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REQUIREMENT- AND COST-DRIVEN PRODUCT DEVELOPMENT PROCESS

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1 Introduction

This paper presents an approach, which enables a cost and requirement driven control of the design process. It is based on the concept of Property-Driven Development (PDD) [WeWD-03]. Integrated in the approach are well established tools like Target Costing and Value Analysis as well as methods of design for requirements.

In the authors' approach, the product development process is controlled by an ongoing target/actual ("Soll/Ist") comparison between target properties and the state of properties currently achieved. For each property, depending on the fulfilment, quality ratings from the customer's point of view are assigned. The aim of the product development process is the maximisation of the sum of these quality ratings. This aim can be realised based on the PDD approach, because it supports the engineer/designer by explicitly representing the interdependencies between the properties (that have to be optimized) and the characteristics that influence these properties.

2 Initial Situation

Nowadays, complex products are mostly developed and designed in teams. These teams often include experts of different departments or companies: Several suppliers and engineering service providers are integrated into such design tasks, which are performed sometimes even across the borders of nations or continents.

The involvement of a large and heterogeneous group of persons in one co-operative development and design project requires exact planning and control of the process in order to coordinate activities and plan the cost and time schedules in advance. Some larger companies try to plan the development process with the help of predefined activity schemes (for example event driven process chains [Sche-94]). However, these rigid schemes do not really fit to the dynamic and creative character of development processes with their numerous iteration loops, decision situations and jumps.

In addition to these approaches, which try to make the overall product development process more efficient, some particular methods have been introduced in order to force design for cost. They come partly from the field of engineering sciences and partly from the field of business administration, e.g. Target Costing [Glas-02] or Value Analysis [VDI-95, VDI-00].

In the opinion of the authors, these methods are not suitable to support or guide the design process if used exclusively.

3 Property-Driven Development/Design (PDD)

Since the proposed framework builds upon the Property-Driven Development (PDD) approach this chapter briefly introduces the PDD. A more detailed description can be found in [WeDe-02, WeDe-03, WeWD-03].

The concept of PDD is mainly based on a clear distinction between characteristics (C_i) and properties (P_j) of a product:

- **Characteristics (C_i)** describe the structure, shape and material consistency of a product. They can be directly influenced or determined by the designer (e.g. material, shape, dimensions, etc.)
- **Properties (P_j)** describe the product's behaviour (e.g. weight, safety and reliability, aesthetic properties, but also things like "manufacturability", "assemblability", "testability", "environmental friendliness" and cost of a product). They can **not** be directly influenced by the designer.

Between characteristics and properties, their exist two main relations, which correspond with the two main activities in the product development/design process:

- **Analysis:** Based on known/given characteristics of a product, its properties are determined or – if the product does not yet exist in reality – predicted. Analyses can, in principle, be performed experimentally (e.g. using physical prototypes) or "virtually" (e.g. using digital simulation tools).
- **Synthesis:** Based on given, i.e. required properties (**PR_j**) the product's characteristics are determined. Synthesis is the main activity in product development: For the customer mainly (only?) properties are relevant, thus the development/design process begins with a list of required properties. The engineer's task is to find appropriate solution patterns and determine/assign their respective characteristics in such a way that the required properties are met to the customer's satisfaction.

