INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED11
15 - 18 AUGUST 2011, TECHNICAL UNIVERSITY OF DENMARK

CONSIDERATION OF GOAL INTERRELATIONS IN LIFECYCLE-ORIENTED PRODUCT PLANNING

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ABSTRACT
Within the innovation process the phase of product planning plays an important role in order to deduce consistent product proposals to be developed and produced by the company. Demands and corresponding product goals as well as trends concerning future solutions have to be anticipated and systematically analysed and opposed in order to place products accepted by customers and at the same time deliverable by the company. Thereby, early identification of goal interrelations and goal conflicts which arise by applying certain product concepts is essential. This paper therefore provides a graph- and matrix-based approach by considering product functions to link product goals among each other via solution elements and respective characterising parameters. The approach focuses further on an integrated lifecycle perspective in order to consider company, market and environmental demands and potentials from the phases of developing and producing until the phases of using and disposing products.

Keywords: Product Planning, Goal Conflicts, Lifecycle, Innovation Management, Innovation Process

1 INTRODUCTION

1.1 Motivation
Within an increasingly competitive environment which is characterised by dynamic market needs and rapidly changing technologies, manufacturing companies face the challenge to enhance their productivity in innovating products [1]. A promising approach in this context consists in frontloading an integrated lifecycle understanding to the early stages of planning future products. The ability to comprehend interrelations among and in-between future product and process potentials and demands increases the transparency of planned goods within corresponding innovation processes. This transparency allows anticipating possible goal conflicts and thus averts preventable changes along the future lifecycle. In consequence, companies avoid unnecessarily provoked lifecycle costs, which grow exponentially the later unintended changes are made within the lifecycle [2].
Still, a qualitative interview study – recently carried out by the authors among practitioners with planning responsibility in various branches – has shown that there is a need for more intensive methodical support in respect to lifecycle-oriented planning. Definitely there are approaches – such as scenario management [3] or Delphi-studies [4] – widely implemented and used in industry to anticipate short-, medium- and long-term aspects considering the context of future products. Further, there are approaches – such as the Quality Function Deployment [5] – considered to link customer needs and technical product specifications. Nevertheless, approaches to further analyse and elaborate on interrelations among anticipated demands and potentials along the whole lifecycle are rarely addressed.

1.2 Research background and procedure
Against the described background this paper focuses on the identification of causal chains and networks which can be deduced based on the anticipation of future product potentials and demands. Further, an approach how to analyse these causal chains in respect to goal interrelations is presented and exemplarily shown. Gathered results are embedded in an interdisciplinary collaborative research centre dealing with the management of recurring temporal patterns (cycles) and their interdependencies within innovation processes (www.sfb768.de). Thereby, this paper builds on preliminary work concerning an integrated lifecycle perspective as well as understanding the

behaviour of company internal and external context factors to be considered within the early stages of product planning.
Besides presenting this preliminary work briefly, also further related work is referred to in section 2. Then requirements concerning the developed approach are deduced at the beginning of section 3. Afterwards a structured framework of information to be dealt with in the approach is explained. In the next stage, the methodology for modelling causal chains among future product demands and potentials is presented and it is shown how goal interrelations can be identified within the presented graph-based models. In order to address lifecycle issues it is further shown how the developed approach can be expanded relating to an integrated lifecycle perspective. Finally, after demonstrating the approach based on exemplary product potentials and demands concerning electromobility in section 4, conclusions are drawn and an outlook on further work is given in section 5.

2 RELATED WORK

2.1 Approaches for product planning

According to Ulrich and Eppinger [6], the task of planning products addresses defining the portfolio of products to be developed by the company, as well as the timing to launch new products on the market. They suggest a planning process, in which there is an evaluation and prioritisation of projects after the identification of respective opportunities. Opportunities can thereby derive from many sources – such as research and development, customers, marketing, benchmarking of competitors – and should being taken into consideration in order to outline the current and future product portfolio and to allocate the resources. The step of identifying opportunities is supported by providing approaches to collect and document information from the different sources. Further, it is shown how to decide about the future products and corresponding projects based on the competitive strategy, technological trajectories, market segmentation and the fit to product platforms.
The engineering guideline VDI 2220 [7] as well as Pahl et al. [8] emphasise in their more detailed procedural models for product planning the step of linking certain demands and potentials. In this context, also very specific methods evolved to link technologies, product functions and product ideas e.g. by Gausemeier et al. [9] have been developed. Still, especially taking in a lifecycle-oriented perspective and providing approaches to shed light on respective interrelations among the identified demands and potentials is not yet discussed, but distinguishes itself to be promising to increase transparency in these early phases of the innovation process.

