ATTRIBUTES IN INTEGRATED DESIGN ENGINEERING - A NEW WAY TO DESCRIBE BOTH PERFORMANCE CAPABILITY AND BEHAVIOUR OF A PRODUCT

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Abstract

Integrated Design Engineering (IDE) is a human-centred and multidisciplinary development approach that integrates products and their lifecycle phases, processes, organisations, knowledge, and information. One of the features of IDE is to describe both performance capability and performance behaviour of a product with different but equivalent and equally important attributes. These are structured into product attributes, performance attributes, and economic attributes. Due to this diversity, IDE attributes offer significantly more and better ways to describe and to develop a product exactly according to various requirements, which are based on the needs and desires of customers, on the different environments in which the product is to be used, and on the respective conditions to which the product must comply. This paper gives an introduction to the IDE attributes and describes how to work with them.

Keywords: Integrated design engineering, Attributes, Interdisciplinarity, Design methodology

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1 INTRODUCTION

Integrated Design Engineering (IDE) is a multi-criteria, interdisciplinary, and holistic approach for the development of any kind of products. Products may be physical objects (discrete or continuous), software, methods, procedures, or other immaterial objects, respectively. IDE is human centred, takes into account the whole product life cycle, and is based on different types of integration (including generalization and integration of products, processes, departments, knowledge, and methods, respectively). Within the underlying IDE procedure model the activities to create a product form self-similar patterns on any level of concept, specification, and realisation. Basic activities within the IDE procedure model are researching, developing and configuration, designing and modelling as well as evaluating, comparing, and selecting, and completing. There is not a prescribed sequence of activities in this model. In fact, the basic activities are event-driven, as they are processed dynamically according to the actual state of product emergence in context with the actual state of requirements [Vajn-2014].
Requirements in the broadest sense merge together both needs and wishes of customers with the conditions for product existence in a given or changing environment (legal, social, etc.) [Otto-2013]. To fulfil the requirements, a product disposes of individual characteristics that make up its respective nature.
Most of actual design methods are focussed on function fulfilment, to which all other goals have to subordinate (a comparison between IDE and other design methods to show the advantages of IDE is provided in [Vajn-2014], chapter 2.5, fig. 2.26). However, it has turned out that functional fulfilment alone is not sufficient enough to meet the requirements and expectations of customers (especially in the consumer goods industry). In fact, the measure of a (longer-term) customer satisfaction is the *overall performance* of a product [JoAF-1995]. In a buyer's market with many alternative products of comparable performance, the decision is no longer made in favour of a product only by objective reasons, but increasingly by emotional reasons (e.g. spontaneous gusto for a product shape, "coolness" of a product), by sustainability issues, by the existence of simple interfaces and usages. In IDE, therefore, features, properties, characteristics, and natures of a product are described and created using eleven different *attributes* of the product.
Attributes are always present, in every product, and throughout its whole life cycle. In principle, they describe performance capability and performance behaviour of a product as the result of their actual appearance, their state, and their interaction. The description may change along the development process. In IDE the final realisation of each attribute is decided as late as possible. Herewith, on the one hand, a product developer in IDE is not restricted in his creativity during design and development of the product, thus can deploy his concepts freely and act individually. On the other hand, advances in technologies, organizations, and processes can always be included as soon as reasonable in the realisation of the attributes. As needed, and mostly based on specific customer requirements, the precise realisation of the product can be pre-determined.
All attributes are *equal* and have all the same relevance, importance, and value. However, they are not similar, because there is always more than one equal opportunity for the realisation of a requirement, if more than one domain, e.g. with mechatronics, is included [VaKB-2011]. All attributes are mutually supportive in a symbiotic manner to create the best possible solution under the current circumstances.

- From the customer's (= buyer, user, sponsor, etc.) point of view the attributes describe the *expectations* to capability and behaviour of the product performance that result from the different customer needs and wishes as well as from the conditions of the environment in which the product is to be used. Attributes from the customer's view form the *target attribute profile*.
- From the provider's (= manufacturer, distributor) point of view the attributes describe the capability and performance *offer* of the product. Especially in the consumer goods market, this offer can also be influenced in the broadest sense by guidelines based on various customer requirements or conditions of the product environment. Attributes from the provider's view form the *as-is attribute profile*.