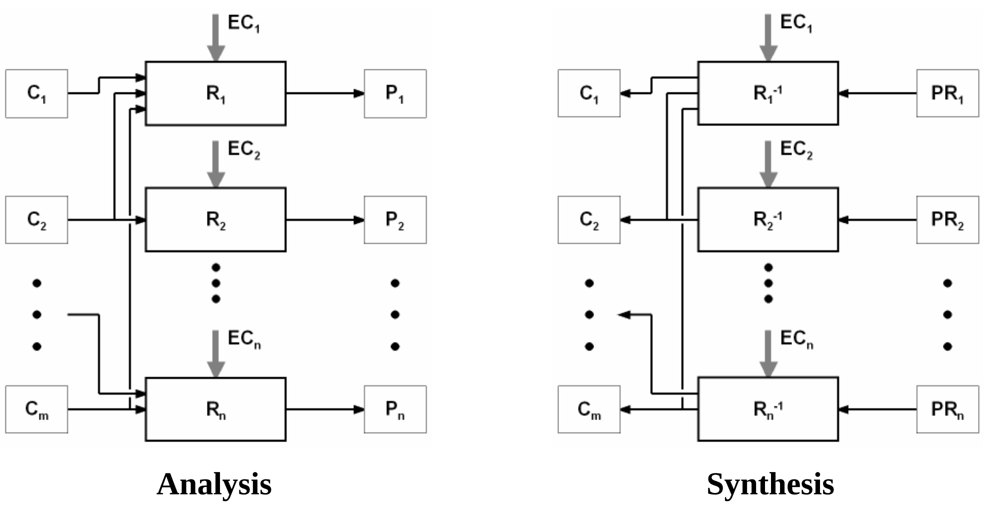

Figure 1. Characteristics (**C_i**), Properties (**P_j**), Required Properties (**PR_j**) and the Relations (**R_j**) connecting both

Characteristics and properties are connected by relations ($\mathbf{R_j}$) in a network like structure (see Figure 1). These relations describe the interdependencies between characteristics and properties and show how they are influencing each other.

4 Existing Methods

There exist several well-established methods and models to consider cost, quality and customer requirement issues in the product development process. In the following subsections, some will be listed and briefly described.

4.1 Kano-Model

The Kano-Model, developed by Prof. Kano in the 1980s, is based on concepts that describe the quality perception of the customer [Berg-93]. The initial idea of this concept is to correlate the level of performance in certain required properties of a product with the "satisfaction level" of the customer. Figure 2 shows the fundamental concept of the Kano-Model.

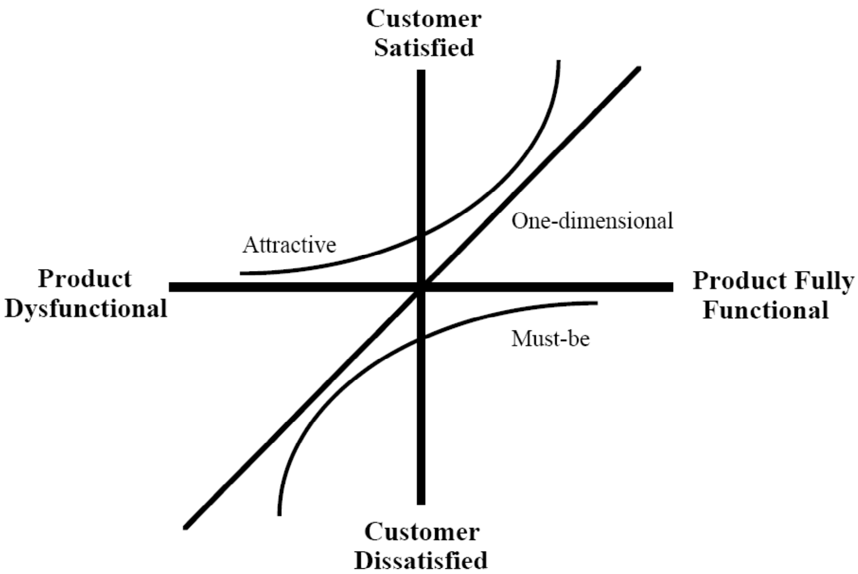

Figure 2. The Kano-Model [Berg-93]

On the horizontal axis of the Kano-model, the level of performance in a required function is plotted. On the vertical axis, the level of customer satisfaction is displayed. Kano distinguishes between three different classes of correlations between the fulfilment of the requirements and the customer satisfaction:

- The first class is the One-dimensional class, which is characterised by a linear correlation between the level of performance and the customer satisfaction. An example is the average mileage (miles per gallon fuel consumption) of a car: The higher the mileage, the higher customer satisfaction with regard to this property.
- The second class is made up by requirements a product has to fulfil compulsory. These are displayed in Figure 2 by the Must-be-curve. This curve represents the fact, that the customer expects the fulfilment of certain requirements and the existence of certain functions. An example are the brakes of a car: The pure existence of an adequate brake equipment which ensures a retardation, which is at least conform with legal requirements, is expected

by the customer and does itself not lead to great customer satisfaction. Or put the other way round: An inadequate brake equipment would be a failure that is not tolerable and leads to dissatisfaction of the customer.

- The third curve in Figure 2 is named Attractiveness. This curve correlates customer satisfaction and the degree of fulfilment of requirements or properties, respectively, which the customer has not expected. An example for this kind of correlation are enhanced functionalities of a mobile phone, that are not connected with the core functions of the phone and the are not expected by the customer, for example a charge free weather or news hotline. The higher the additional benefit of these services, the higher the customer's satisfaction with this additional functionality.