2.2 Lifecycle orientation and context factors

To structure the search fields for future product potentials and demands diverse research has been carried out within the collaborative research centre SFB 768 'Managing cycles in innovation processes'. To enhance the lifecycle understanding of products, e.g. Hepperle et al. [10] – already focusing on the high degree of interrelations concerning lifecycle issues – deduced a detailed lifecycle model consisting of the superordinate lifecycle phases 'Product planning', 'Product development and design', 'Production process preparation', 'Production', 'Distribution', 'Utilisation', 'Maintenance', 'Modernisation lifecycle' and 'Product disposal'. Thereby, the model has been realised based on existing literature in engineering design (e.g. [8, 11]) and product lifecycle management (e.g. [12, 13]). This first product lifecycle model has later also been extended towards an integrated understanding of products and corresponding services [14].
Additional dimensions for the identification of product demands and potentials come in when considering company internal and external context factors. Langer and Lindemann [15] therefore built a systematic framework to classify sources influencing the development process. They distinguish between factors deriving from the own company, the market and the environment. Furthermore, context factors can be assigned to the categories 'Technology/knowledge', 'Socio-economics, 'Politics/Legislation' or 'Resources'. Although this framework was established for the development of products, it can still being taken into consideration for the earlier planning tasks, as it describes factors in general of interest when innovating products. This categorisation scheme in combination with the mentioned lifecycle-orientation supports the integrated identification of relevant demands and potentials. Thus, this preliminary work is an important basis for lifecycle-oriented product planning; still, it does not yet allow the systematic analysis of interrelations between product demands and potentials.

Another important dimension in planning lifecycle-oriented products is the temporal aspect. Thereby, often the product launch is focused and respective product roadmaps are designed. Expanding this view to a ‘lifecycle roadmap’ – in which subsequently following lifecycles are outlined – increases also the transparency in screening product demands and potentials over the time [16]. This again sensitises the product planner in choosing an appropriate method for developing future scenarios according to different planning horizons. The need to analyse interrelations of the demands and potentials which can be derived from the subsequently following lifecycles can thereby be identified, but so far no respective research has been carried out.

2.3 Approaches for mapping information

While sections 2.1 and 2.2 focused approaches in planning future demands and potentials, this section presents related work in respect to linking information from various domains. This perspective represents an essential basis for developing approaches to analyse goal interrelations. At first, the Multiple-Domain-Matrix (MDM) [17] – a graph- and matrix-based approach to detect and analyse structures of networks across different domains (e.g. functions, processes, components, stakeholders, etc.) is considered. It evolved based on the Design Structure Matrix – a method supporting systems engineering by providing a comprehensive and visual representation of a complex system and supporting decomposition and integration problems [18]. This approach, applicable to various design and development challenges, provides an excellent basis for analysing structures and manifold structural patterns have been researched in the past years [19]. Nevertheless, there is still a need to support the data acquisition and preparation for MDM-analyses. In particular approaches supporting the data acquisition and analysis for product planning issues are not focused so far.

Another interesting approach in the context of this paper – deriving from marketing and psychology research – considers so called Means-End-Chains [20]. Means-End-Chains focus the linkage between customers’ values, product functions and product properties. Although the specific algorithms to use these chains in marketing are not relevant for this paper, the general idea how customer demands can be addressed on different abstraction levels provides a proper basis for structuring future potentials and demands. In order to specifically link customer requirements and technical product specifications the QFD (Quality Function Deployment) [5] represents an approach which is widely accepted in industrial practice. As this method in particular supports the development process, it can be used as another relevant basis for lifecycle-oriented product planning. Nevertheless, the method of QFD and respective evolved approaches do not meet the specific requirements arising when considering product potentials and demands throughout the different lifecycle phases.