2 ATTRIBUTES IN IDE

There are eleven attributes in IDE to describe performance capabilities and performance behaviour of a product. These are divided into three groups, the product attributes, the fulfilment attributes, and the economic attributes. The respective names of the attributes were selected in a way that easy measurability and simple assessment are already reflected in the names (most of them have the "ability" syllable in their names). This wording shall support the easy attribute evaluation and the uncomplex comparison with other products.

2.1 Product Attributes

The first group of attributes describe capabilities and behaviour of a product based on requirements, involving influences and constraints of the product life cycle and of the application environments. They embody as well the (usually unconscious) expectations of a customer. This type of expectation is powered by recurring experiences that led to the same or (quite) similar results (as an example: It can be assumed that the lever mounted left of the steering wheel in a car is the signal lever if the car is designed for right-hand driving).
The six product attributes are Product Design, Functionality, Handleability, Producibility or, alternatively, Availability, Maintainability, and Sustainability.

- Product Design endows objects with culture, identity, aura, and presence. It describes shape, appearance, look-and-feel, and aesthetics of a product; in short, its visual and emotional charisma that reflects (or promises) both its performance capability and performance behaviour to the (possible) user. Product Design provides the fulfilment of requirements such as sensuality and sensibility, in order to realise product properties that meet the individual needs and possibilities of the user. In every case, however, the human is the only measure of such creative work, never the technology. Form does not necessarily follow function any more, as functions alone are not able to provide the individual sensual experience of a product. The product developer can influence Product Design directly by freely choosing shape, material, colour, structure, and surface characteristics. According to Weber's theory of Characteristics-Properties Modelling / Properties-Driven Development (CPM / PDD) [Webe-2011] Product Design is a characteristic of a product, unless a customer requests it explicitly as a product property.
- Functionality is the ability of a product to transform functional requirements into corresponding user-related functions, and it describes the ability of the product to fulfil adequately either a specific requirement or a set of any requirements, regardless of whether these can be realised as mechanical, electrical, electronic, hydraulic, optical, or software functions, or combinations of these. In short, it covers all direct and indirect functions that a product provides for the usage.
- Handleability describes in a broader sense performance, usefulness, and quality of the interfaces between user and product. A powerful and versatile handleability is essential for the success of the product. Therefore it has to be intuitive, reasonable, and understandable. Handleability, on the one hand, is closely connected to Product Design, because this attribute influences the handling of the product at least by shape, material, colour, and surface texture. On the other hand, it influences Functionality, since the functions can only made available to the user via the interfaces provided (it goes without saying that in IDE products are adapted to humans and not vice versa).

The following two attributes Producibility and Availability typically occur alternatively in the attribute profile, depending on who (customer, provider) is requesting it. Usually, they are mutually exclusive. Both attributes are directly affected by the product developer and thus are characteristics, unless a customer requests them explicitly as a product property.

- *Producibility* provides information on whether, how, and on what terms of technical, organizational, logistical, and financial means a product can be produced (= manufactured, assembled, tested, etc.). This can be executed internally with the available options of the provider or the product has to be produced externally. Another option is to add manufacturing equipment if the possible profitability of the product is promising. Producibility is primarily of interest for the provider, because, if a product is not producible, it cannot be delivered to a customer or to the market, and thus cannot generate profitability. Producibility can be of interest for such customers who are interested in e.g. a fair and sustainable manufacturing of the product.

