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CUSTOMER FOCUSED REQUIREMENT ENGINEERING AND SYSTEM DESIGN FOR PLUG-IN HYBRID ELECTRIC VEHICLES (PHEV)

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ABSTRACT

This paper focuses on the quality of requirements dependent on the level of system abstraction. Chosen example is the design of a Plug-In Hybrid power train. The requirements to specify the scaling of the high voltage storage (HVS) for Plug-In Hybrid vehicles (PHEV) is the focus of this paper.
The shown approach discusses important quality characteristics of requirements to answer the needed information and system quality and to identify the required information for the system scaling. Therefore, the system level PHEV is abstracted in an appropriate way to merge it with the available customer data set. The abstraction and a concluding description of the requirement space based on the "Münchener Produktkonkretisierungsmodell" is presented. Furthermore, the recorded data are prepared to derive the required information for the system scaling.
The approach offers a methodology to integrate a customer behavior in the early stage of product design. Goal is to rise in this case the energy efficiency of the system to offer the customer a power train with reduced fuel consumption.

Keywords: requirements, user centred design, automotive development

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1 INTRODUCTION

Central question of this paper is: How can functional requirements based on the customer behavior be integrated in the early stage of a system development process to increase the efficiency of a designed system?

The ability of an increase in energy efficiency to add value to a system is strongly correlated to the customer's behavior and use of the system. This is particular true for hybrid powertrains.

The electric engine substitutes particular operating points of the combustion engine (ICE) to increase the energy efficiency of the whole system and reduces the fuel consumption of the ICE. The need to increase the energy efficiency and decrease fuel consumption is based on not only legal but also corporate motivations. But in order to realize these benefits there must be an overlap between the engineered operating area of the electric system and the area in which the customer actually operates the system.

Therefore requirement engineering is a crucial step in the design of systems. Customers ask for systems which fulfill their needs, but the customers do not know what they can expect from new technologies. This disparity can be solved with help of appropriate requirement engineering, allowing the system design to better serve the needs of the customer, thereby improving the usability of the system for the customer. In this case, the usability is quantified as the high energy efficiency but can also incorporate further advantages such as reduced cost or lower taxes. In general system usability can be raised through customer adapted system scaling. In the case of energy efficiency, the consideration of customer data is a necessary step since the points of operation that are dependent on user behavior must correlate to the design parameters of the system in order for the system to be effective. In this way, recorded customer data sets can help to specify requirements particular for new system technologies.

In the early stage of system development the quality of requirements has a significant role. In the early stage of the system development process the detailed description of the technical system does not exist and the existing data about the customer behavior can help to connect customer functions with technical system parameters.

Figure 1 shows the presented approach of this paper to appropriately scale a system for a customer by using the customer behavior and the new technology's system functions as the initial input. To realize a maximum system benefit, it is necessary to transform the requirements and the system modeling to a similar level of abstraction. The similar level of abstraction serves to merge the requirements of the customer with the system parameters. In the next step, requirements for system parameters and system functions can be defined. The procedure is repeated on different level of abstraction. The focus of the approach is the system abstraction and the ability of requirement engineering to integrate customer specific requirements in the early stage of system development.

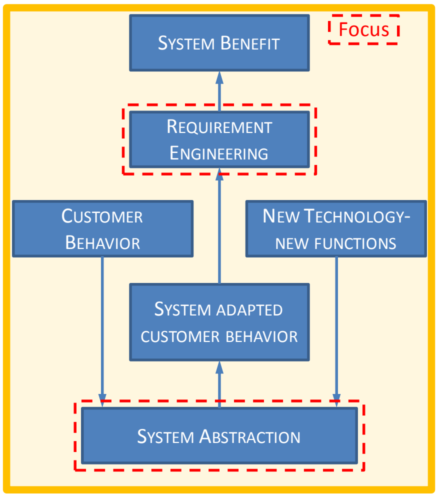

Figure 1 schematic approach

2 STATE OF THE ART

The two relevant fields for this approach are the system abstraction and the requirement engineering with the focus to specify the requirements for system parameters and system functions with help of the available data set of customer data records.

2.1 Requirement quality attributes

According to Balzert et al. (2009) the solution view and a problem view are dependent on each other. If it is not possible to solve a problem, the problem has to be modified to solve it. This is an iterative procedure which can be repeated on different levels of system abstraction.