[Berg-93] shows possibilities to perform customer interrogations to determine requirements and to rank them into one of the three presented classes. Recapitulating, the Kano-Model can be seen as a valuable support to determine the relevance of certain product properties in the eyes of the customer.

4.2 Target Costing

Target costing was developed in the 1960s in Japan [Glas-02, Tana-89]. This method is especially used by the financial departments of companies to control (limit) the production costs. The Target Costing method breaks down the planned retail price to the individual cost of each component of the product according to the preferences of the customers. Basically, Target Costing consists of the following steps:

- Determine the possible retail price for a product with a certain functionality and quality;
- Subtract margins (incl. all costs) in order to find the allowed maximum cost of production;
- Identify main functionalities and their importance/value for the customer;
- Analyse, which components of the product facilitate the identified functionalities to what extend;
- Distribute the share of the allowed cost of production to the components according to their contribution to the main functionalities and the importance of these functionalities.

Thus, the Target Costing method puts the needs of the customers (or better: the things the customer is willing to pay for) first. Only components that meet the target price will be realised. This method helps to focus on the functionalities, which are important for the customer. Functionalities, which are not so important for the customer (i.e. the things he/she is not willing to pay for) are not realised in the first place.

There are a few drawbacks to Target Costing: In order to exactly determine the possible retail price, the customer must already have a good idea of the appearance and functionalities of the future product. This is especially complicated if the product is a completely new design or if new (partial) solutions are used in known products (e.g. ABS in an automobile). Target Costing uses the allowed cost per component as exclusive control factor. It is not taken into account that for technical reasons some components may be realised at a much lower cost than calculated while others, which are very important but not noticed by the customer, may be much more expensive than allowed (e.g. components for the active and passive safety of a car). Target Costing does not support the design process itself. It is an analysis/evaluation method, but does not provide any methods for product synthesis.

The fundamental idea of Target Costing is that only the customer decides which functionalities are important for him/her (i.e. which he/she is willing to pay for). In the authors' opinion, this principle can be a helpful guide to aid and control the product development process.

4.3 Value Analysis

L.D. Miles formulated the core of Value Analysis (sometimes also called "Value Management" or "Value Engineering") in the middle of the past century. The "VDI-Zentrum Wertanalyse" carried on with the development of the Value Analysis [VDI-95, VDI-00]. Similar to Target Costing, in this method the allowed total costs of a product are distributed to its individual components, according to their importance to the main functions of the product. In addition, Value Analysis provides some support for the generation (synthesis) and selection of solutions in the design process. For each alternative solution, the total benefit (for the customer) is calculated based on the sum of the values of the different functionalities. The total benefit influences the price a customer is willing to pay for the product. Figure 3 shows the relation between total benefit and the price of a product.

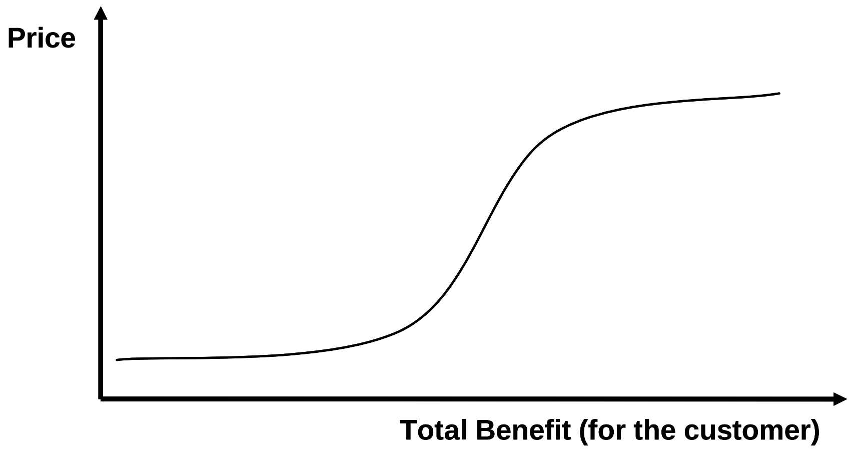

Figure 3. Total benefit - price diagram of the Value Analysis

The optimal solution (according to the Value Analysis method) is the alternative with the greatest difference between costs (production/manufacturing costs) and the attainable retail price as a result of the total benefit of the product. Thus, the optimal solution is not automatically the one which generates the lowest production costs or which allows the highest retail price.