- *Availability* means on the one hand that the product is available for the customer, is supplied to him, and installed within the agreed period of time. On the other hand, it means that the product is always ready for use in the intended application area, according to the requirements, and during the expected lifetime (i.e. readiness for usage). Customers usually are interested in Availability, because a customer wants to obtain a product at his particular point in time. He neither can nor will buy a product that cannot be produced. Exceptions are those customers who are interested in e.g. a fair and sustainable manufacturing of the product. Availability can be of interest for such providers that rely on an extensive supply chain for their products.
- *Maintainability* describes the ability and the ease with which a product can be modified for rapid correction of error states, because of new requirements, to improve maintenance, or to adapt to a changed environment [ISO 25000]. These actions must be possible without limitations to put the product back into the usable state and to ensure its availability.
- *Sustainability* means that a product respects ecological requirements to be as important as technical, social, and economic requirements. This leads to a balance of economic, social, and environmental targets [Beys-2012]. Sustainability demonstrates the high responsibility of product development because it creates in its phases the conditions for a sustainable product (Hubka already required in 1976 from the product designer an ethical responsibility to society and economy [Hubk-1976]).

The attributes Product Design, Functionality, Handleability, and Maintainability can be summarized under the generic term "usability", i.e. the focus on the sufficient and appropriate usage of a product, by the intended user, and within the planned application context.

2.2 Fulfilment Attributes

The fulfilment of requirements by every attribute is considered with the tripartition of type, degree, and excellence of fulfilment:

- The type of fulfilment refers to the way of how a requirement was realized, e.g. by selecting a suitable technical mode of implementation out of a set of alternatives that result from the manufacturing possibilities of the provider (what was realized how and with what?).
- The degree of fulfilment describes the relationship between a requirement and its (proportional) realisation (what was realized to what extent?).
- The excellence of fulfilment describes both nature and value of the fulfilment, which means that it rates both the type and the degree of fulfilment (how sound was it fulfilled?).

One example for this tripartition is a multi-function switch on the steering wheel of a car, which enables the operation of blinkers, wipers, and different lighting functions.

- Fulfilment type: The switch may consist of metal or plastic and it may include mechanical or electronic switches.
- Fulfilment degree: The number of functions realized in the switch (e.g. steps for varying the length of the interval between two movements of the wiper), which may differ depending on the respective level of extras.
- Fulfilment excellence: This is manifested in ease of operation, precise latching, repeatability, and durability both of the switching steps and the entire switch.

Type, degree, and quality of fulfilment depend on the current requirements for the product, on the current conceptions, goals, factors, and boundary conditions of the company, e.g. corporate strategy and corporate identity, on profitability expectations and Code of Conduct (Corporate Social Responsibility). The rating of the respective fulfilment takes place in relation to the requirements or to an agreed standard. This results in subjective outcomes in relation to each requirement. However, the more precise requirements and conditions are formulated, the less scope is left for the respective fulfilment (until the exact presetting).

The combinations of the three types of fulfilment are represented by the attributes safety, reliability, and quality, Figure 1.

