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CUSTOMER PERCEPTION OF VEHICLE DYNAMICS AND ITS TRANSFER TO TECHNICAL CHARACTERISTICS

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ABSTRACT

Vehicle dynamics are well described by technical parameters in existing literature. But in order to fulfill customer requirements, there is a need to take further perspectives on vehicle dynamics into account. In particular, it is essential for the automotive industry to be able to match the customer perception of vehicle dynamics to the corresponding technical characteristics. In the past years, research in this context has been carried out, but in most of the performed case studies a very limited view on singular, isolated characteristics is given. Thus, there is a need to approach the transfer of customer perception to technical characteristics in an integrated way. This work therefore provides an overview of areas relevant to consider for researching the transfer between subjective perception and objective parameters. Based on different perspectives on the technical parameters concerning vehicle dynamics, a selection of existing approaches to match customer perception and technical characteristics is presented. The different perspectives are further outlined in a framework in order to enable a more transparent, integrated view on vehicle dynamics. This paper is a result from the cooperation between the *Technische Universität München* and the *BMW Group* in the scope of the virtual enterprise *CAR@TUM (Munich Center of Automotive Research).*

Keywords: vehicle dynamics, customer perception, automotive industry, customer requirements

1 INTRODUCTION – CUSTOMER PERCEPTION OF VEHICLE DYNAMICS

1.1 Background

In times of increasing globalization issues and markets which are flooded by a growing number of product variations and brands, it becomes more difficult for companies to tie present and to acquire new customers. A branch especially worth looking at in this context is the automotive industry. Almost all major OEMs (original equipment manufacturers) expand into market niches in order to address new target groups of customers. Nevertheless, competitive products often show a high degree of similarity in size, exterior and interior equipment.
To convince customers of a certain product, companies are therefore forced to create further unique selling points by certain vehicle characteristics. In this context, finding the appropriate characteristics concerning vehicle dynamics shows high potential to tie certain target groups to a company. Growing costs of purchase and operation and an increasing customer-sensitivity for environmental issues of course make customers more contemplative about fuel consumption and CO_2-emission. Nevertheless, characteristics concerning vehicle dynamics are important criteria regarding the customer's motivation to purchase a car.

1.2 Subjectivity of customer perception concerning vehicle dynamics

At a first sight vehicle dynamics are often reduced to technical – objective – characteristics, which are extensively described in corresponding literature e.g. of Mitschke and Wallentowitz [1], Kiencke and Nielsen [2] and Jazar [3]. Both technical characteristics for longitudinal and lateral dynamics are researched in depth. But according to Petiot and Yannou [4], to improve attractiveness on the market, well-designed products should also satisfy consumers' psychological needs, by essence subjective. These needs can be traced back to the perception of customers. Thus, to design cars appropriately in the context of giving the consumer a feeling of ease, it is crucial to focus on the subjective customer perception of vehicle dynamics and to find ways to transfer the subjective customer perception to technical characteristics.

Existing research shows that this transfer is quite a challenge – especially when trying to map various emotions on different technical characteristics. One reason is that the average customer does not have the distinctive technical knowledge to assign his subjective perception of vehicle dynamics directly and adequately to technical characteristics. The customer rather tends to perceive a whole package of configurations and then decides, whether this package feels good in means of vehicle dynamics or not. Thus, a challenge exists in finding the lever for adjusting technical characteristics target-oriented. Furthermore, people show a high degree of individuality in their physical perception. For this first step of perceiving information from the environment, different senses are responsible. And these senses are again developed and characterized individually from human being to human being; e.g. some people show a higher sense of touch than others, and this circumstance then allows different interpretations of vehicle dynamics from person to person. And the senses also change their characteristics during the lifetime of a person. For example, older people often show hardness of hearing, as their aural sense degenerates by the time. The senses which are most essential for perceiving vehicle dynamics are shown in Figure 1. With it an example for every sense concerning vehicle dynamics is given.