4.4 Quality Function Deployment

The concept of Quality Function Deployment (QFD) was developed by Prof. Yoji Akao in the late 1960s and was introduced into the Japanese industry in 1972 [Akao-92]. In Europe, the QFD concept is applied since the early 1990s. The concept supports the designer by enhancing the quality of the technical system he/she intends to design and to match it to the customer's requirements. In the sense of QFD, the term "quality" means the customer-perceived value of a certain property. The initial point of the product development process in the QFD concept is the table of customer requirements, which contains the quality properties of the product or system as required by the customer. By means of the required quality properties, quality elements are defined, which can be described by so-called quality characteristics that ensure the required properties.

The determination of these quality elements as the actual synthesis step within the product development is hardly supported within this concept. In the authors' opinion, QFD can be applied in a reasonable way, if a more or less known and stable product concept exists. If an adaptation or a variation has to be realised, the QFD concept can be chosen to enhance the quality by correlating the quality requirements of the customer and the characteristics that describe the product. By this, conclusions can be drawn as to which characteristics have to be changed in which way in order to enhance the quality of the product. An interesting element of the QFD approach is that also properties are weighted by their importance for the customer and depending on the quality of competitive products in order to draw conclusions for the enhancement of the product. A similar approach that seems to be applicable, if no initial concept of the technical system to be designed exists, will be presented within the framework for quality and cost driven design in section 5.

4.5 Total Quality Management (TQM) and Design for Quality (DfQ)

Total Quality Management is a company-wide framework, which should ensure a corporate philosophy that is focused on customer satisfaction and quality [Freh-93]. Due to the conceptual character of the framework, no specific guidelines and methods are given, but it can support an atmosphere, where quality and cost-driven design has the first priority. Design for Quality (DfQ) is the application of certain methods like failure modes and effects analysis (FMEA) or fault tree analysis (FTA), which should ensure a quality-compatible design [PBFG-03].

Cuber shows in [Cube-96] the integration of the presented quality methods into a design methodology.

4.6 Quality concept of Andreasen and Hein

The quality concept of Andreasen and Hein is worth a closer look, because it is partially based on TQM and QFD [AnHe-98] and at the same time emphasises the view on the complete lifecycle of the product. They divide the term quality in three categories, which seems to be useful:

- Obligatory qualities, which have to be realised by the product due to its market traditions and the quality of competing products;
- Expectation qualities, which are unique to the company and express its image;
- Positioning qualities, which the company builds in the product as sales argumentation and surprise effect on the market, comparable to the 'Attractive' qualities from the Kano-Model.

Similar to the Kano-Model Andreasen and Hein distinguish between the properties of a product and the customer perception of the quality as a reaction of a certain value of one or more properties (Figure 4).

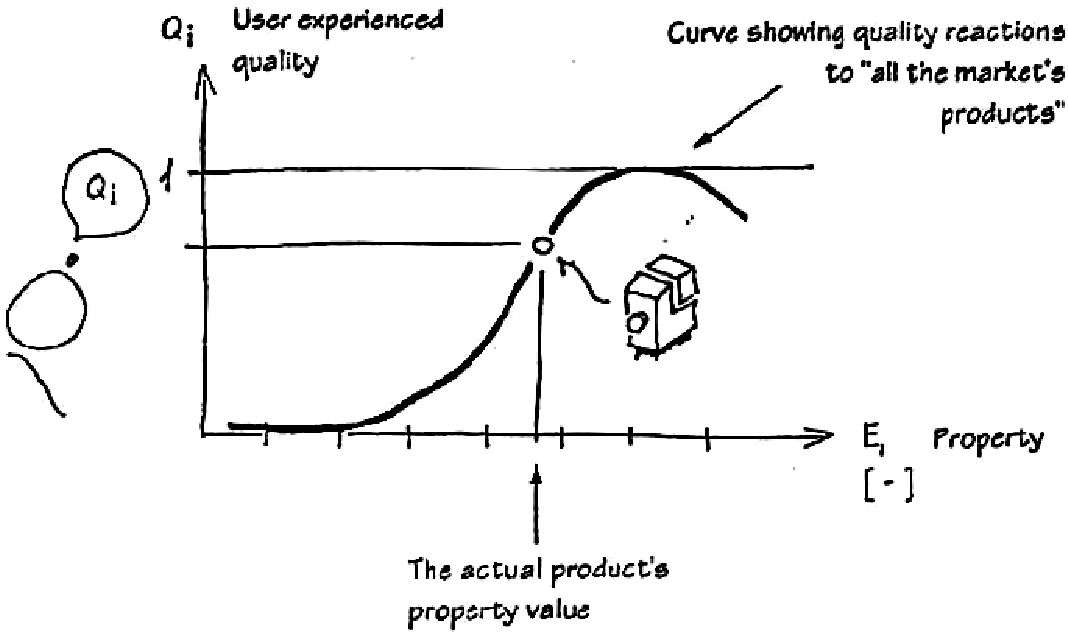

Figure 4. Correlation between properties and product quality [AnHe-98]