3 APPROACH FOR LIFECYCLE-ORIENTED PRODUCT PLANNING

3.1 Aims concerning the developed approach

The aim of research presented in this paper is to support the early phases of the innovation process by providing a lifecycle-oriented approach to identify and analyse goal interrelations among future demands and potentials. In order to be aware, which aspects should be covered by such an approach, a systematic clarification of requirements for the approach is essential. Based on the reflection of weaknesses and strengths of related work, general as well as planning-specific requirements for developing new approaches, the following aims concerning the lifecycle-oriented approach applicable in various branches can be identified:

- Focusing information relevant and manageable in planning phases
- Compatibility to existing planning procedures and applicability to various branches, products, levels of innovation (radical and incremental), etc.
- Pursuing a modular approach to allow the partial use according to the respective planning task
- Compatibility to existing organisational structures within company (both considering upstream (e.g. information acquisition) and downstream (e.g. product development) processes)
- Allowing consideration of process and product related potentials and demands arising along different lifecycle phases
- Allowing traceability of causal chains among abstract context factors to concretised solution opportunities
- Increasing transparency in causal networks of product potentials and demands by integrating

structural complexity management approaches

- Consideration of both Market-Pull and Technology-Push approaches to detect and set trends
- Providing a framework to deduce consistent product concepts by increasing transparency concerning product goal interrelations
- Enhancing innovativeness by solution neutral goal formulation and openness for functionally equivalent and better solutions independent from known existing solutions

Bearing these qualitatively formulated aims in mind at first a structured framework for illustrating elements dealt with in the developed approach is presented in section 3.2. Based on this framework, a graph-based method to represent goal interrelations under consideration of product potentials and corresponding product concepts as well as of demands arising from the company, market and environmental context is described.

3.2 Structuring considered elements within approach

In this section, coactions of different subjects relevant in lifecycle-oriented planning with the aim of identifying goal interrelations are presented. The superordinate task of identifying future potentials and demands is illustrated by the upper box in Figure 1. Thereby, the model of context factors by Langer and Lindemann [15] describes an important basis to detect issues from the environmental, market and company context. Another important dimension in analysing the context concerns the lifecycle perspective. That means, that future potentials and demands should be identified from the planning and development and production phases until the later phases of distribution, utilisation and decomposition [10]. On the side of anticipating and analysing demands and underlying conditions, both product and process related topics should be taken into consideration and an understanding of the causality between product demands and underlying conditions as well as deduced product goals has to be developed. On the side of anticipating and analysing future solutions, two different kinds of opportunities should be considered. First there are already existing and available solution elements which can be used in future products (e.g. products already used in other branches). Secondly there are potentials which have not yet been implemented in products. These potentials (e.g. findings in research) have to be developed and projected to product solutions in order to be later reasonably being considered in the analysis of goal interrelations.