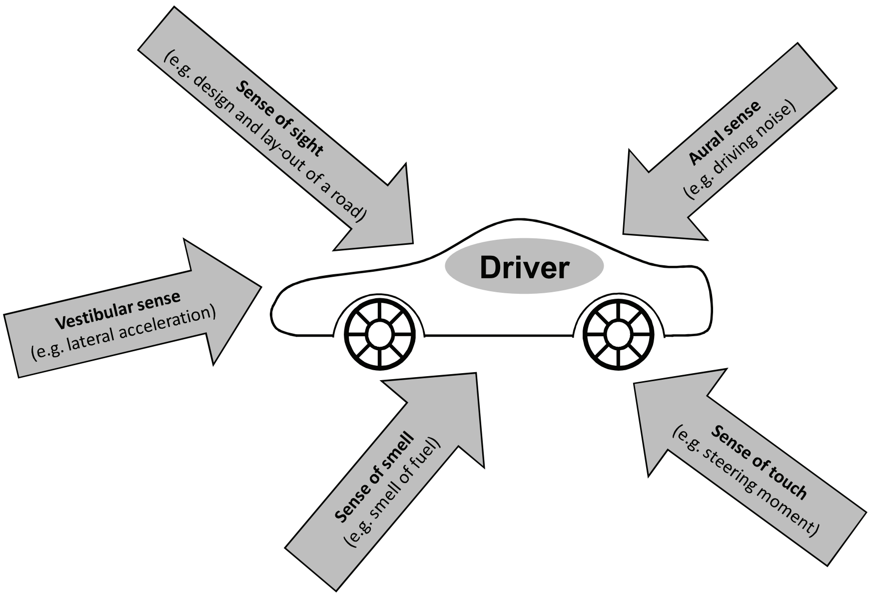

Figure 1: Essential human sensory perception in a motorcar (according to Tomaske and Meywerk [5])

Besides differences in the physical perception of stimuli when driving a car, people process and interpret the perceived information in very different manners. One reason is that people have very different driving experiences and also show different preferences concerning their driving style; e.g. some people are more sportive drivers and some people are more relaxed drivers, and thus, a certain situation might be fun for a sportive driver, whereas the relaxed driver does not feel comfortable with it.

These first aspects already show that finding a car configuration which is appropriate for various people who individually perceive vehicle dynamics in very different ways is quite challenging. Nevertheless, automotive industry is getting increasingly aware that understanding the subjective perception of customers shows a high potential for designing market and customer-oriented cars. Thus, this paper gives an overview about the different and highly interlinked facets on this topic.

1.3 An approach of describing the framework of facets concerning vehicle dynamics

This section shows which perspectives are focused in this paper to finally present a framework of aspects relevant for the transfer of customer perception to technical characteristics. Therefore, in chapter 2 it is shown, how vehicle dynamics can be approached from a technical point of view. This chapter gives an idea of the high degree of interdependency within and in-between technical parameters and components concerning vehicle dynamics. In this context, relevant components are presented and a selection of technical parameters is given. Chapter 2 also looks at the industrial design of cars, as it describes an important influence factor on the subjective perception of customers.

In chapter 3 existing methods – to measure and technically interpret subjective perception of vehicle dynamics – are introduced. A focus lies on the correlation and regression analysis but further methods like 'artificial neural networks' are also shown and reflected.

On the basis of the first three chapters a framework of facets concerning vehicle dynamics is carried out in chapter 4. Besides the technical characteristics and existing mapping methods, further aspects which should be taken into consideration when approaching vehicle dynamics in an integrated way are focused; e.g. the high degree of interdisciplinary work which is necessary to approach this topic is addressed. Finally, in chapter 5 conclusions are drawn and an outlook on future research concerning the transfer of customer perception of vehicle dynamics to technical characteristics is given.

2 TECHNICAL CHARACTERISTICS CONCERNING VEHICLE DYNAMICS

2.1 Different perspectives on technical characteristics

Technical characteristics influencing vehicle dynamics can be detected and categorized at different levels of abstraction. A first perspective in section 2.2 provides different driving situations of which every single one is described by a certain selection of technical parameters. These parameters already provide a second perspective on vehicle dynamics, as they point out vehicle responses at a more detailed level. In order to get a better understanding of the high interdependency of technical parameters and driving situations, the technical parameters are assigned to the driving situation. In section 2.3 technical parameters are referred to components corresponding to vehicle dynamics. Further perspectives are provided in sections 2.4 in order to show, from which directions the topic of vehicle dynamics can already be approached from a more technical point of view. One of these further perspectives deals shortly with the industrial design of cars as being an important technical factor for human perception.

2.2 Technical parameters concerning vehicle dynamics

Heißing and Brandl [6] suggest diverse driving behaviors in their explanations concerning the subjective assessment of vehicle dynamics. They differ between following driving situations:

- Start-up behavior
- Braking behavior
- Behavior concerning straight running
- Steering behavior
- Cornering ability
- Driving comfort

For each driving behavior suggestions concerning driving maneuvers, development objectives and a huge amount of influence factors – i.e. certain technical parameters – are given. Looking at the parameters, some show a higher importance for influencing vehicle dynamics than others.

Based on a literature research and on expert opinions parameters with a higher importance are outlined in Figure 2. Besides assigning parameters to driving situations, the driving behaviors are referred to lateral and longitudinal vehicle dynamics. This differentiation is not explicit, as some driving behaviors are characterized by lateral and longitudinal dynamics. Despite, this is another possibility to approach vehicle dynamics from the technical side.

Figure 2 shows that some parameters are assigned to different driving behaviors, e.g. the angle and speed of yaw. This characteristic is part of the behavior concerning straight running, of the braking behavior and of the cornering ability. This little example already shows that tuning one certain parameter, e.g. changing the braking behavior, might also have negative consequences for the cornering ability. Thus, on the one side the braking behavior might have been improved concerning vehicle dynamics, but on the other side, the cornering ability may now be perceived worse by the customer. Therefore, this perspective already shows the high degree of interdependency and corresponding complexity in adjusting certain technical parameters according to customer requirements. Furthermore, the parameters themselves are often interdependent; e.g. the car's center of gravity is an important variable for different parameters. Thus, changing the center of gravity leads to various changes in the different driving behaviors and with it also in the perception of vehicle dynamics.

