groups, treated as one group.

THE METHOD

Through the years FEV has developed a standard procedure for the objectivation of the subjective ratings in vehicle behavior. This has been successfully used in NVH and other areas.

The basis for this methodology is that a car is tested subjectively and at the same time the objective data are gathered. The subjective rating is performed by a minimum of 10 persons. A statistical tool is first used to determine whether the subjective ratings are relevant and consistent. If the subjective rating is relevant, objective parameters are established from the measurement data. The parameters used are those that are assumed to have some relation with the phenomenon and some others of which it is not sure.

Methodology to develop Objective Parameters

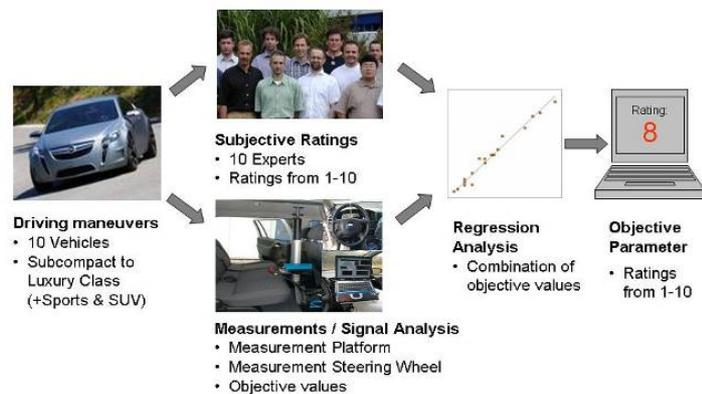


Figure 2: The methodology

With the statistical tool a model is established that shows a relevant correlation between the objective parameters and the subjective results. Finally this model is analyzed for its physical relevance and if all boundary conditions are met, the model is declared valid and after additional blind tests, released for use within the company. In the case of the item steering response, it seemed not possible to find a robust model based on the measurements during the subjective test and in this case a new technique was used, where objective parameters were added that were obtained from a separate test.

SECONDARY RIDE COMFORT

For the item secondary ride comfort 3 different roads were used where the cars were driven for subjective evaluation and measurement. The speeds were given and afterwards it was checked if they were within the tolerance band defined (± 2 km/h). All roads were parts of a proving ground. This is done to guarantee consistent road conditions also in the coming years.

The first road is characterized as “broken asphalt”. It is a relatively flat road with course asphalt where many irregular parts of the asphalt are missing (diameter 2-20 cm and depth about 1.5 cm)

The second road consists of cobble stones, layed in an uneven manner giving irregular disturbances in the range until 0.5 to 1.5 cm.

The third road can be characterized as a pothole road, although the potholes are quite small (max 20 cm diameter) and very irregular. All 3 roads are rated separately and for each road 2 different speeds were used, both in the range that is expected to be used by normal customers.

For the objective data it was chosen to measure the accelerations in three directions on the seat rail and the suspension domes. In theory it would be better to measure the accelerations closer to the human body and thereby include the filtering of the seat in order to have the best correlation between subjective and objective evaluation. But earlier research showed that the accelerations measured at the human body show so much variation between test runs and drivers that the error introduced by measuring on the seat rail is much smaller.

At first the correlation between the drivers was evaluated. The correlation on all tested conditions is good; nevertheless differences in a normal range occur. On the pothole road the variation between the drivers is larger than on the other 2 roads. An analysis of the measurement data shows a larger variation on this road. The reason is most likely the uneven distribution and size of the disturbances that result in different conditions between the test runs. The tests on the cobble stone at 70 km/h and broken asphalt at 50 km/h are very reproducible, so the analyses are focused on this.

For the correlation analysis the objective parameters peak, RMS and squared acceleration weighted in all directions and weighted in different frequency ranges were investigated. Based on these parameters statistical models were built and checked for their validity. After the analyses a model was found to be valid for both types of road. It contains an average acceleration in the longitudinal and vertical direction over a broad frequency range. The factors for both directions are not the same as found in earlier discomfort studies but the reason for this can be found in the fact that the accelerations are measured on the seat rail rather than the human body. In figure 3 the final result of the calculated vs. given rating based on the established model can be seen.

The simplicity of the model is also its strength. The predicted value can immediately classify the test car but also the separate factors for vertical and longitudinal level give an indication in what direction the best possibilities for improvement are. By using an appropriate filter characteristic it is then possible to quantify the overall comfort rating improvement obtained by a certain countermeasure.