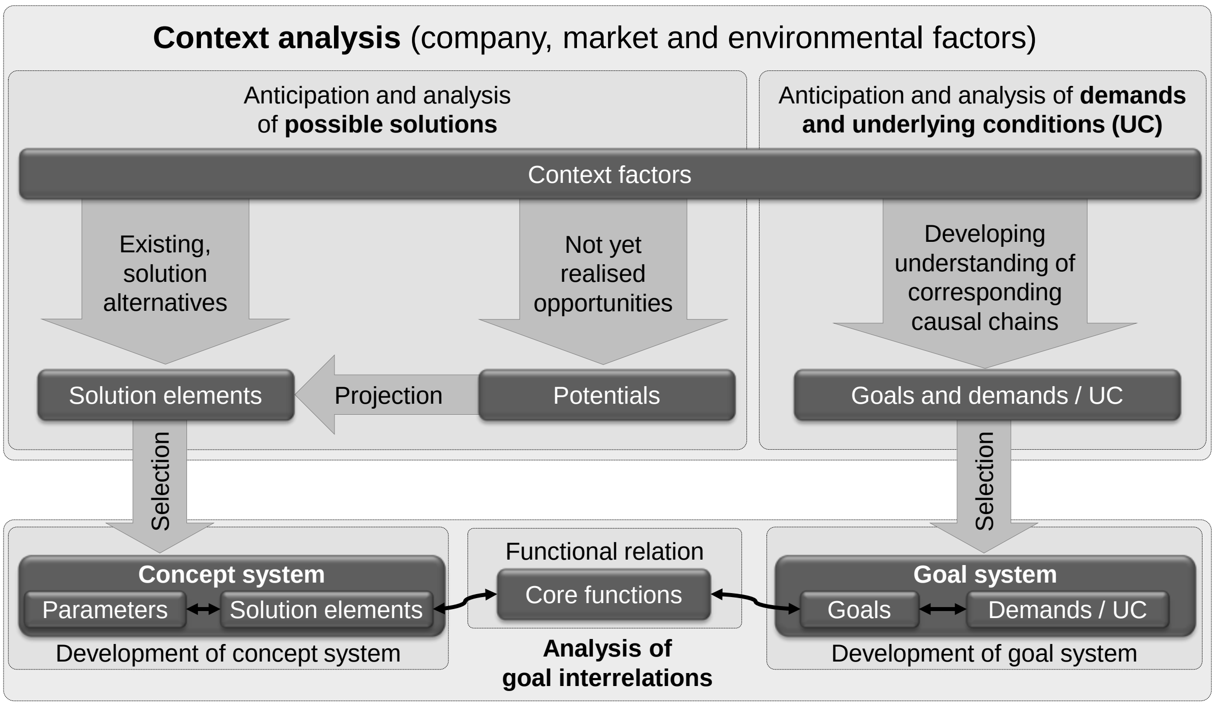

Figure 1. Framework for analysis of goal interrelations

In order to allow on the one hand a manageable analysis of goal interrelations and on the other hand to focus on the task of planning products, a first selection of solutions and demands further to be

analysed should be carried out. This step is not elaborated on in this paper, but can for example be performed against the background of the company strategy and economic aspects.
After anticipating and selecting planning relevant demands and potentials, the collected information is further processed. Thereby, the elements are aligned based on the idea of Means-End-Chains [20]. On the right side (Goal system), the chain starts with demands and underlying conditions (e.g. deriving from trends in society such as ecological awareness) and is then associated to product goals (e.g. maximum for energy consumption). These product goals are again assigned to product functions. Against the background of product planning, not all product functions should thereby being considered. Thus, especially core functions, predominantly responsible for the implementation and operation of the future product should be considered. On the left side, the concept system is developed based on anticipated and preselected solutions. Solution elements which are concretised by planning relevant parameters are directly linked to the mentioned core functions. Thus, a functional relation between the goal system and the concept system is provided. As information acquisition of both sides can be carried out separately and the information is linked afterwards by core functions, concurrency in applying the approach is provided. Another essential advantage of the framework is the flexibility of allowing both Technology-Push and Market-Pull approaches, as the starting point for deducing product concepts can be both on the side of the concept system as well of the goal system. Based on the shown framework, the next section shows, how the described elements can be translated to a graph-based approach.

3.3 Graph-based approach for identifying goal interrelations

In order to implement the described framework by a graph representation, it is important to further understand which kind of goal interrelations should be considered. Thereby the question arises, which kind of goal interrelations do exist and why do two goals interrelate:

- First, goal interrelations can occur, because two goals follow the same characteristic, but with different values (e.g. customer 1 prefers speed > 150 km/h, customer 2 prefers speed < 120 km/h). This goal interrelation and corresponding conflict can already be identified by comparing and handled by prioritising the different available values. This type of goal interrelation is not further followed in this paper, but still has to be considered in planning and deciding about future products.
- Another type of goal interrelation can occur if two product goals are linked by the solution element(s) to achieve the goals. E.g. customer 1 demands goal 1 (energy consumption when operating the car < 4 litres/100 km) and at the same time demands goal 2 (acceleration from 0 to 100 km/h in less than 6 s). There is no direct goal conflict between these two goals. Still, if taking solution A (specific combustion engine) to achieve goal 1, goal 2 cannot be achieved and vice versa. This kind of goal interrelations is considered in the following.