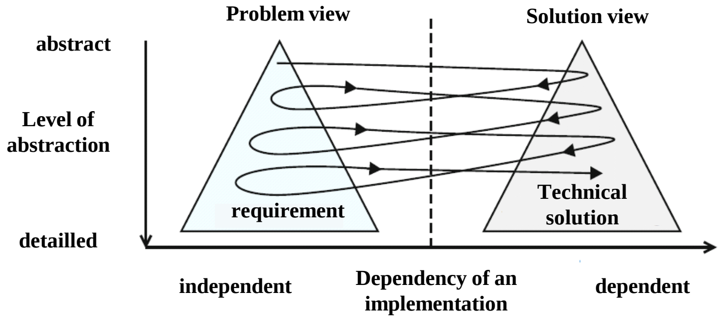

Figure 2 Interaction in between problem- and solution view dependent on the requirement quality according to Balzert et al.(2009)

Balzert et al. (2009) and describes the quality criteria of system requirements. They categorize these quality attributes as functional, reliable, usable, efficient, maintainable and portable. In the following, important criteria are listed with their significance with respect to a PHEV.

- Suitability (functionality) – capability to offer adequate functions in order to meet a user's goals
  PHEV context: function of an adequate electric driving, capture a specific dynamics, to actualize a certain fuel economy
- Attractiveness (usability): Capability of a system to be attractive for the user
  PHEV context: capability to optimize the fuel economy for a specific type of user
- Time behavior (efficiency): System performance regarding time invariance
  PHEV: Electric Energy Performance regarding changing conditions
- Resource utilization (efficiency): Adequate resource utilization for defined system functions
  PHEV context: defined fuel economy for installed electric range and defined electric speed
- Adaptability: Capability of a system to fit to the surroundings
  PHEV context: Align the electric velocity to varying customer needs

Balzert et al. (2009) describes the requirement engineering in the context of software development. Here the quality of description is well developed and suits to be transferred to other areas. Also Davies et al. (1993) and Partsch (2010) employ the listed criteria to develop requirements.
Rupp et al. (2007) lists "evaluated" as one further quality criteria of requirements. In the context of PHEVs this criteria is important, because an evaluation depends on the given quality of information allowing the evaluation to be relative opposed to being compared to a defined reference or absolute.

2.2 System modeling and abstraction

The added value of system models is according to Sommerville and Sawyer (1997) and Nuseibeh & Esterbrook (2000) reasoned in the number of perspectives in order to analyze a system and identify necessary information.
Focusing on the solution, several models exist to describe the development of the solution starting at the early stage of the system development up to the physical system.
The 'Münchener Produktkonkretisierungsmodell' by Ponn and Lindemann (2011) offers beside other views to concretize or abstract a system dependent on the required system view. This model includes

different levels of abstraction to describe a system on the solution side. The level of system abstractions defines the dependence compared to a technical solution. Every level of abstraction requires appropriate requirements to describe the system. These requirements have to be adapted to the levels of abstraction of the developed system models. In consequence a requirement for the same attribute of a system distinguishes in the quality of the requirement to describe the system abstraction. Ponn and Lindemann (2011) do not detail the requirement space. The difference of a requirement for a detailed or an abstract system level is not specified. To answer a more detailed level of system abstraction, requirements dependent on the level of abstraction have to be developed. The criteria which can be relevant for the level of abstraction of a requirement can be the quality. This quality is described with help of the named criteria of Balzert et al. (2009).