Recapitulating, the approach of Andreasen and Hein and also the Kano-Model seem to be suitable to ensure a quality oriented product development, which focuses on the needs of the customer. An integration of these concepts into a framework that is based on the PDD approach seems to be promising. The correlation between certain properties and the impression that the product leaves to the customer can be displayed. This can be an initial point to influence the characteristics of the product by the relations that are displayed in the PDD approach.

5 Framework for the control of the product development process driven by cost and requirements

The main task of the engineer/designer is to develop a product for which a customer is willing to pay a price, which is higher than the total expenditures of the manufacturer for development, production, distribution, etc. of this product. The price the customer is willing to pay depends on the extent to which the product meets the expected properties (look, function, quality, …). This relationship was already described in the context of Value Analysis (see section 4.3) and is summarised in Figure 3.

The bottom line of product development is to maximise the difference between actual expenditures and the possible revenues (price paid by the customer) of a product. Therefore, it is necessary to find a clever way to represent characteristics, which are determined by the designer, and the value of the product for the customer, which depends on the extent to which the product meets the expected properties. This will help engineers to tailor their products to the needs and wishes of their customers, driven by cost and requirements. The concept of Property-Driven Development/Design (PDD), as briefly described in section 3, provides a framework to model the product characteristics, the perceived product properties/qualities and the relations between them. It also allows the integration of accepted methods like Target Costing and Value Analysis.

As already shown in section 3, properties of a product are listed on one side of the PDD model, and the characteristics (**C_i**) influencing the properties on the opposite side. Both sides are connected by the relations, which show the interdependencies between characteristics and properties. The properties must be further differentiated into the desired/required properties ("Soll-Eigenschaften", **PR_j**) on one side and the actual properties ("Ist-Eigenschaften", **P_j**) at a certain time during the development process. The actual properties are discrete values or have to be quantified in order to become discrete values. The required properties can be described with the functionrating-value curves. The functionrating-value curves represent the relation between the extent to which a certain function, quality or property is developed (functionrating) on the x-axis and the value of this function/quality/property for the customer (i.e. the retail price he/she is willing to pay for it) on the y-axis. This relationship can be understood similar to the ones described in the Kano-model (section 4.1) or in the DFQ-approach (section 4.5). Figure 5 depicts the four main types of functionrating-value curves:

- Type I (Figure 5, I) shows a positive correlation between the functionrating (extend to which a certain property is fulfilled) and the share of the price the customer is willing to pay for this specific property. For example, the higher the computing power of a notebook, the higher the price the customer is willing to pay. This type of curve typically has an area with a high gradient because already a small change in the computing power will have a great effect on the value perception of the customer and thus influencing the retail price strongly. Above and below a certain point, the gradient is often much lower because the customers perception does not get any better or worse.