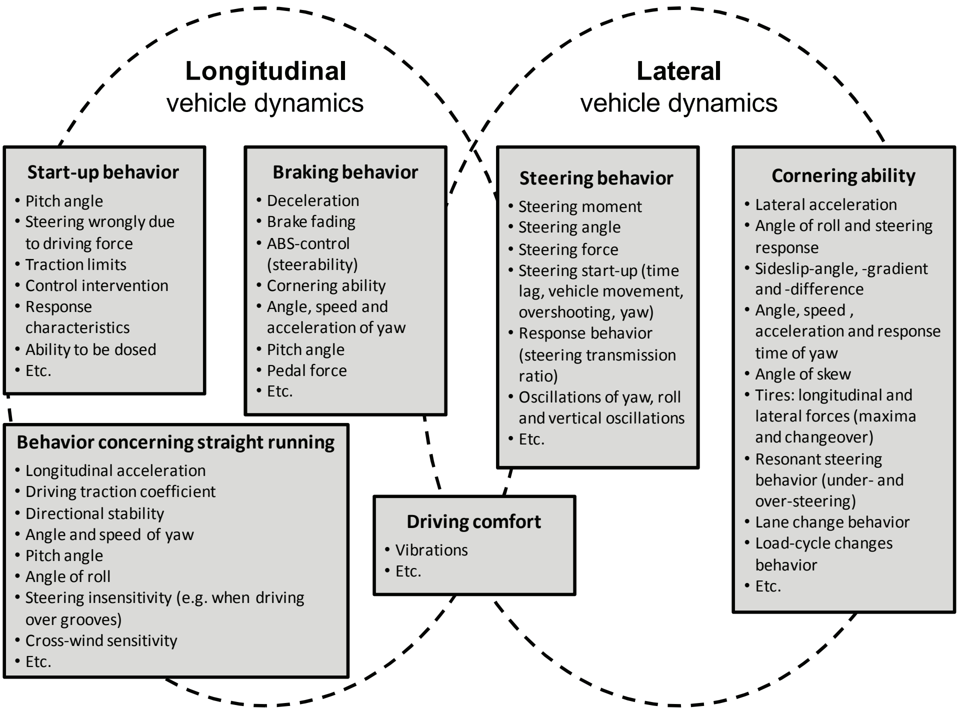

Figure 2: Driving behaviors and corresponding technical parameters

2.3 Components concerning vehicle dynamics

This section gives an overview about different components influencing vehicle dynamics. This perspective provides a next step towards transparency, but also shows that interdependencies concerning vehicle dynamics can be detected on different levels of abstraction. Heißing and Brandl [6] focus on nine different groups of components concerning vehicle dynamics. These can be named as follows:

- Body of car
- Chassis
- Complete vehicle / package
- Brakes
- Control systems
- Power train elements
- Mounting of power train
- Wheels / tires
- Seating system

To these groups of components certain areas of technical parameters can be assigned which are influenced by the design and setup of the components. Figure 3 provides a selection of influenced areas, which show a high degree of dependency to the corresponding components. As the seating system rather shows the character of being part of the interior equipment than influencing fundamental driving behaviors, it is not considered in the figure. The power train elements and the mounting of the power train are both combined within the group 'drive system' and the tires and wheels and brakes are subsumed under one group of components in Figure 3.