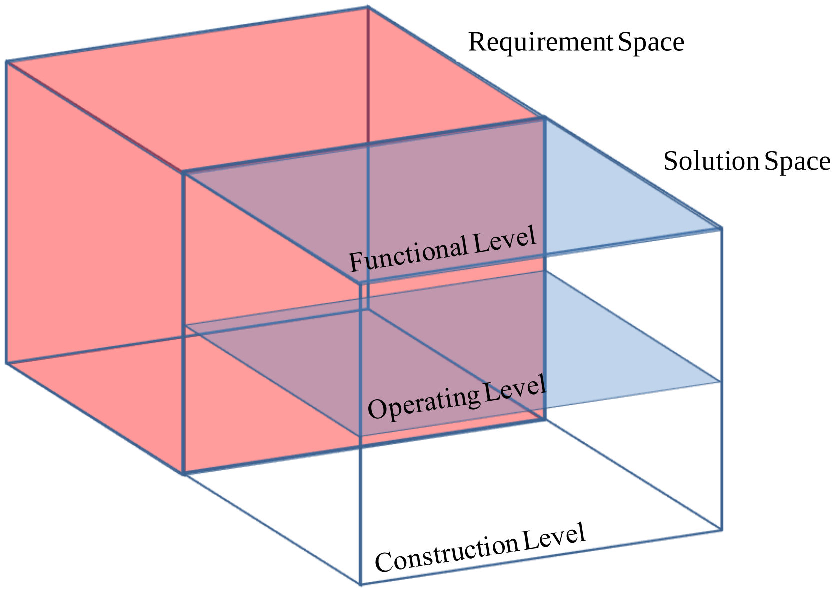

Figure 3 Levels of system abstraction according to Ponn and Lindemann (2011)

2.3 Requirement dimensions in combination with the quality attributes

Requirements for a system normally have many different sources. These sources are all seen as a single dimension in the requirement engineering. Different requirement dimensions serve to define the requirement space. According to Lindemann (2009) these dimensions can be sources like technology, customer, market, competitors or production. These sources serve to describe the system for one single perspective. Dependent on the level of abstraction for the regarded system the requirements have to be adapted, independent to the source. The more information one source can offer the better the system is described. According to Balzert et al. (2009) it is possible to differentiate requirements with the help of the listed quality criteria when analyzing information from a given source. By merging the quality criteria with the different dimensions of requirement it is possible to describe a system on different levels of abstraction. This has two advantages. First, the requirement space is described through different dimensions of requirement sourcing. Second through the different levels of abstraction, it is possible to merge requirements of a source with appropriate system dimensions.

Focus of this paper is to describe the requirement space with the help of different dimensions of requirements. Here the description of the customer is the main relevant dimension. The developed requirements serve to design a customer tailored system with a maximized benefit in fuel economy.

3 ADEQUATE SYSTEM ABSTRACTION AND IDENTIFICATION OF RELEVANT SYSTEM DIMENSIONS

The system abstraction is a necessary step to translate a solution-dependent system description into a non-solution related one. Main requirement dimensions for this approach are the use behavior of a customer and the technical specification of the electrical system. Varying the level of abstraction of these dimensions enables the integration of customer requirements to system requirements to maximize the system benefit. With recorded customer data and the system abstraction it is possible to

define solution independent functional requirements. In this case only the customer behavior is analyzed.
To use the customer data set for the system scaling design, the customer behavior as well as the technical system must be brought to the same level of abstraction. The reasoning behind this is that it is not possible to deduce an electric energy content depending on a prepared customer use profile (e.g. as a velocity profile). For the technical system, relevant technical sizes are taken and abstracted up to a functional level (e.g. the electric energy content is a physical size in kWh). For the customer, the electric energy content is not a relevant parameter. Relevant dimensions for the customer are electric range, electric speed or fuel efficiency. These dimensions are rather system-independent dimensions whereas the electric energy content is a typical system dimension. The goal of the abstraction is to merge the customer behavior and the system dimensions in order to extrapolate requirements for the system definition which is in this case the electric energy content. This is strongly dependent on the quality of the requirements. The requirements are significant for the quality of system description and thus the level of system abstraction according to Ponn. Increasing quality in the single requirement dimensions help to create a more detailed system description with increased quality. Figure 4 shows the three relevant elements for the approach: The requirement dimensions, the quality of requirements and the system abstraction. The requirement dimensions are sources of requirements such as the customer or a competitor. The quality of the system description increases with a more solution dependent system model. Therefore, the requirements have to be adapted to a given solution space in order to meet the needs of a given level of system abstraction. Result of the approach is to describe the developed system models using the appropriate requirements. Purpose of the approach is to use customer data for a user oriented system scaling.