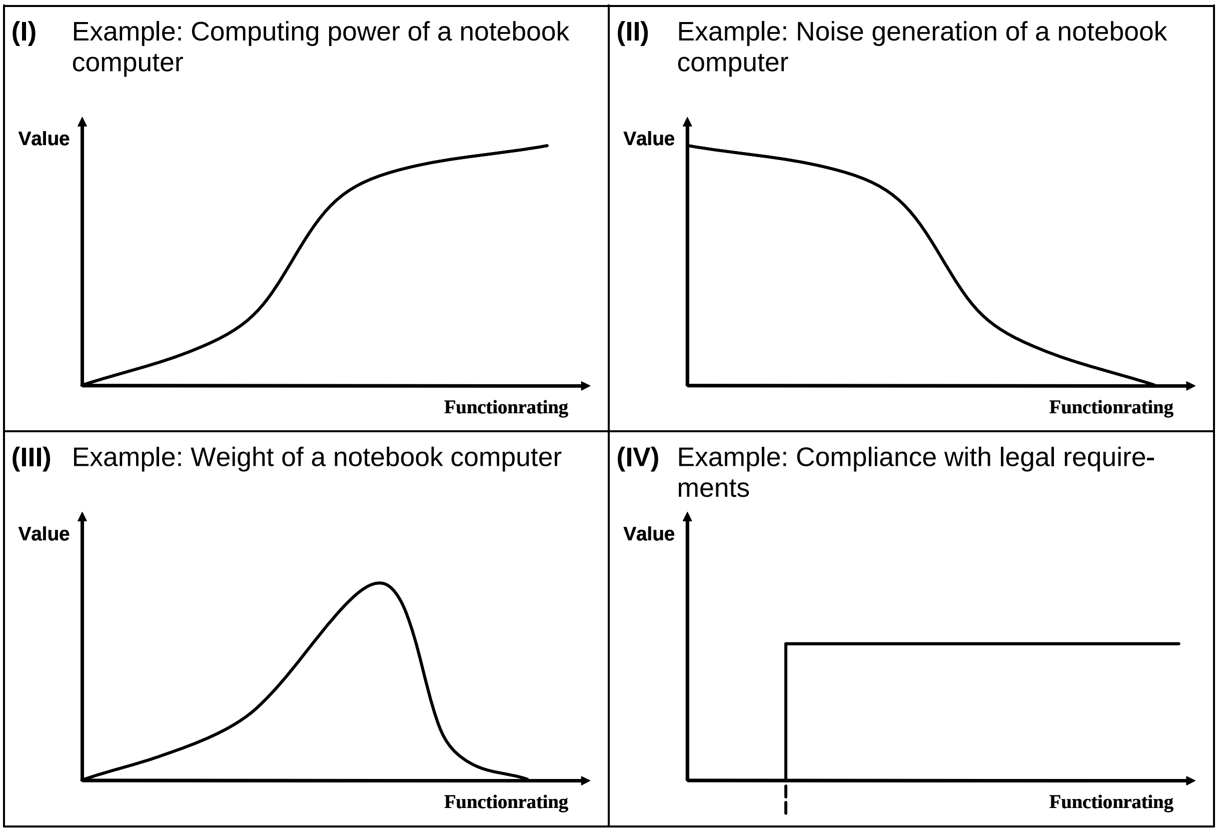

Figure 5. Types of functionrating-value curves

- Type II (Figure 5, II) describes the same relationship as Type I but just inverted. Examples could be the noise generation of a notebook computer or the fuel consumption of a car (the lower the value of the property the higher the price the customer is willing to pay).
- Type III (Figure 5, III) is used if the customer likes a property in a certain peculiarity. An example could be the weight of a notebook computer. If the computer is too heavy, the customer cannot carry it and if it is too light, the customer might think that the computer is a low quality product. In both cases, the customer is not willing to spend as much money for the product as if the weight would be just right. Another example for this type of relation is the force necessary to close the lid of the notebook computer.
- Type IV (Figure 5, IV) describes the influence of "must have" requirements. The compliance with legal requirements such as safety regulations can be described with this type of relation. Only if the legal requirements are fulfilled the customer is willing to pay a certain price for the product. This price does not change regardless how good the legal requirements are fulfilled or even more than fulfilled. If the legal requirements are not fulfilled the customer is not willing to pay for the product at all.

Figure 6 depicts how the designer can use a functionrating-value curve to assess how the extend to which a certain property is fulfilled (functionrating) influences the price a customer is willing to pay for this specific property (value). In the example shown in Figure 6 the designer has calculated a top speed of 200 km/h for a car based on the known characteristics of the actual state of the design. The functionrating-value curve shows, that the 200 km/h top speed result in a value of about 4750 Euro for the customer. Thus, the customer is willing to pay 4750 Euro because the car has a top-speed of 200 km/h. Each relevant property of the car (safety, reliability, space, comfort, design etc.) has its own functionrate-value curve. The sum of the values of these curves is the total price the customer is willing to spend for the entire car.