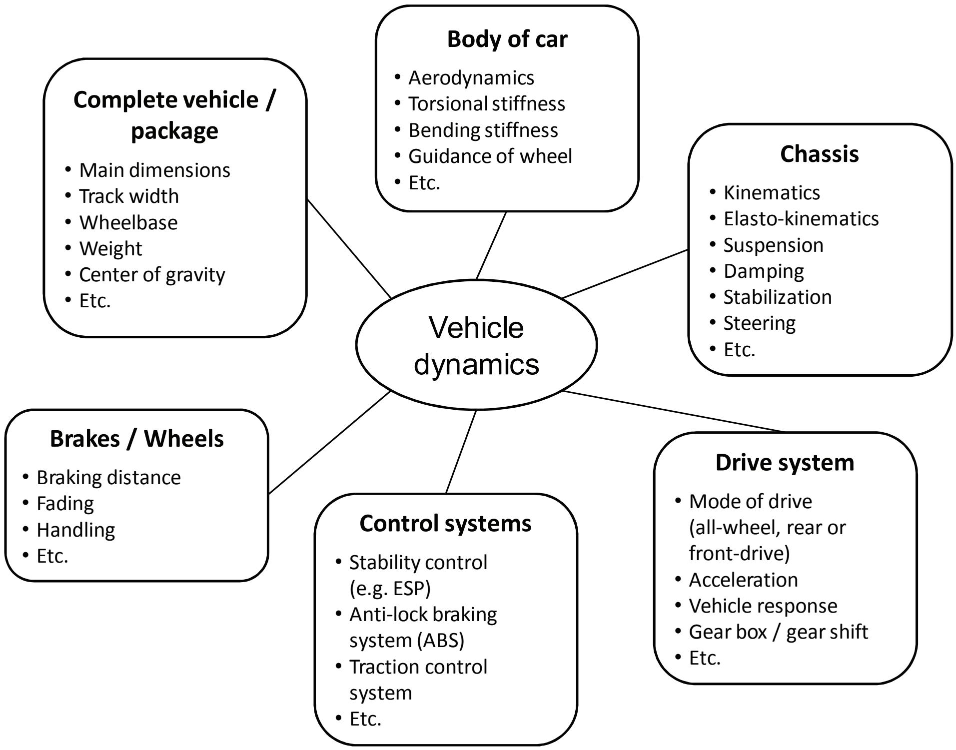

Figure 3: Components and influenced areas of technical parameters

In the next step it would be possible to assign the singular technical parameters in Figure 2 to the areas of technical parameters in Figure 3. This way the interdependencies within and in-between technical parameters, driving behaviors and components can be detected. Although this is not explicitly followed, considering Figure 2 and Figure 3 emphasizes again that it is difficult to adapt singular characteristics concerning vehicle dynamics isolated from others.

Beside the challenge of adapting the characteristics without having too many change propagations in other areas of vehicle dynamics, the different perspectives also show that the average customer will not be able to point consciously at certain characteristics and components by his perception of vehicle dynamics. Thus, case studies are often forced to focus on a very limited range of characteristics. Despite, this paper provides a framework of what other areas might be influenced and these areas then could be part of a following case study.

2.4 Further perspectives on technical characteristics

The characteristics mentioned in the sections before get defined at different steps in the design process. This circumstance allows another perspective on vehicle dynamics. Specifications which have do be defined early in the innovation process can not or only hardly be adapted shortly before being launched. This makes it even more difficult to adjust cars according to subjective requirements of customers. Thus, it is necessary to perform early driving simulations to save costs in the design process but in particular to gather information concerning the subjective customer perception at an early stage of the innovation process. However, it is still unclear how applicable driving simulation is to the real world, because analyses of perceptual criteria carried out in driving simulation experiments are controversial [7].

Characteristics defined at an early stage of the design process and having a high influence on vehicle dynamics can exemplarily be seen in the main dimensions of the car, the wheel base, the car's center of gravity and the aerodynamics. Some of these parameters can partly be traced back to industrial design. Thus, the industrial design is an important factor when looking at vehicle dynamics. Besides influencing the technical characteristics, the industrial design shows a high importance for the customer's visual perception. People tend to relate certain elements of industrial design to certain shapes of the car. Some points of action concerning industrial design are introduced according to Kohler [8]:

- **Materials**: materials concerning both exterior and interior design show psychological effects
- **Colors**: to be referred exclusively to visual perception and often influenced by the chosen material
- **Shapes**: the cars' industrial design is intensely characterized by its proportions, dimensions, outlines and structures
- **Symbols**: can be used to accentuate certain characteristics
- **Surfaces:** characterized by the chosen material, color, shape and used symbols, but further the conditioning of the surface influences the character of the car strongly

This is only a small selection of criteria which should be taken into consideration concerning vehicle dynamics as they influence the components, the driving behavior and furthermore the visual perception. The industrial design is also interdependent to the vehicle class, brands or vehicle concepts. Vehicle concepts thereby can exemplarily be divided into limousine, station wagon, cabriolet, cross-country vehicle, sport-utility-vehicle, coupé, roadster, etc.

This chapter has shown that very different perspectives on the technical characteristics concerning vehicle dynamics can be shared. The overview gives an idea of the high interdependency within and in-between the driving behavior, the corresponding technical parameters, components, industrial design and further mentioned aspects. Thus, it is quite challenging to design a car in respect to the customers' perception. However, being aware of the different perspectives on vehicle dynamics helps to select the aspects which should be taken into consideration adapting vehicle dynamics in an integrated way.

3 EXISTING APPROACHES TO MAP SUBJECTIVE PERCEPTION OF VEHICLE DYNAMICS TO TECHNICAL CHARACTERISTICS

3.1 Variety of approaches

With the background of technical characteristics described in chapter 2, existing approaches concerning the transfer from the subjective customer perception to the technical characteristics are introduced and described in this chapter. In the past years a lot of research has been carried out in this context.

What most approaches have in common, is that at the start the object of investigation has to be defined. This step can be quite challenging, as on the one hand aspects concerning the subjective customer perception have to be defined and formulated and on the other hand, the set of investigated technical characteristics has to be made up. In the next step the way of data acquisition has to be selected, specified and performed in the context of the chosen objective and approach. Besides driving simulations, data acquisition concerning vehicle dynamics is often performed by driving maneuvers, which are partly standardized in literature. Based on the data acquisition, information concerning the customer perception is correlated to the technical characteristics, which have been recorded during the driving sequence. Thereby, in particular correlation and regression analyses (see section 3.2) play an important role. Still, further approaches to enable the transfer from customer perception to technical characteristics are addressed in this chapter. They are based on the idea of 'artificial neural networks', 'grounded theory' and 'causal models' (see section 3.3).