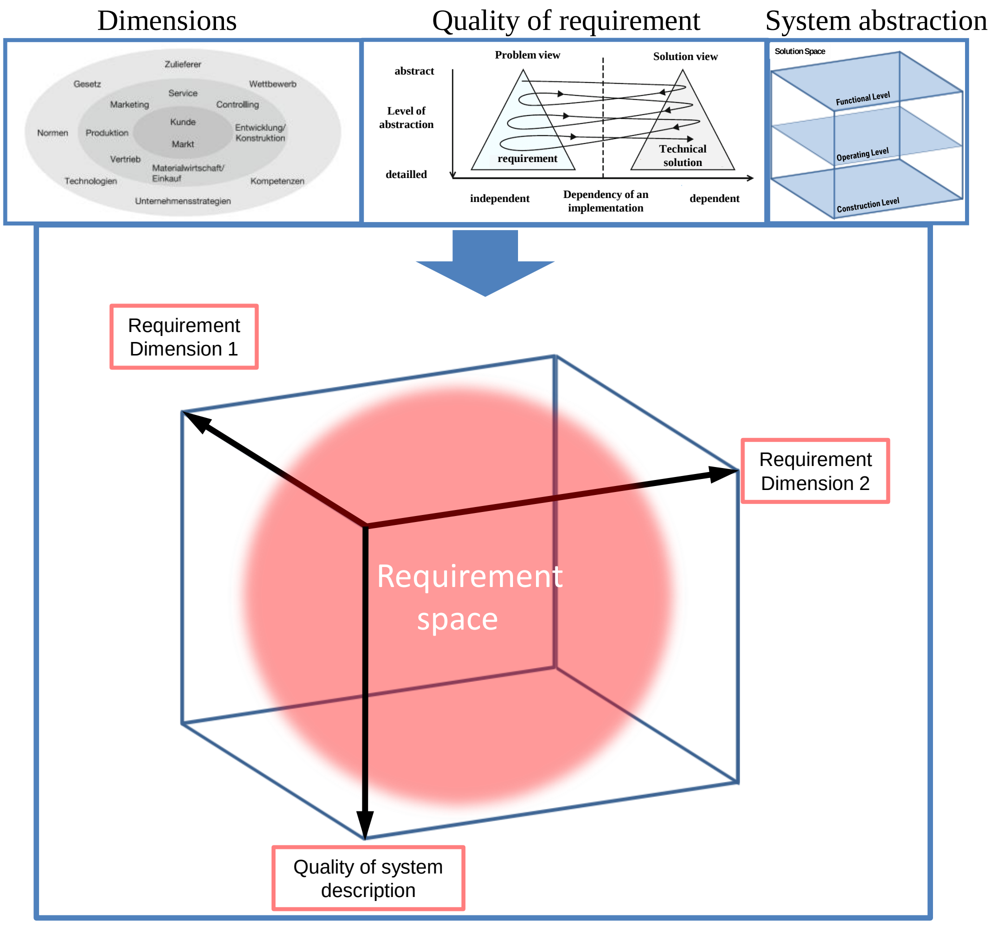

Figure 4 The developed requirement space dependent on different requirement dimensions and a resulting system description (Balzert et al. (2009), Ponn and Lindemann (2011), Lindemann (2009))

4 PREPARATION OF CUSTOMER DATA

The customer data have to be appropriately prepared in order to deliver the required information. The velocity profile is analyzed to obtain the daily distance travelled. With the assumption of charging

once a day, the daily distance is the relevant dimension for the evaluation. This dimension is an important dimension to calculate the system's potential which is dependent on the available electric energy. The potential of the system is the ability and amount to reduce the fuel consumption. Second, it is necessary to identify the ratio of fuel consumption to distance travelled which is dependent on the speed. With help of this size, the maximum possible substitutable energy ratio can be calculated and used to identify different types of customers. The energy ratio is taken because the calculation does not allow an absolute calculation of the fuel consumption because of the system abstraction and the missing information about components. This metric allows for a more effective means of storage scaling.
The measured data has a very high resolution. To handle the data in an appropriate manner, the resolution has to be adapted. So there are three different categories of required sizes:

- Per day
- Dependent on the velocity
- Different resolution

Figure 5 shows the analysis of the daily distance distribution for one customer. As illustrated, the customer has a focal point in using his car at daily distances of 0 up to 20 kilometers.