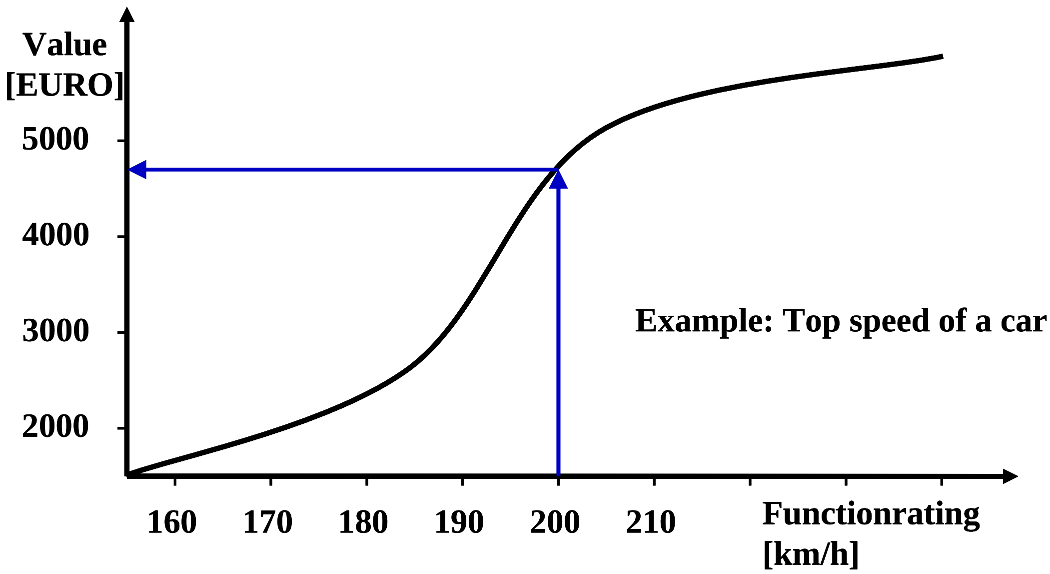

Figure 6. Use of functionrating-value curves

An established way to anticipate the customer's wishes and needs from the field of business administration is the conjoint analysis [Gust-00]. It is an empirical method to evaluate the customer's preferences depending on certain parameter values, which can be seen as properties in the sense of PDD. The representation of the correlation between the customer's preference and the value of a property is realised by certain curves, which are very similar to the functionrating-value curves.

The PDD-approach is able to model the product development process in a very descriptive way. During the product development process, the engineer/designer switches back and forth between synthesis and analysis. In the synthesis cycles, characteristics are assigned in order to realise the required properties. In the analysis cycles, actual properties are determined, based on the assigned characteristics. Figure 7 gives a schematic overview on this interpretation of the product development process.

In the proposed framework, the product development process of a new product follows the basic steps listed below:

- Definition of required properties ("Soll-Eigenschaften", PR_j) in the form of functionrating-value curves. These curves display the needs of the customers.
- In a first synthesis step, some characteristics are assigned by the designer based on the required properties shown in the functionrating-value curves (Figure 7, I)
- In the next step the designer has to determine/predict the actual properties (P_j) based on the assigned characteristics (Figure 7, II).
- The actual properties are charted into the functionrating-value curves (Figure 7, III). The result is the concrete value of a certain property for the customer.
- The total value of the actual combination of characteristics can be calculated by adding up all the single values of the functionrate-value curves of the properties (Figure 7, IV). The result is the total benefit of a certain solution for the customer.
- In the following cycle, the designer aims to raise the total value of the solution. This starts by assigning or modifying characteristics (synthesis step). In the next step, the actual properties and their value for the customer are predicted again, and so on.

The product development process terminates after the determination of all the characteristics and relations needed to calculate the relevant properties and their values for the customer. Only now, it is possible to check the exact position of the actual design on the functionrating-value curves. The relations show with which characteristics a certain property can be influenced and which other properties will be influenced if a certain characteristic is changed.

The position on the functionrating-value curves indicates shortcomings, but also additional potentials of the actual design solution. The intention to eliminate the shortcomings and to use the potentials is the driver of the product development process. It is most effective to optimise those properties, where already a small change in the functionrate will result in a high (positive) effect on the value for the customer (large 1^{st} derivation). This concept supports the typical trade-off decision making, because the total benefits for the customers of different variants (i.e. different combinations of characteristics) can be compared against each other.