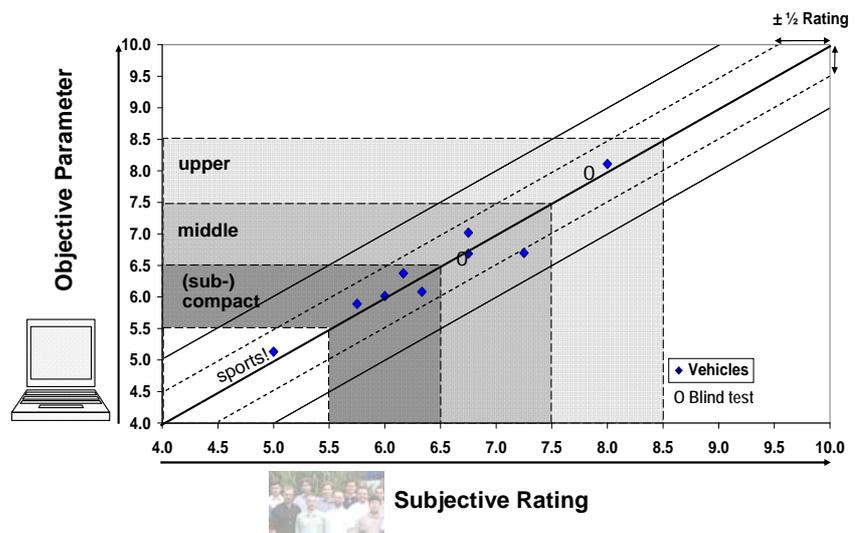


Figure 3: Ride comfort metric: Objective vs. subjective rating

In figure 4 the differentiation between the 2 accelerations can be seen. From a conventional analysis without the weighting model it only becomes clear that the improvement of the vertical comfort on car #10 is very promising. With the evaluation tool a precise prediction of the total comfort level is possible. It is chosen to use both the cobble stone and broken asphalt road and the average of both roads to give the final overall rating of the car for secondary ride comfort.

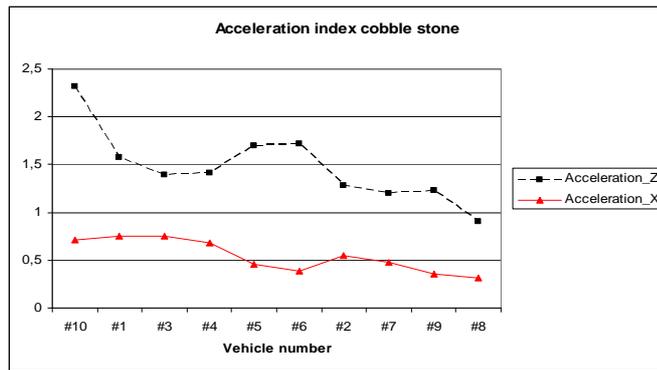


Figure 4: Comfort metric: Separation in sub items

STEERING RESPONSE

Steering response is an item that can not be treated like ride comfort. The steering response is good when it matches the handling behavior and character of the car. In the evaluation the steering response is quantified and this is not automatically a qualification.

Since steering response is not a constant factor because it depends on the magnitude of the steering action and on the vehicle speed, choices had to be made to narrow down the property. The choice is made for typical country road conditions, meaning speeds between 80 and 90 km/h and lateral accelerations around 0.35G.

All tests were performed on a proving ground with basically flat road conditions. Two different tests were performed and two different tracks were used for this purpose.

The first test is a step steer test at 80 km/h with a steering angle to reach 0.35G. The test cars were prepared with a marker on the steering wheel so that all drivers would use the same steering angle. The test was performed on a vehicle-dynamics-area. In this test the drivers were asked to evaluate:

- Quickness of steering
- Directness of steering
- Overall steering response

The second test was called “free driving”; here the car is driven as in normal subjective evaluation of steering response. From straight ahead (80 or 90 km/h) the driver generates several steering inputs with varying steering speed to evaluate the vehicle response. This test was performed on a general oval road where the testing was performed on the straights. In this test the drivers were asked to evaluate:

- Quickness of steering
- Directness of steering
- Rear axle delay
- Overall steering response

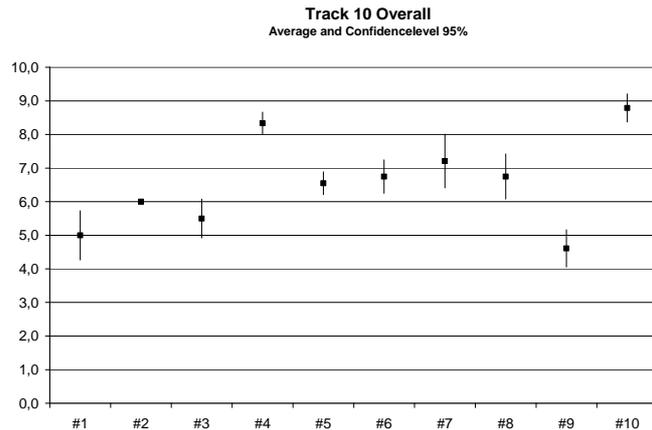
The correlation study of the subjective ratings shows the following results:

The overall steering response correlates well between all drivers. The results for both tests also show a high correlation. The variation for the separate groups follows the experience with the subject. It is small for the experts, larger for the vehicle engineers and largest for the normal customers. The tendency for all groups however is equal and the confidence of the ratings is still high enough when the results of all evaluators are taken into account.