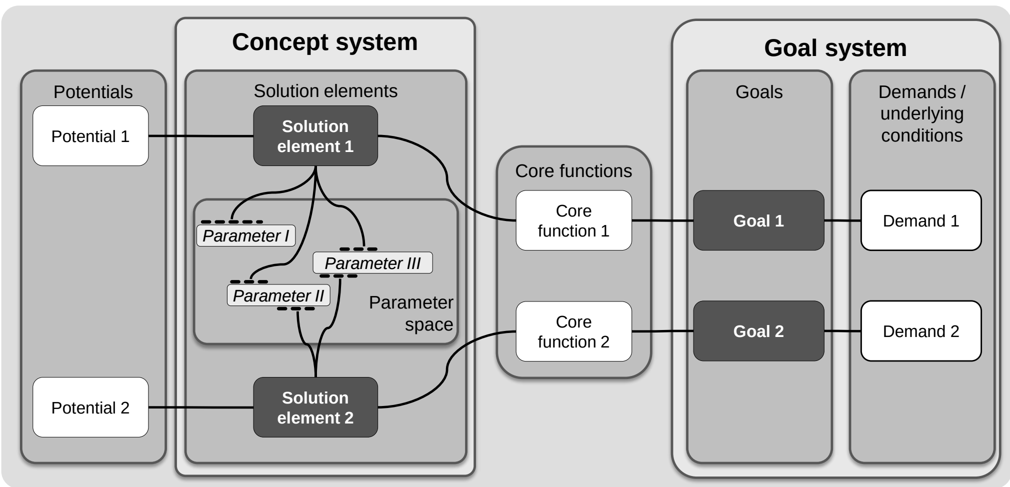

Figure 2. Simplified, abstract example for graph-based representation of goal interrelations

This means, that pursuing a consistent combination of solution elements would allow achieving the considered product goals. Otherwise, if two goals cannot be achieved by the potentials and solutions detected, goals have to be prioritised or iterations in respect to finding further solution elements have to be carried out. To implement the above described framework with the background of identifying goal interrelations, a graph representation for a simplified, abstracted example is shown in Figure 2.

The elements described in the previous section can again be seen in the graph representation. The demand is thereby linked to a goal which is again linked to a core function. From the other side, a potential is linked to a solution which is again linked to a core function. As Figure 2 is a simplified example, there are only ‘one to one’ connections between two elements considered. Nevertheless, applying the representation technique to practical examples would also allow ‘many to many’ connections. For example, a goal can be linked with different core functions or a demand can be linked to different goals and vice versa (e.g. one goal for different demands).

Further, the elements ‘parameters’ are considered within the graph representation in order to characterise the solution elements. As different solution elements can be assigned to the same parameter, an indirect link between two solution elements may arise (see ‘Parameter 2’ and ‘Parameter 3’ in Figure 2). Thus, following the respective chains from the solutions to the goals, a goal interrelation between ‘Goal 1’ in Figure 2 and ‘Goal 2’ exists via the two parameters.

Until now, this only shows if there is an interrelation between two goals, going one step further it is of interest if this is a goal conflict. In the abstracted example of Figure 2 a goal conflict via ‘Parameter 2’ exists, as the solutions point at different ranges of this parameter. In contrast there is no goal conflict via ‘Parameter 3’ as the ranges are overlapping. Pointing at the range of a parameter is just one alternative how solutions can be characterised. Further alternatives are shown in Figure 3. Thereby, the scale for characterising a parameter can differ. If very precise information is available in respect to the solution element, the quantitative scale can be considered. In particular of interest for planning issues is the qualitative scale, as anticipating future solutions often only provides vague and qualitative information. Furthermore, there is the possibility of a binary scale, i.e. that the solution e.g. fulfils the parameter or not. Another dimension refers to the type of parameter interrelation. Thereby, it has to be distinguished, whether the solution allows a whole range of parameter values (range) or only a specific value (discrete). Concerning these alternatives one should be aware that different ways of characterising solutions within one network of elements can be considered; nevertheless, solutions sharing one parameter should be described similarly in order to allow detecting an interrelation between the solutions.