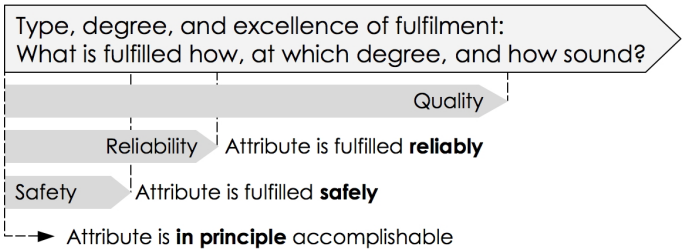

Figure 1. Different forms of requirements fulfilment

- *Safety* describes the specific combination of fulfilments that the product attributes must meet at least to assure that the product never can harm the user (or another person concerned) when it is used in the intended way (including a certain tolerance against misuse). It may well be the case that Safety requires a higher fulfilment than e.g. is needed to fulfil Reliability. For the entire product and its components, Safety of the entire product corresponds, on the one hand, to the interaction of the individual Safety attributes of the components, on the other hand, to the degree and the excellence of the interaction of the components within the product. It also means to prevent the propagation of the failure of one component to further failures of other components or of the product, regardless of whether a person is involved or not. Safety can be understood as fixed or knockout criterion, because if a product does not fulfil the safety requirements, it cannot be used under any circumstances.
- *Reliability* is the combination of fulfilments to ensure that a product will behave always reliably for its intended purpose and that it can be used with a certain tolerance against misuse (robustness). This has to be ensured during or after an application [DIN-40041], over its specified or expected lifetime, or in a given time interval under given conditions. Reliability is understood here as the ability for utilizing (which is not the same as "usability") as well as the readiness for use. The reliability of a product and its components corresponds to both the sum of the individual reliabilities, the (additive) interplay of the individual reliabilities as well as their synergistic co-operation within the entire product. Reliability can also be interpreted as a minimum criterion, i.e. the lower limit of fulfilments.
- *Quality* describes the actual level of excellence of the product, i.e. nature, suitability, and value of the combination of the fulfilment of product requirements. This definition is in accordance with the definition of ISO 9000:2005. According to this standard, quality is the totality of characteristics of an entity, with which (in terms of their suitability) defined needs and implied needs are satisfied [DIN-9000]. Quality never is an absolute value, but always the relationship between requirements and their manifold fulfilments, always depending on the respective frame of reference. Such a reference frame is usually made up by the totality of the requirements to the product, its possible application environments with their inherent conditions, and further environments (legal, social, etc.). Quality is not just a physical quantity, but the sum of relevant characteristics and properties in a particular environment (respecting the aspect of manifoldness). The importance of Quality varies along the product life cycle [EhMe-2013]. It can be understood as the sum of nice-to-have criterions, thus always having the subjective dimension.

2.3 Economic Attributes

The third group of attributes contains the tangible and the ideational aspects and thus (in the broadest sense) the economic aspects of the product, i.e. profitability and added value or overvalue, respectively.

- *Profitability* describes the economic aspect of the product from the perspective of the provider. It is the ratio of the attainable profit from the attribute profile of the product in relation to the expenditures needed to realize this profile in a billing period. The expected profitability is, for the provider, one of the main reasons to opt for development and production of a product.
- *Added Value* (or Overvalue) is the relation between the as-is profile of the product attributes that exist in different fulfilments, and the expenditures for procurement, application, maintenance, and disposal for the product. For the customer, Added Value does not only describe the financial increase in value (e.g. by a cheap price or low usage costs), but also the ideational increase of value through possession and use of the product, such as prestige and status, attitude to life and a

certain preference (e.g. for a specific provider, for a specific product, or for certain innovations). While the Added Value for customers in the investment goods industry is measured mainly financially, the ideational reasons play an increasingly important role with customers in the consumer goods industry.

Profitability and Added Value must both be present at each product. Only if the provider can expect a reasonable return, he will manufacture the product. Only if the product provides him an adequate and suitable added value, this customer will buy this product.

2.4 Attributes and their Context

The three groups of attributes have the following context, Figure 2.

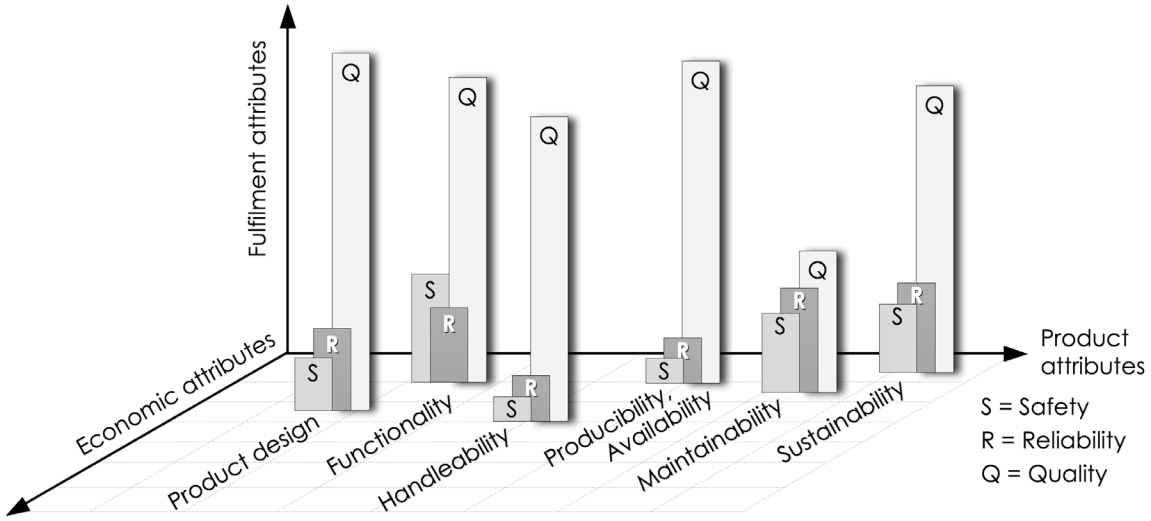

Figure 2. Context of attributes, fulfilment combinations, and economic attributes