The correlation of the items quickness and directness is insufficient for the whole group. There is a very strong relation between the overall response and the items quickness and directness and the variation in the last 2 items is significantly larger. This is valid for the group as a whole but also for the experts.

It is already clear that it is very difficult to differentiate between directness and quickness. The correlation with the objective results will confirm this.

Figure 5: Average and confidence level of all drivers



The objective data consists of time recordings of the following properties: Steering angle, steering torque, yaw rate, lateral acceleration as the most relevant ones but all 6 DOF of the vehicle are measured as well as side slip angle.

Many parameters are derived from the time signals to find the best correlation with the subjective results.

The first analysis was to find out if the experts could differentiate between quickness and directness. For directness the most logical parameter yaw gain or lateral acceleration gain could not be correlated with the subjective evaluation. This confirms the expectation above. Because of this result the study is focused on the item steering response overall only. For this the same parameters are used and also some “strengthened” parameters. To give an example, the parameter phase delay between steering angle and yaw rate could be established from the measurements taken during the subjective evaluation. Between the different tests however there is relevant variation and to exclude this variation from the analysis, a separate test “pseudo random steering input” was performed to measure many of the analyzed parameters very accurately. The result of these “strengthened parameters” correlated well with those obtained from the step steer and “free driving” tests but as expected improved their reliability. With the help of these “strengthened parameters” good correlations are found, both for the expert group and also the complete group. Therefore results of the complete group are used for the final model of the objective metric.

	Subjective	Objective	Speed
Step steer	x	x	80
Free driving	x	x	80,90
Pseudo random	-	x	80,90

Figure 6: Overview of handling tests

The objective metric “steering response” consists of steering yaw gain (yaw rate/steering angle) and the delay of lateral acceleration response. With three measured metrics the subjective impression of the steering response can be described accurately. The correlation to the subjective impression is high ($R > 0.9$).

Figure 7 shows the relation between the subjective and objective results. Where in the ride comfort results the cars can be tied to a certain vehicle class, this is more difficult for the

steering response item. It is clear that a sports car will have a high steering response but a luxury high level car does not need to have a low response.

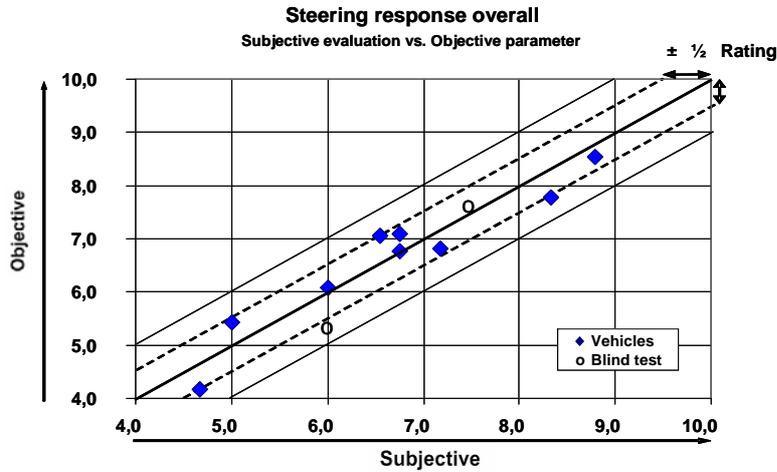


Figure 7: Handling: Objective vs. subjective rating

Again the parameter can be split, this time in quickness and directness, based on the objective parameters (see figure 8). Predicted on the parameter one can easily detect the reason for a high or low steering response, e.g., as assumed the sports car #10 is rated very good (almost 9) regarding the steering response.

The reason for this is the outstanding small delay in the lateral acceleration response, whereas the yaw gain is on a similar level like other cars.

The reason for the bad rating of vehicle #9, which is rated below 5, is that it combines a very low gain with large delay.