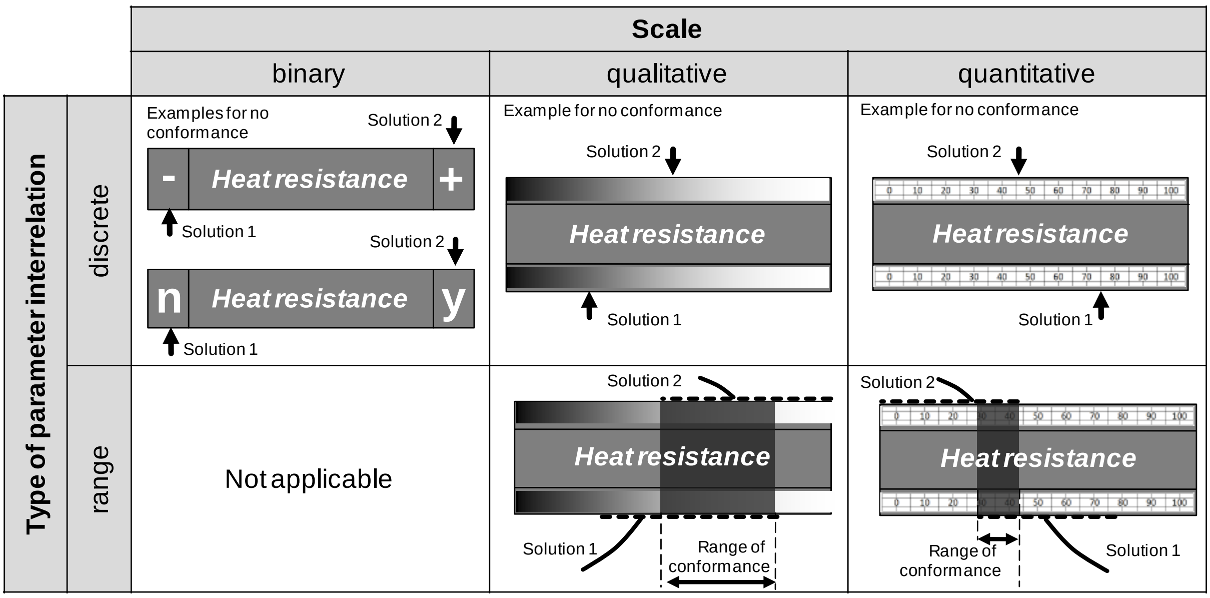

Figure 3. Alternatives of linking product parameters (e.g. heat resistance)

Another important note in respect to applying the graph representation to practical examples is to bear in mind that parameters can also be linked to other parameters. Then the interrelation between two solutions is represented via two or more parameters (e.g. solution 1 is assigned to the energy density of a battery which is again linked due to physical reasons to the volume of the battery which is again linked to the volume of the boot which is again linked to a specific boot solution).

The presented approach and corresponding graph representation shows that goal interrelations via solution elements to be considered within a future product concept can be detected. Looking at the

values of parameters even allows detecting goal conflicts. In order to be able to handle the information for many different elements, the approach has further been exemplarily implemented by graph- and matrix-based approach of Multiple Domain Matrices (see section 2.3 and [17]). Using these MDM-based methods, goal interrelations can automatically being identified by so called path analyses.
Not presented in this paper, but already addressed in current research of the authors is an appropriate approach to characterise the relevant solutions comprehensively. Furthermore, it is also researched how a combination of solutions (i.e. product proposals) can be prioritised and selected based on the shown approach. In this context it is in particular of interest how to decide if certain goal conflicts cannot be cleared in the planning stage. As the focus of the approach is additionally directed on an integrated lifecycle perspective, the following section shows, how the approach can be used against the background of considering manifold lifecycle phases.

3.4 Lifecycle-oriented goal interrelations

Definitely, the product planning has to focus the phase of utilisation in order to suggest product proposals for development, which address the customers' needs and which e.g. fulfil current legislation in respect to operating the product (e.g. CO_2-emssion for cars). Also focusing the phase of utilisation, potentials concerning new product technologies to operate the product are of interest and have to be evaluated in respect to their compatibility with the customer's needs.
Nevertheless, the company's strengths and weaknesses responsible for differing from competitors may be assigned to other lifecycle phases. E.g. if a company possesses unique features in respect to their production technologies or also in respect to ways of distributing their products, it is essential to take demands and potentials of these phases also into account. The approach presented in the previous sections can therefore easily being applied to various lifecycle phases at the same time. In order to maintain a high level of transparency, it is suggested to develop the framework for the different lifecycle phases in extra boxes (see Figure 4). Thereby, solution elements for the different phases are characterised and consequently linked by parameters; as the major aim of product planning is to detect and suggest product proposals, the respective parameters should be product-related (e.g. the 'production technology A' provides a geometrical product allowance of less than 0,1%).