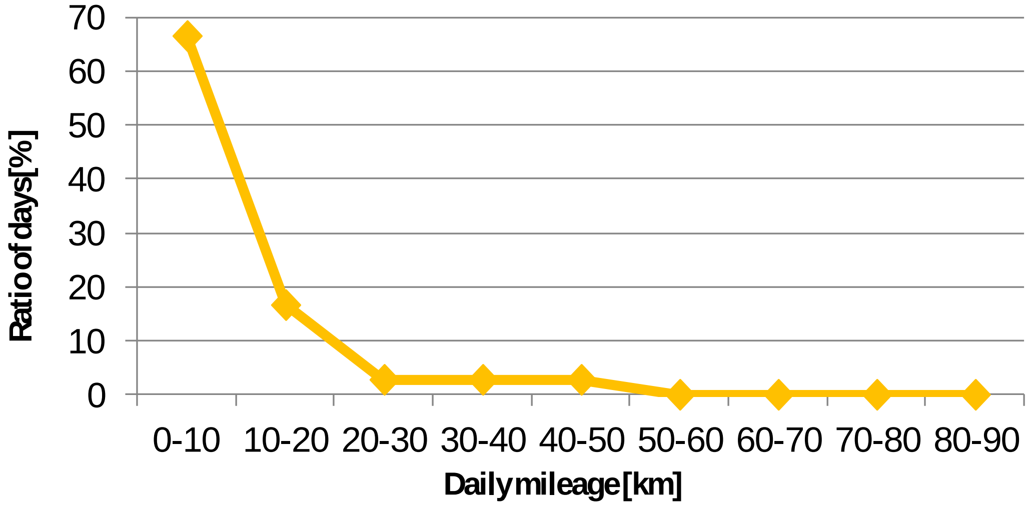

Figure 5 Example of analyzed customer day- distribution of the daily mileage

The identification of customer use behavior is independent to any technical systems. These data sets serve as a base for the identified customer-related requirements independent of a single technical solution.

5 PRESENTED MODEL

This approach aims to clarify the requirement space of the model from Ponn and Lindemann (2011). In comparison to the system levels, the requirement space is not defined. The three dimensions of the system abstraction are variation, analysis and concretization and vie versa. These dimensions are defined in the requirement space of the model from Ponn and Lindemann (2011). Clarifying the requirement for the scaling of the HVS of Plug-In Hybrid vehicle (PHEV), two defined dimensions help to clarify the requirement space and thus to specify single requirements:

- Using behavior of the customer
- Specification of the technical system

In combination these two dimensions create the ability to further ascertain a more detailed description of the system. This more determined description is realized through the increasing quality of the requirements. Also as single dimensions, it is possible to describe the system more deterministically. The requirements are distinguished through their quality. To work with detailed requirements, it is important to provide appropriate information. For the technical system, information from which the solution space can be determined is necessary. On the customer side, it is necessary to describe his behavior in increasing detail. Therefore, a framework has been developed which provides a description of the customer and permits a detailed description to determine the dimension of the regarded system.

The required data are supplied with help of recorded customer data which is transferred into the mentioned description of a customer.
Figure 6 shows the application of the two requirement dimensions; the technical system and customer behavior, on the requirement space. Developing the quality of requirements for the single dimensions permits a more detailed description of the system.

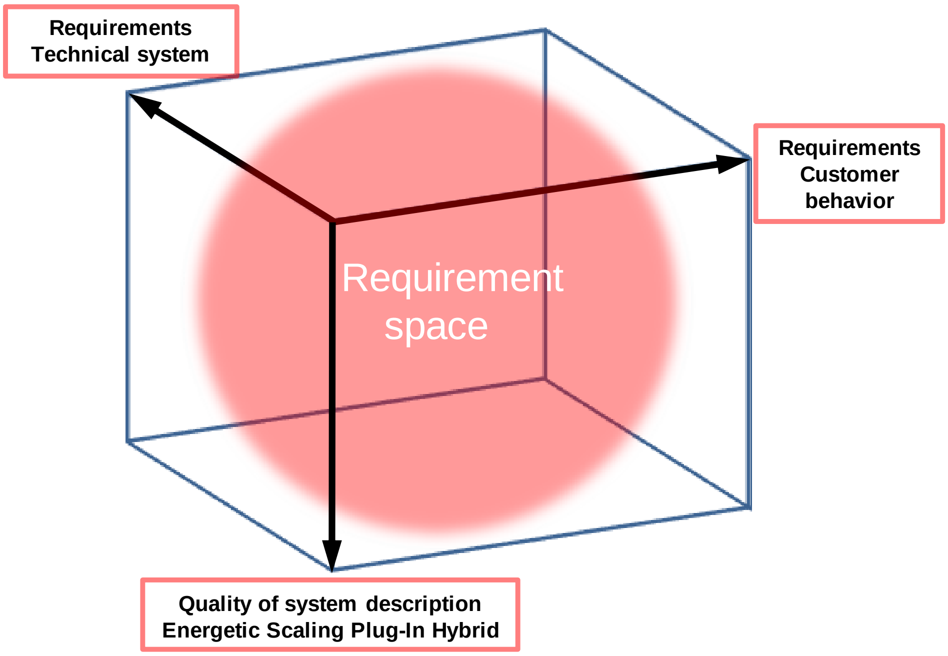

Figure 6 Application of different requirement dimensions on the requirement space

6 APPLICATION OF THE APPROACH

The presented approach of chapter 6 will be applied in chapter 7 using the example of system scaling of the electric power train for PHEVs with the help of recorded customer data.