3.2 Correlation and regression analyses

The correlation and regression analysis is the most frequently used method concerning the transfer from subjective driving perception to objective parameters. According to various existing literature, the layout of the interview should not exceed the maximum of eight test persons and three different aspects concerning vehicle dynamics. The results of the analyses are in particular dependent on the preparation of the method. According to Kudritzki [9], correlation and regression analyses are amongst others subject to following aspects:

- The correlation can be referred to a certain regression which can be linear or non-linear, whereas non-linear usually provide better results.
- There must be distinguished between trained and non-trained test drivers. Furthermore, the physical perception, experiences and ideals differ from person to person. In addition, the time duration of the test plays an important role.
- There is a need to eliminate extremes as far as possible – but with care as the elimination of results with high importance would again lead to worse analysis results.
- There is a need to find a compromise between manageability and quality of the analysis.
- Etc.

Gies [10] points out further aspects which should be considered:

- Test vehicles, which can be assigned to a certain brand, may impact the interpretation of the perceived vehicle dynamics (visual effects).
- If certain characteristics are perceived exceedingly good or bad, the interpretation of other characteristics may be influenced (Halo-effects).
- If test persons use the same car for different analyses, they may get prejudiced in respect to a favorite car.
- Etc.

In order to counteract possible disadvantages of correlation analyses in the context of perceiving vehicle dynamics, Kudritzki [9] points out following aspects:

- Performing pre-tests in order to evaluate the setup of the tests.
- Using a reference-car.
- Incorporating all known interdependencies concerning the researched topic.
- Etc.

As a summary, major challenges using correlation analyses can be seen in the high individuality of the test persons, the high effort of detecting interdependencies, the statistical uncertainty and the limited transferability of results. Further detected correlations may become rapidly obsolete due to innovations concerning safety requirements and control systems. However, one chance is to extrapolate the correlations to define new development goals [11].

3.3 Further approaches

Albrecht [12] focuses in his research on 'Modeling of Comfort Ratings from a Customer's Point of View on the Example of the Automated Start-Up Procedure' which can be seen as an important aspect concerning vehicle dynamics (see 'start-up behavior' in Figure 2). As Albrecht focuses on artificial neural networks besides correlation analyses, this method is shortly presented on the basis of his explanations. Artificial neural networks originate from modeling the nervous system and correspondingly the brain of human beings by simple analogies. Today there is a focus on using and developing artificial neural networks in respect to information technology issues. Based on a period of training, artificial networks are capable to adapt certain specifications due to the input they get. That means in the context of vehicle dynamics that the artificial neural network can adapt certain specifications – e.g. concerning the start-up behavior or the cornering ability – based on data gathered by driving tests and simulations with test persons. According to Albrecht [12] it is important to be aware that commonly it is not possible to deduce certain rules, how the network is interlinked, from a successfully trained artificial neural network. This can be a disadvantage in respect to the transparency of interdependencies within and in-between technical characteristics, driving behaviors and components (chapter 2).

Schulte-Fortkamp et al. [13] consider in their research the approach of 'grounded theory' [14] which originates from social sciences. The approach can be seen as a methodology on a meta-level, which can thus be applied independently of the kind of available data and of certain research disciplines. According to Schulte-Fortkamp et al. [13] 'grounded theory' suggests strict rules for the analysis process and thus, an objective access to the perception of human beings is made available to the analysts. Comparing the results of different analysts who act independently from each other allows the validity of the gained results. Within their research Schulte-Fortkamp et al. used 'grounded theory' in order to understand and evaluate the perception of sound in cars. This approach is again of interest, as the information absorbed by the aural sense also influences the perception of vehicle dynamics.
Further approaches at least mentioned but not described in detail consist in the use of causal models [15] and machine learning [16]. Thereby, the approach of using 'machine learning' shows similarities to the artificial neural networks. Causal models in contrast also resort back to correlation analyses. The goal of causal models consists in reproducing the causal chain from the design parameters of a car to the driver's opinion by splitting it up into singular detailed steps (models) which can be easier correlated and comprehended.

3.4 Summary

Indeed, there are far more existing approaches and methods to map customer perception of vehicle dynamics to technical characteristics than introduced in chapter 3. However, the described approaches give an idea of the plentitude and variety of approaches, which can be applied in this context. Existing methods definitely provide the possibility to understand singular interdependencies. Still, some major challenges in research and industry application remain. On the one hand, most of the approaches can only be applied for a limited area of interest as data acquisition and analysis is too intricate in many cases; e.g. for correlation analyses, test drivers should not be overloaded by too many questions, and to gain data for artificial neural networks a lot of time-consuming training of the networks has to be performed before they can be used. Further, for certain approaches specific scientific backgrounds are needed – like psychologists, social scientists, experts concerning information technology, etc.
Thus, there is still a need for an integrated approach to detect and further consider interdependencies at a super-ordinate level (e.g. customer perception concerning many different components, driving behaviors and technical parameters). The next chapter therefore shows which aspects should be taken into consideration in order to get a step further towards an integrated approach.