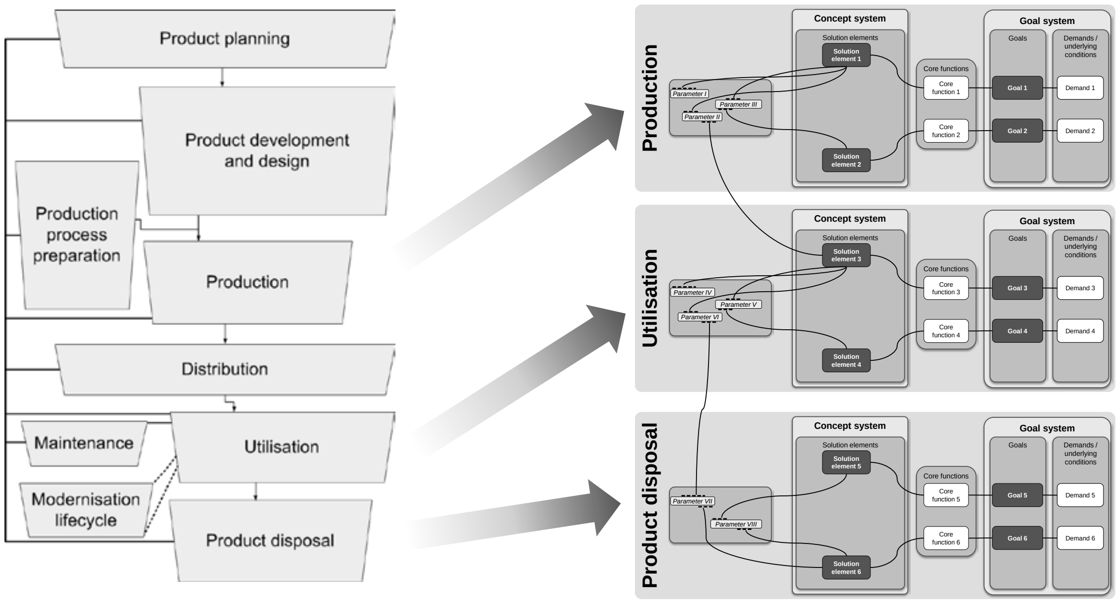

Figure 4. Extending approach to lifecycle-oriented issues

4 APPLYING METHODOLOGY TO THE FIELD OF ELECTROMOBILITY

4.1 Background of application

Due to the high energy consumption and corresponding CO_2-emissions which can be assigned to the transport sector as well as the preference of people for individualised car mobility leads to an increased responsibility for automotive industry in developing their cars. Sharing an abstract perspective on car configurations, main components have been the same for a long time. In particular in respect to the superordinate core function of moving the car the storage and utilisation of energy has only rarely changed, i.e. chemical energy (fuel) is changed to mechanical energy within the motor, then transmitted within the gearbox and forwarded to the tires via the axles. The classical power train has therefore reached over the decades a high technological maturity. Therefore innovative solutions for fulfilling the new demands deriving from society and legislation have to be pursued.

4.2 Exemplary application of methodology

Due to the high number of components as well as the heterogeneity in customer needs and varying legislation in different countries, planning future product concepts becomes very complex. Thus, the following presented example is simplified and focuses only a small part of an overall concept. Nevertheless the basic mechanisms of the approach can be comprehended based on the example. In order to emphasise the lifecycle perspective, two different lifecycle phases – the utilisation and the disposal phase with corresponding product and process related technologies and demands – are considered.

Against the described background, demands concerning the increased ecological awareness of customers concerning the operation of the car are considered. Therefore, the goal of less energy consumption can be assigned to the core function ‘store energy’ for the periods of energy recuperation when operating the car. Concerning the goal system of the phase product disposal, the toxicity safety for workers as well as an increased recycling quota are deduced from various demands and can be assigned to the core functions of separating materials and recovering raw materials. From a solution oriented perspective, different battery concepts can be detected and show future potential in order to fulfil the function ‘store energy’. One important – planning relevant parameter – in this context is described by the risk potential when handling the batteries. Also regarding the product disposal phase different possibilities to separate materials and to recover raw materials can be considered.

Analysing the network, various goal interrelations can be detected, still keeping the lifecycle-oriented transparency; e.g. the goal ‘less energy consumption’ is linked to the goal of ‘increased toxicity safety’ for workers by different chains. Still, only certain paths are characterised by a goal conflict. E.g. choosing manual disassembly and lithium ion accumulators would lead to a goal conflict between the two goals, as the assigned ranges for the parameter ‘risk potential’ do not overlap. Performing path analyses via MDM-based computer supported tools, further goal interrelations can easily being detected.