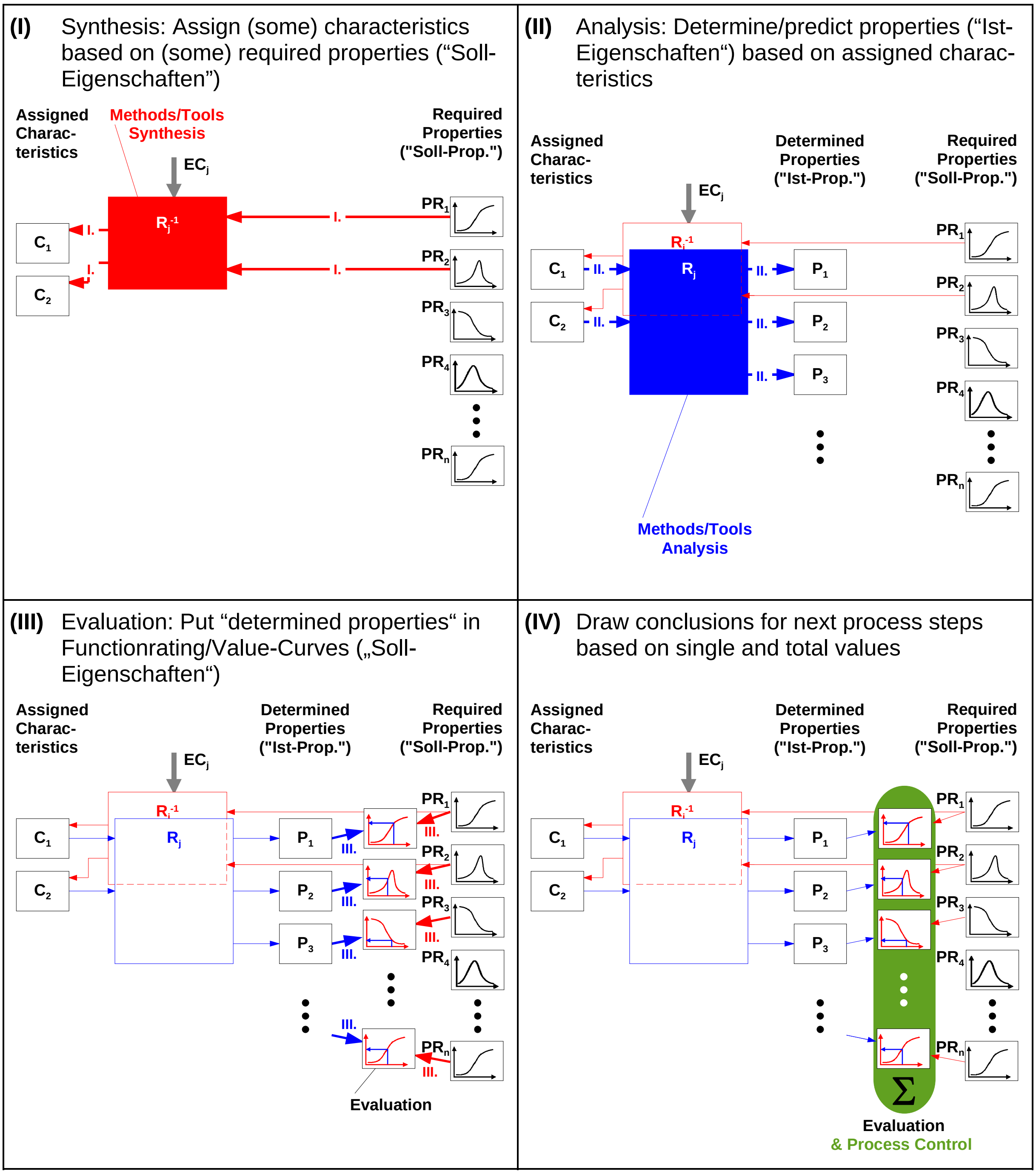

Figure 7. Product development process (schematic)

The explicit modelling of the relations between characteristics and properties in the proposed framework help the designer to find out which characteristics he might change in order to affect a certain property (similar to the QFD method). At the same time, the designer can predict the consequences a change of a characteristic will cause to the properties.

6 Conclusion

The concept of the Property-Driven Development (PDD) can be used as a framework to explicitly model and display the product structure and the relations between the product describing characteristics and the product qualities (properties) that are perceived by the customer. Furthermore, it is able to integrate various methods like the concepts of Target Costing and Value Analysis. In addition, methods from the field of other engineering disciplines like QFD are suitable to connect product characteristics and quality perception of the customer within the PDD approach.

The framework described in this paper builds a direct relationship between the properties, which are important for the customer, and the characteristics, which can be influenced by the engineer/designer. The values, which the different properties create for the customer, drive and control the product development process. The aim is the development of products with properties creating such a value for the customer, that he is willing to pay a price, which is higher than the cost of development, production, distribution, etc. To maximise the difference between retail price on one side and production costs on the other side is vital for every company.

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