4 A FRAMEWORK FOR ANALYSING CUSTOMER PERCEPTION OF VEHICLE DYNAMICS

4.1 Objectives of consideration

In chapter 4, a framework for the transfer of the subjective perception of customers to technical characteristics concerning vehicle dynamics is set up based on the information introduced in the previous chapters. In addition, some further aspects are mentioned in this section and also considered in section 4.2 when presenting the framework.
In chapter 1, aspects concerning physical perception of stimuli (visual, aural, etc.) in particular in respect to vehicle dynamics and the high degree of individuality concerning the further information processing have been described. In this context, persons can be assigned according to certain groups. This can for example be done based on following characteristics: age, gender, body dimensions, profession, personal preferences, level of education, driving experience, social milieu, etc. Further, as already described, the preferred driving style can differ a lot from person to person as the following selection of driving styles shows, e.g. according to Luh [17]: defensive, emphasis on comfort, speedy, aggressive.
In chapter 2 and 3 different perspectives on vehicle dynamics have been described. On the one hand technical characteristics referring to vehicle dynamics have been introduced. On the other hand approaches to map those to the subjective customer perception were shown. It became clear that there is a high degree of interdependency in-between industrial design, vehicle concepts, components, driving behaviors, respective technical parameters, etc. Furthermore, the plentitude and variety of approaches for the transfer from subjective perception to technical characteristics have been indicated and are also incorporated in the framework. In addition, standardized test maneuvers should also be considered; e.g. the kind of maneuver (steady-state skidpad testing, double change of lane, load

change response, etc.) and how it is set up (open-loop or closed-loop tests) [1]. An overview about the literature referred to in this paper in order to build up the framework is given in table 1.

Table 1: References corresponding to the framework

<table>
<tr><th colspan="2">Area of interest for vehicle dynamics</th><th>Reference</th></tr>
<tr><td colspan="2">Individual physical perception concerning vehicle dynamics</td><td>Tomaske and Meywerk [5]</td></tr>
<tr><td colspan="2">Driving behaviors</td><td>Heißing and Brandl [6]</td></tr>
<tr><td colspan="2">Components</td><td>Heißing and Brandl [6]</td></tr>
<tr><td colspan="2">Industrial Design</td><td>Kohler [8]</td></tr>
<tr><td colspan="2">Tests and maneuvers</td><td>Mitschke and Wallentowitz [1]
Heißing and Brandl [6]
Kemeny and Panerai [7]</td></tr>
<tr><td rowspan="5">Existing approaches and methods to map technical characteristics and subjective customer perception</td><td>Correlation and regression analysis</td><td>Kudritzki [9]
Gies [10]</td></tr>
<tr><td>Artificial neural networks</td><td>Albrecht [12]</td></tr>
<tr><td>Grounded theory</td><td>Schulte-Fortkamp et al. [13]
Dilger [14]</td></tr>
<tr><td>Causal models</td><td>Jürgensohn et al [15]</td></tr>
<tr><td>Machine learning</td><td>Jürgensohn et al. [16]</td></tr>
<tr><td colspan="2">Driving styles</td><td>Luh [17]</td></tr>
</table>

4.2 The framework

Figure 4 presents the framework worked out based on information provided in the previous sections. In particular, the high interdependency within and in-between the singular areas is emphasized. The framework can definitely be expanded when going further into detail for the different disciplines. Further, many aspects concerning a broader range of environmental issues of vehicle dynamics (as traffic situation, infrastructure, etc.) are not directly addressed. Nonetheless, the presented framework allows an overview on factors relevant for transferring subjective to objective characteristics concerning vehicle dynamics – for research and industrial application. Further, the need for interdisciplinary scientific work is demonstrated, in order to better understand the relationship between customer perception of vehicle dynamics and technical characteristics in an integrated way.