As shown above, Safety must be above the knockout criterion and Reliability must fulfil the minimum criterion, otherwise the product cannot be used. However, it is possible (as with the Functionality attribute in Figure 2) that, to achieve reliability, a lower fulfilment can be sufficient than to fulfil the knockout criterion for safety. The individual attributes and their respective fulfilments lead to different profitabilities and added values. This is illustrated by their different positions in Figure 2.

All attributes influence each other to varying degrees, whereby stronger effects result from the attributes Product Design and Producibility / Availability because both are directly affected by the product developer (left side of Figure 3). Thus, these two attributes are to be preferred when product changes have to be performed because they have the highest impact (and thus may save adaptation efforts) as long as the corresponding boundary conditions are observed, which can be modelled, for example, with design rules or with the approaches of Design for X (DfX) [Meer-1994].

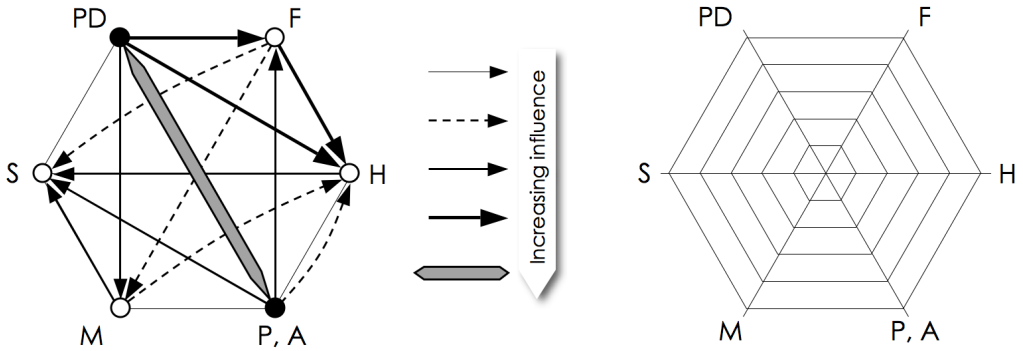

Figure 3. Left side: Different influences from and to attributes. Right side: Basic spider diagram (PD: Product Design, F: Functionality, H: Handleability, P: Producibility, A: Availability, M: Maintainability, S: Sustainability)

In order to provide a simple way of modelling the attribute context, and for the separation between the target attribute profile (which the customer dictates) and the actual profile (which is the result of the provider's work) the spider diagram is introduced that is spanned by the six product attributes (right side of Figure 3), in which the fulfilment increases from the inside to the outside of the diagram.

3 WORKING WITH ATTRIBUTES

Working with IDE attributes is in the focus of the actual research of the author. Resulting procedures are incorporated into the processing of multidisciplinary product development projects that serve as a test environment. Currently, the following steps to work with attributes have been identified:

- Generating product requirements from the needs and desires both of customers and of the market in connection with the conditions of the environments in which the product is to be used. The result is a list of requirements that can be prioritized and weighted.
- Mapping the requirements on the product attributes for generating the target attribute profile. Currently, this is carried out with an adapted form of Quality Function Deployment. Further options are researched as well, e.g. the Computer-Integrated Manufacturing (CIM) model with its multiple assignment possibilities [VPJN-1989]. The fulfilment attributes describe the expected performance of the six product attributes, whereas the economic attributes assess the performance. The assessment is based on the cost-benefit analysis, the Balanced Scorecard [KaNo-1997], and the multi-criteria Benefit Asset Pricing Model (BAPM) method [Scha-2004]. Result is the target attribute profile from the customer's perspective. Possible requirements, e.g. how to fulfil a particular product attribute in a prescribed way, are considered in the fulfilment attributes and the economic attributes.
- Creating the as-is attribute profile of a (potential) product, according to the possibilities of the provider, based on a request of a customer or from the market. This is followed by the comparison of the target profile and the as-is profile and the assessment of the fulfilments. A distinction is made according to the type of product. If it is a capital good, there should not be a difference between the as-is and the target profile. If it is a customer good, there may be differences as long as the minimum target profile of the intended market is fulfilled. These (possibly desired) differences can be used e.g. to better differentiate the product against potential competitors.