6.1 Description of the different system levels for a PHEV

The goal of the approach is to merge customer requirements into the system scaling process to maximize the benefit of the installed electric system. The identified requirement dimensions are the technical system and the customer behavior. To implement the presented approach for the energetic scaling of PHEVs, the two dimensions have to be described in different levels. Table 1 shows the suggested three abstraction levels of the two dimensions. The functional level contains a description of a range in both dimensions. This view permits the merger of the distribution of the customer range and the installed electric range in order to deduce a requirement for an installed electric range for a defined benefit. The listed criteria described in Chapter 3 are applied to the various levels of system abstraction. According to the requirement dimension, the requirements are developed. The installed electric range is concretized with the vehicle size to calculate the required electric energy content. This step adds the quality of adaptability to the requirement. In this case the electric range is adapted to a vehicle size.
The abstraction of the technical system as the table shows enables to match the customer requirements with the system requirements. The installed electric range quantifies the physical size energy content on an abstract level. In consequence customer requirements can be integrated into the system design. Continuing this approach it is possible to describe the system in increasing detailed. Through the analysis of the type of customer, and the definition of a vehicle, it is possible to quantify the required energy content on a physical level.

6.2 Implementation of the example PHEV regarded on the functional level of system abstraction

In the following section the presented model is applied at a concrete system level of the PHEV and requirements for the needed electric range are calculated. This example I presented analog by Nies et al. (2012).

The PHEV is defined as an electric power train with an electric machine with a power P and an electric storage with an energy content E. The goal is to quantify the benefit as a function of the system scaling. Therefore the requirement dimension "Technical system" is abstracted on the listed characteristics on the functional level:

- Required electric range x
- With a maximum electric speed v

Table 1 Different levels of system abstraction

Requirement Dimension	Technical System	Customer behavior	Evaluated Dimension
Functional level	Installed electric range Maximum possible electric speed	Distribution of the daily range, distribution of fuel consumption	Potential of fuel consumption (PFC) dependent on installed electric range (km)
Physical level	Vehicle size	Identification type of driver (sport, economy)	PFC dependent on installed electric energy (kWh)
	Climate conditions in combination with vehicle size	Environment, car conditioning, charging behavior	PFC dependent on installed electric energy (kWh)
Component level	Energetic operation strategy	Navigation information	Absolute fuel consumption [l/100km]

On this functional level, the customer specific requirements will be defined.
The dimension "Customer behavior" is specified with help of the following characteristics:

1. Distribution of the daily range
2. Distribution of the fuel consumption

The quality criteria fulfilled by these listed requirements are attractiveness and suitability. This is required for the applicability of the requirements for the calculation model of the fuel consumption benefit of the system. Furthermore, the requirements serve to support the attractiveness through evaluation the customer's benefit of the system.
To determine concrete requirements for a system scaling for a concrete example of customer behavior the benefit of the system is calculated for specific installed electric ranges combined with an electric speed.
Figure 7 shows the approach for an example customer. The diagrams on the left in Figure 7 show the characteristics of the customer. The fuel consumption is dependent on the velocity. For this particular customer, a great part of the fuel consumption occurs in the speed range of 50 km/h. The distribution of the daily distances shows the customer makes mostly trips with short distances up to a range of 30 kilometers. To realize a substitution of fuel consumption, the two characteristics, range of electric speed range and installed electric range have a significant role. Depending on these two parameters, the benefit is calculated for the presented customer behavior. The diagram on the right in Figure 7 illustrates these benefits. As seen for all installed electric ranges, the benefit increases with an increasing electric speed, but is also satisfied when reaching higher velocities. Electric speeds above 150km/h lead to a decreased potential. Installing more electric range brings additional benefit, but this benefit decreases with increasing electric ranges. Furthermore, the additional installed electric range does not bring the same incremental benefit. For example with an electric speed of 60km/h the additional benefit with an electric range of 20km instead of 10km or 10%, whereas 10km of electric range brings 40% more system benefit. To derive requirements for the system scaling, further requirement dimensions like costs can be considered to optimize the ratio benefit to cost. But even without additional dimensions of requirements the following recommendations can be proposed:

1. The satisfying benefit with an increasing velocity can define the electric speed range

2. The additional benefit between two different installed electric ranges can be a criteria to install more electric range or not. An important aspect of this example is that it is possible to quantify the benefit of a system and thus to scale it appropriately for the customer.