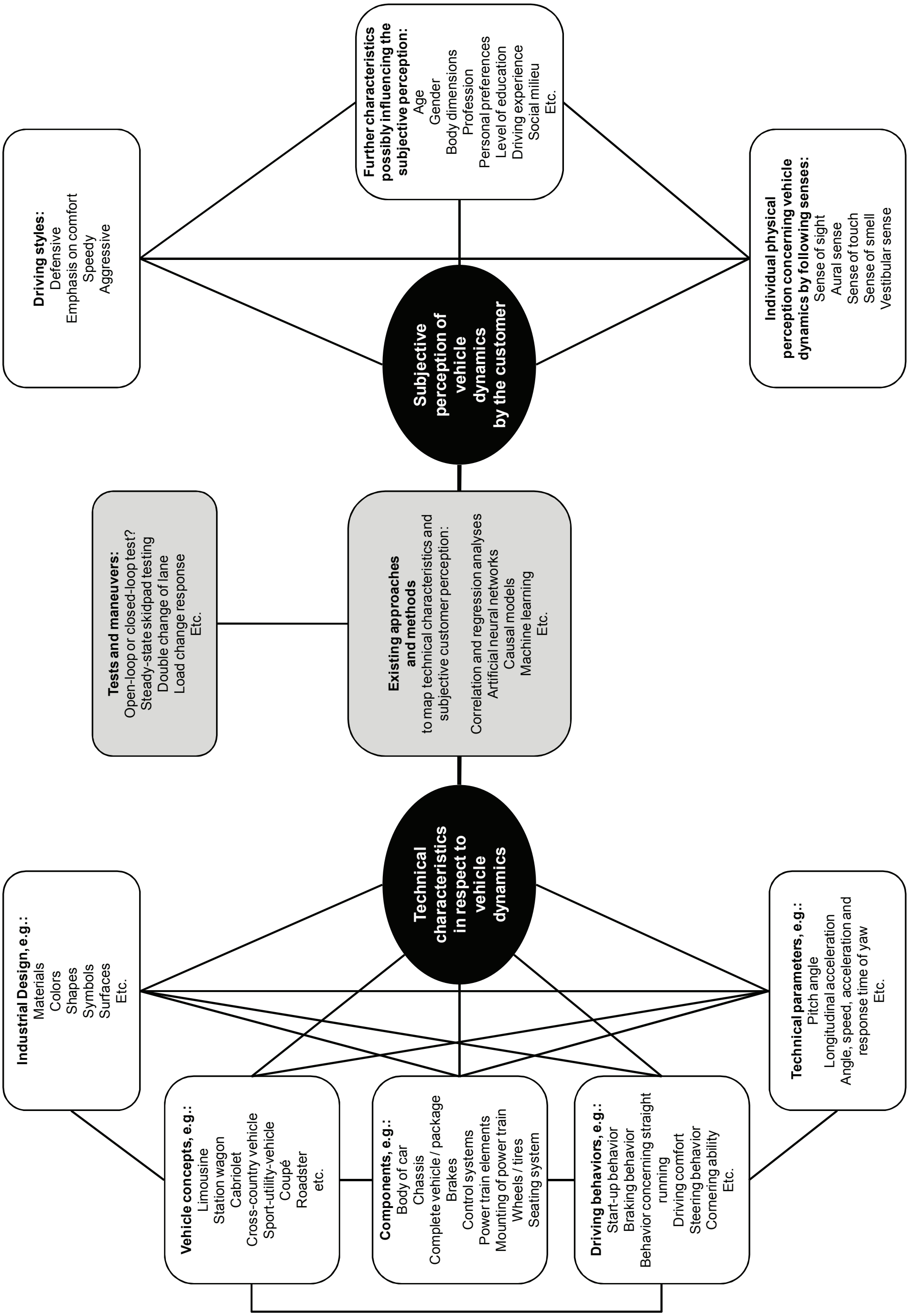

Figure 4: Framework for the transfer of customer perception of vehicle dynamics to corresponding technical characteristics

5 CONCLUSIONS AND OUTLOOK

5.1 Conclusions

Due to today's global market issues, OEMs in automotive industry are forced to maintain existing and to create further unique selling points. Thereby, vehicle dynamics provide promising starting-points in automotive design. But to find the appropriate technical set-up of vehicle dynamics, the subjective customer perception of vehicle dynamics has to be understood and transferred to technical characteristics. In the past years various research projects have been carried out and documented in literature. However, most approaches focus only on singular relationships between the customer perception and objective technical characteristics due to the high complexity in data acquisition and analysis. To support future research projects in approaching vehicle dynamics in an integrated way, this paper presents a framework taking different perspectives on the topic into account. Thereby, in particular technical characteristics, aspects referring to the subjective interpretation of vehicle dynamics and approaches to map those domains were focused.

The pursuit of approaching the topic in an integrated way shows a variety of advantages in respect to the competitive behavior of OEMs. Therefore, it is important to shed further light on the multitude of interdependencies in the network of technical characteristics in the context of subjective perception of vehicle dynamics. This helps to meet customer requirements more sophisticated. As a consequence companies would be able to avoid unintended change propagations in the design process. Further, the design process as a whole can be improved in respect to the points of time to consider certain requirements from subjective customer perception. Nevertheless, an appropriate balance of effort and benefit describes a major criterion for future industrial application. This can only be achieved by widening the scope (e.g. by means of a framework) and then by focusing on key factors – thereby being aware of potential interdependencies.

5.2 Outlook and further work

Further work in this context is suggested, as many needs cannot be satisfied yet. Therefore some options for future tasks are described. A well known methodology which is frequently applied in (automotive) industry in the context of assigning customer requirements to technical characteristics is Quality Function Deployment (QFD) [18]. Therefore, a next step consists in combining the presented approaches and aspects in respect to vehicle dynamics to the singular stages of QFD. From the engineering design perspective, considering QFD could also help to increase the level of transparency concerning an integrated understanding of vehicle dynamics.