These steps have to be repeated when changes occur at the needs situation, the market, or the application environments with their respective boundary conditions.
Figure 4 shows three types of attribute profiles.

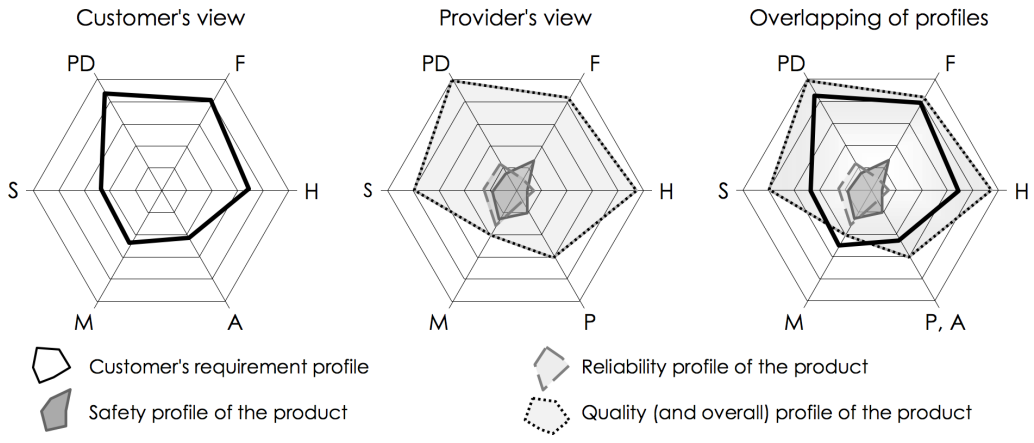

Figure 4. Spider diagrams with target profile (customer's view), as-is profile (provider's view), and the overlapped profiles (PD: Product Design, F: Functionality, H: Handleability, P: Producibility, A: Availability, M: Maintainability, S: Sustainability)

- The *customer's view* shows the customer's requirement profile for the product (or for a class of comparable products e.g. from competitors) in a given market (which does not need to be the market where the customer is located) at a given time or period. This is the target profile. For the customer, the availability of the product is more important, not necessarily its producibility.

- The *provider's view* shows the as-is profile as proposed or realised by the provider, detailed into the three fulfilment attributes Safety, Reliability, and Quality, for a similar period, for the requested market or for that market where the customer is located. This distinction is necessary especially for consumer goods, if the product is available in different markets with different usage environment conditions. For the provider, the producibility of the product is of more importance than its availability.
- The *overlapping of profiles* puts on top of each other the two profiles and thus allows a direct comparison of the targeted and the as-is performance. In this example the overall performance of the as-is attributes profile fulfils the target profile except of Maintainability.

There are different attribute profiles depending on the product and its application area. Figure 5 shows the profiles of a capital good and a consumer good, both from the provider's view.

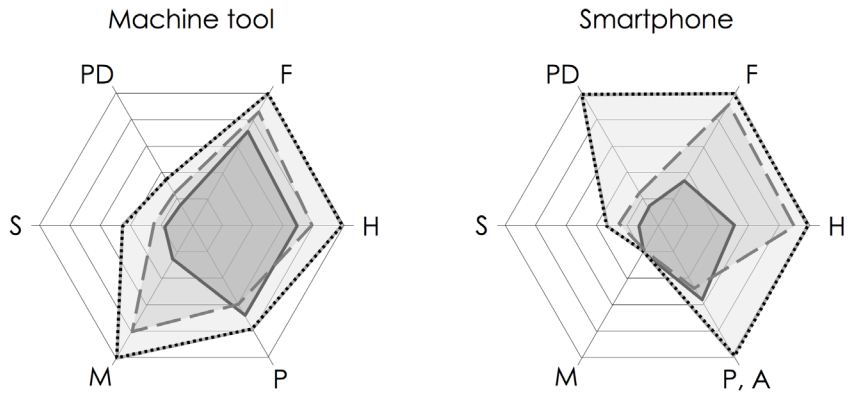

Figure 5. Attribute profiles of a customer good (left) and a consumer good (right), both from provider's view (legend as in Figure 4)