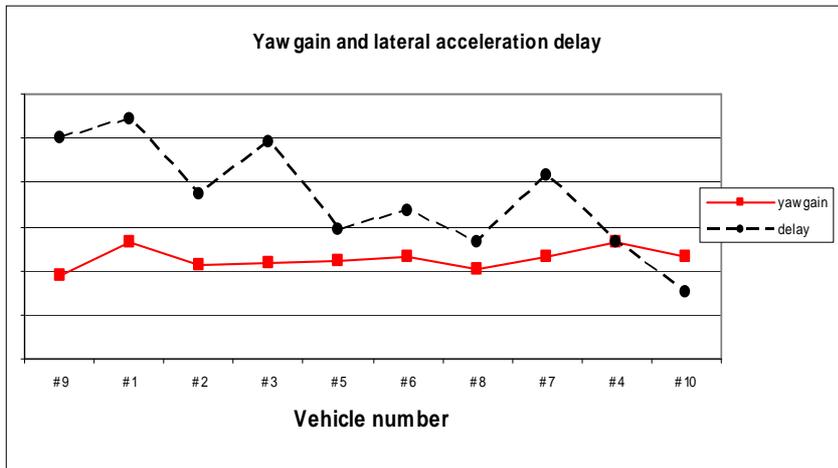


Figure 8: Handling: Separation in sub items

SUMMARY

Objective parameters for important vehicle behaviors (lateral, vertical and longitudinal) will be developed by FEV to quantify these behaviors independent of market, vehicle type or class. The ratings are based on the international rating scale 0-10. The development of the first 2 parameters shows that it is possible to obtain these parameters based on simple tests and subjective evaluators ranging from experts to normal customers. In both case studies “secondary ride comfort” and “steering response” it is possible to differentiate between sub-items of the analyzed behavior to give an indication for possible improvements in terms of target cascading. Therefore the tool will be enlarged in future on additional vehicle behaviors and will be used for trouble shooting and target definition purposes. For benchmarking reasons it can deliver a more reliable evaluation.

Analysis of the cars as a whole shows no clear relation between the factors comfort and handling. The sports car combines good response with poor comfort, the SUV combines good comfort with poor response, the luxury car combines very good comfort with fair response but otherwise the cars scatter. The reason for this must be found in both the variety of concepts and the variety in OEM characters. Figure 8 gives an overview of the combined results. Cars can be rated along the arrow as becoming better. A deviation from the center line shows a trend towards more sporty or more comfortable character. The upper left triangle is reserved for pure sports cars where the lower right triangle car will be found that are overproportionally comfortable.

However, for each car it is possible to indicate which improvement direction (steering or comfort) shows the highest potential, depending on the desired character of the car.

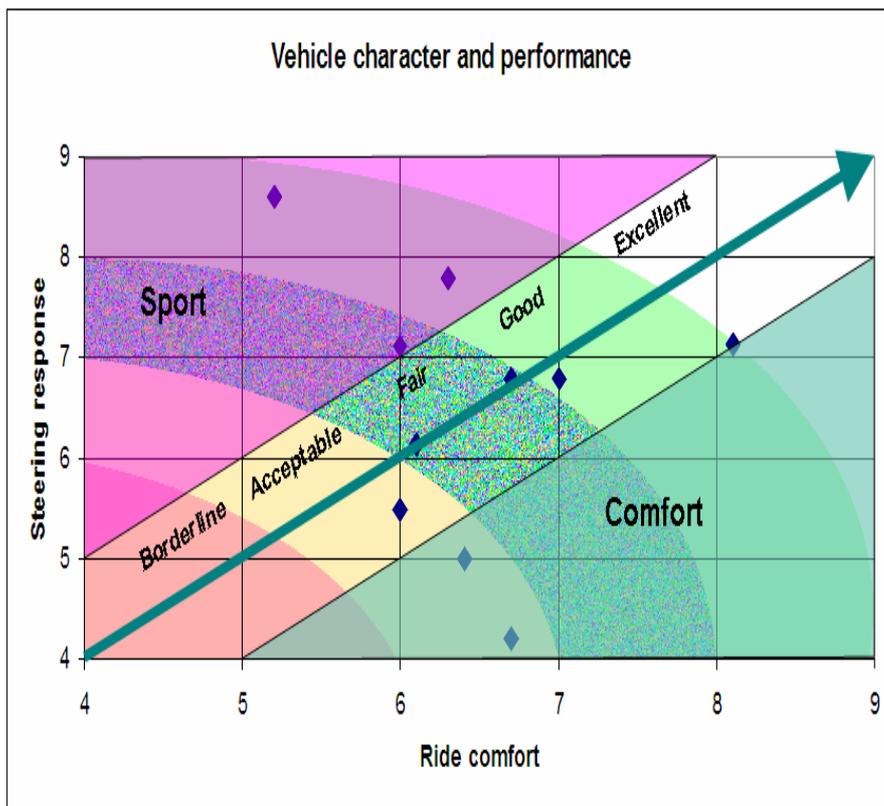


Figure 9: Combined comfort and response