In order to appropriately apply the presented approaches, scientists from different disciplines need to work together. Pursuing an integrated approach, this becomes even more relevant as the more perspectives an approach considers the more various the required research disciplines are. Thus, another point of near future work is to expand the presented framework in respect to different sciences which should be considered for certain research questions and how the different disciplines should work together: for example, to properly implement artificial neural networks, specialists from information technology should be integrated in the research team; another example arises in the use of causal models – thereby, medical and ergonomic scientists are capable to build the possibly required models of the biomechanics of human beings.

Finally, in order to increase transparency concerning an integrated understanding of vehicle dynamics, it is suggested to analyze interdependencies within and in-between the subjective and technical characteristics by using methods dealing with structural complexity, e.g. by applying Design Structure Matrices (DSM), Domain Mapping Matrices and Multiple-Domain-Matrices (MDM) [19].

REFERENCES

[1] Mitschke M. and Wallentowitz H. *Dynamik der Straßenfahrzeuge.* 2004 (Springer, Berlin).
[2] Kiencke U. and Nielsen L. *Automotive Control Systems. For Engine, Driveline, and Vehicle.* 2000 (Springer, Berlin).
[3] Jazar R.N. *Vehicle Dynamics: Theory and Application.* 2008 (Springer, Berlin).
[4] Petiot J.-F. and Yannou B. Measuring consumer perceptions for a better comprehension, specification and assessment of product semantics. In *International Journal of Industrial Ergonomics*, 2004, 33, 507–525.
[5] Tomaske W. and Meywerk M. Möglichkeiten zur Vermittlung von Fahreindrücken mit Fahrsimulatoren. In *Becker K. (Ed.): Subjektive Fahreindrücke sichtbar machen III,* 2006 (Expert, Renningen-Malmsheim).
[6] Heißing B. and Brandl, H.J. *Subjektive Beurteilung des Fahrverhaltens.* 2002 (Vogel Verlag, Würzburg).
[7] Kemeny A. and Panerai F. Evaluating perception in driving simulation experiments. In *Trends in Cognitive Sciences*, 2003, 7(1), 31-37.
[8] Kohler T. *Wirkungen des Produktdesigns, Analyse und Messungen am Beispiel Automobildesign*, 2003 (Deutscher Universitäts-Verlag, Wiesbaden).
[9] Kudritzki D. Möglichkeiten der Objektivierung subjektiver Fahreindrücke. In *Becker K. (Ed.): Subjektive Fahreindrücke sichtbar machen,* 2000 (Expert, Renningen-Malmsheim).
[10] Gies S. and Zelkjko M. Merkmale der subjektiven und objektiven Beschreibung. In *Becker K. (Ed.): Subjektive Fahreindrücke sichtbar machen,* 2000 (Expert, Renningen-Malmsheim).
[11] Meyer-Tuve H. Modellbasierte Analyse von subjektiven Fahrdynamikbewertungen. In *Becker K. (Ed.): Subjektive Fahreindrücke sichtbar machen III,* 2006 (Expert, Renningen-Malmsheim).
[12] Albrecht M. *Modeling of Comfort Ratings from a Customer's Point of View on the Example of the Automated Start-Up Procedure.* 2005 (IPEK, Karlsruhe).
[13] Schulte-Fortkamp B., Genuit K. and Fiebig A. Benchmarking – Ein Challenge für die subjektive Evaluation. In *Becker K. (Ed.): Subjektive Fahreindrücke sichtbar machen III,* 2006 (Expert, Renningen-Malmsheim).
[14] Dilger M. *Grounded Theory – Ein Überblick über die charakteristischen Merkmale.* 2000 (Freie Universität Berlin).
[15] Jürgensohn T., Willumeit H.-P. and Irmscher M. Fahrermodelle als Hilfsmittel zur Objektivierung von subjektiven Bewertungen der Fahrbarkeit. In *3. Berliner Werkstatt Mensch-Maschine-Systeme 1999.* (VDI Fortschrittbericht Reihe 22, VDI-Verlag Düsseldorf 2000).
[16] Jürgensohn T., Müller W. and Scheffer T. *Verbesserte Methoden zur Objektivierung von subjektiven Bewertungen des Fahrverhaltens.* 1996 (Research Report, Technische Universität Berlin).
[17] Luh A. *Untersuchung des Einflusses des horizontalen Sichtbereichs eines ACC-Sensors auf die Systemperformance*. 2006 (Engineering Department, Darmstadt).
[18] Akao Y. *QFD – Quality Function Deployment.* 1992 (Moderne Industrie, Landsberg/Lech).
[19] Lindemann U., Maurer M. and Braun T. *Structural Complexity Management: An Approach for the Field of Product Design.* 2008 (Springer, Berlin).

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