Capital goods allow a customer himself to produce products that are sold either in the capital goods industry or as consumer goods. The expected period of use of capital goods is long. The expected period of use of a machine tool, as shown on the left side of Figure 5, should not cover less than 25 years. Therefore, the attributes *Safety* and *Reliability* play a dominant role, as well as *Functionality*, as the required functions must be at the highest *Quality* level, and the machine must be usable in reasonable and consistent way. *Producibility* must ensure that the fulfilment of the respective customer requirements is guaranteed. The focus on a very distinct *Maintainability* keeps downtimes as short as possible. In this case, the attributes *Product Design* and *Sustainability* are of less importance (because the long period of use is already positively influencing *Sustainability*). Since capital goods are usually designed and manufactured for a specific customer, the actual as-is profile offered by the provider will be largely identical with the target profile of the customer.

On the right side of Figure 5, the as-is profile of a smartphone is shown, a typical consumer product of today. At this product class it can be shown that the statement "form follows function" is not necessarily true any more. Smartphones are design-driven and optimized for maximum usability. Actual product design does not reflect the functionality of the smartphone. Main reasons for this are, on the one hand, the increasing miniaturization of components today, on the other hand, the increasing replacement of mechanical functions by electrical, electronic, and software functions, etc. The typical customer of a smartphone is interested in the following attributes: *Product Design* (appealing, convincing), *Functionality* (smooth, safe, and powerful), *Handling* (simple and intuitive), and in *Availability* (high and continuous during the lifetime of the device). For the provider, *Producibility* is added to this in order to achieve maximum profitability. However, *Availability* plays a certain role as well (not as dominant as Producibility), as in the consumer goods market a product, to be successful, has to be available at the right time on the market. *Maintainability* and *Sustainability* of smartphones (and generally of products of consumer electronics) are not, however, in the focus, although, since June 2013, a Dutch company produces and sells sustainable smartphones [Fair-2013].

In the consumer goods sector, the provider offers a product to a target market. In order to gain a higher buying incentive for his own product, the as-is profile of the offered product must be better than the minimum target attribute profile required for this market (Figure 6, Provider's view). Such minimum attribute profiles are usually identified by the marketing department of the provider.

- For a new product, this profile describes the need situation in the market.
- For an existing product in this market the profile reflects the experience gained so far from the success of the product or a class of similar products, i.e. sales, distribution, application, customer satisfaction, recommendation, etc.

A customer will decide to buy an offered product if it promises an added value to him and if its as-is profile of the attributes provides a better fulfilment than his own subjective target profile regarding type, degree, and quality, in short, if the product meets his (partly vague) expectations to his subjective estimation. This estimation is the result of own experience with the same or similar products and from external knowledge sources such as test and experience reports from various sources (magazines, friends, internet, etc.). This can lead to the following decision alternatives:

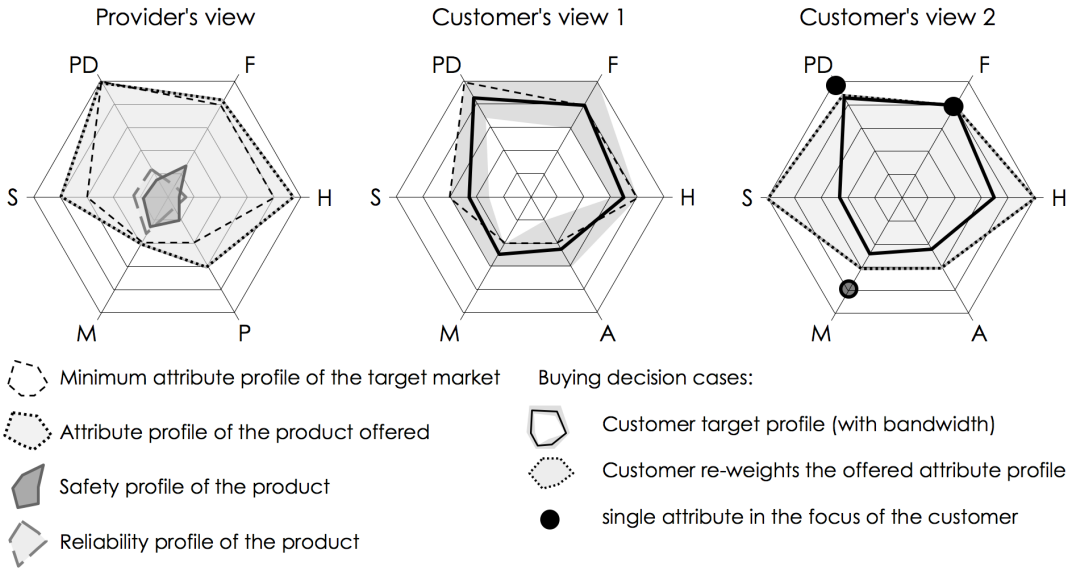

Figure 6. Decision alternatives when buying a product

- At the beginning of the decision-making process a customer commonly has notions of the desired attribute profile. But, due to his mostly his vague expectations, this profile comes along with a certain bandwidth (grey band in 'customer view 1' in Figure 6). Such a target profile fits into various as-is profiles, so the customer may investigate products of several providers. During the selection process (and with increasing knowledge of both the product and its application), the bandwidth is decreasing and the target profile becomes clearer (black profile). If this target profile fits into an offered as-is profile, the corresponding product is purchased. If there are several suitable as-is profiles (i.e. product alternatives), then the decision is in favour of the product with the highest expected added value.
- During the decision phase it may happen that a customer, based on the knowledge acquired during selection, individually re-weights and rebalances both the presence of single attributes and their respective levels of fulfilment in the as-is profile of the product. This results in a changed as-is profile in which the target profile of the customer may now fit better ('Customer's view 2'). It is also possible that a customer compensates the (subjectively) not adequate fulfilment of an attribute with the fulfilments of another attribute or more other attributes.
- The customer is only interested in the performance of individual attributes with a certain level of fulfilment that he expects at least (black circles in 'Customer view 2'). The other attributes and their fulfilments do not matter in this case.

It is often the case that a product provides the customer a high emotional satisfaction due to e.g. a preference for a certain company or a product, to expected prestige, or to desired status. Although the customer ha not a concrete idea yet if and how he wants to use the product, he "has to" buy it - a so-called "must-have" product. In this case, the fulfilments of the individual attributes do not play a significant role. The offered as-is profile should, however, not fall below a minimum profile, which is either a generally accepted one or one recognized subjectively by the customer to be sufficient.

4 CONCLUSION AND OUTLOOK

Integrated Design Engineering (IDE) is a human-centred and multidisciplinary development approach that integrates products and their lifecycle phases, processes, organisations, knowledge, and information. One of the features of IDE is to describe both performance capability and performance behaviour of a product with different but equivalent and equally important attributes. Due to this diversity IDE attributes offer significantly more and better ways to describe and to develop a product exactly according to various requirements, which are based both on the needs and desires of customers as well as on the different environments in which the product is to be used and to the respective conditions of which the product must comply.
The different groups (product attributes, fulfilment attributes, economic attributes) and different views (customer's view with target profile, provider's view with as-is profile, overlapping view) allow simple and easy traceable comparisons of the differences between the requirements of customers and the offer of the provider.
Current and future research in IDE is performed on the mapping of requirements to the attributes, on the measurability of fulfilments, and on the modelling of interdependencies between the attributes. One of the goals of this effort is to find out the attribute(s) in the as-is profile with which changes of requirements and / or application environments can be realised at the most sustainable and the most efficient means.

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