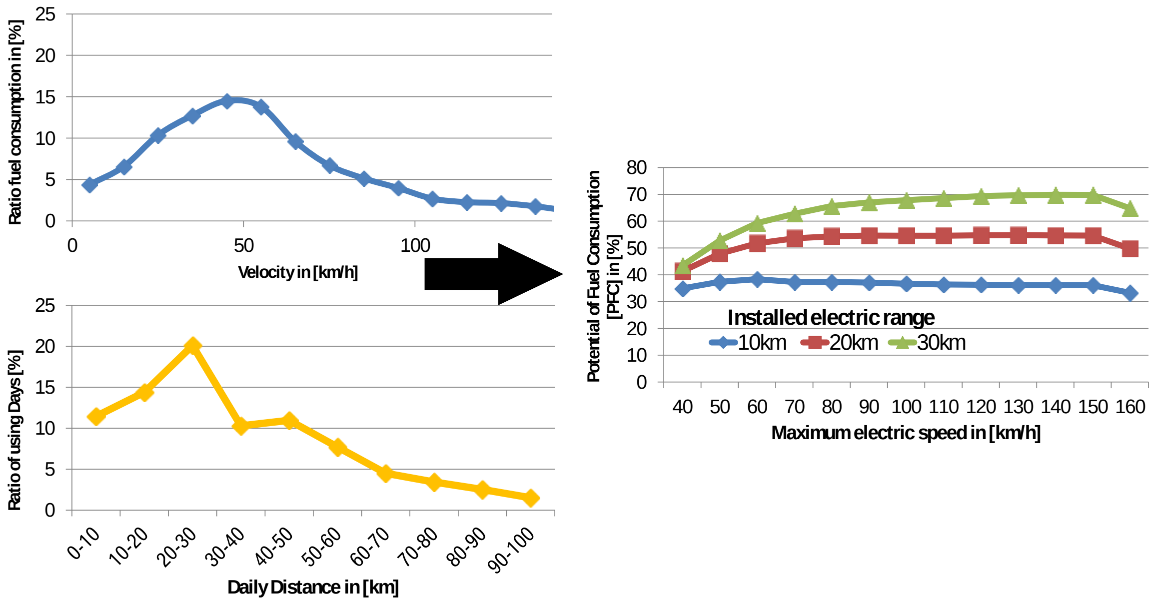

Figure 7 Application of the presented approach

7 CONCLUSION

When designing systems, it is very important to use an established methodology for requirement engineering. According to van Lamsweerde & Letier (1998) requirements are often a result of ideal assumptions. In consequence, there is the necessity to develop relevant requirements. By integrating requirements based on customer behavior, the system efficiency for the customer of a system can be increased. For the software industry customer individual requirement engineering asks for high quality requirements (van Lamsweerde (2004)). Facing this challenge, a precise definition of the requirement space serves as a methodology to integrate requirements resulting from recorded data of customer behavior. With the help of different dimensions of requirements combined with a various number of system level abstractions the consideration of customer data sets for the system scaling is realized. Customer requirements are one dimension, among other dimensions like legal aspects which are not focus of this paper. This approach allows the scaling of a system for a specific customer behavior in an early stage of the product development. Therefore different levels of system abstraction are defined. These levels distinguish in degree the system models and the requirements are dependent on a technical solution. In the presented example the functional level, the operating level and the construction level are used. By applying the requirements of the customer behavior to the different system models, the solution can be specified on different abstraction levels. Thus an estimation about the system efficiency is possible and serves to design a more efficient product. During the advancement in the design process many other dimensions of requirements must be implemented and can cause a conflict of goals. The presented methodology does not offer an opportunity to simultaneously resolve these conflicts and reduce the time of the development process. Furthermore it is necessary to have data about the customer behavior of a product.
The main contribution of this approach is to integrate customer behavior in the early stages of product development with the goal to increase the energy efficiency and thus the added value for the customer.

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