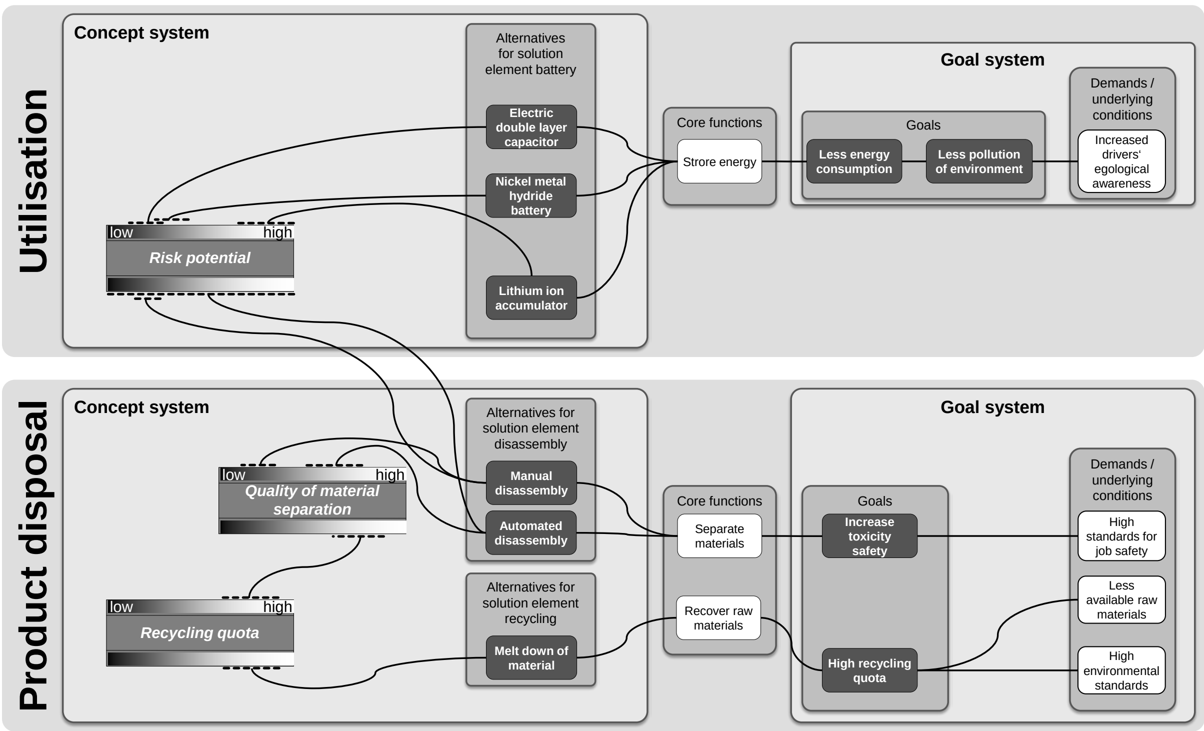

Figure 5. Simplified example for lifecycle-oriented electromobility

5 CONCLUSIONS AND FURTHER WORK

5.1 Conclusions

This paper presents a systematically developed approach to identify goal interrelations and in consequence goal conflicts deriving from different sources along the future lifecycle in the early product planning phases. An essential role in this approach plays the linkage of goals and demands from one side with possible future solutions and potentials and corresponding characterising parameters from the other side via assigning these in each case to core functions. Performing the information acquisition for goals and solutions independently from each other allows on the one hand a concurrent approach in planning phases. Furthermore, the goals can be detected against a solution neutral background and are then assigned to solutions in a second step. This helps to increase the innovativeness but at the same time allows detecting consistent product proposals for future development projects. As the approach also enables the consideration of 'many to many' connections between the considered elements, a network of goals, functions and solutions is provided. Thus, different solutions and in combination different product concepts for fulfilling a goal can be opposed; this describes a basis for decision making within the next steps of the planning process.

So far a graph-based approach has been chosen to visualise causal chains among the considered elements. Using simple graph representations reaches soon limits in respect to increasing transparency among these causal chains. Thus, it is of interest to provide formalised models which can be implemented within computer-based tools. This issue has already being faced in a first step by applying MDM-based approaches and using corresponding available tools. Thereby, assigning the different elements within the presented approach (goals, functions, parameters, lifecycle phases, etc.) to different domains within the MDM-based computer tools maintains the transparency among considered elements and their relations. Thereby, in particular the identification of goals interrelations is provided, while the next step of analysing these in respect to possible conflicts is not possible so far. Besides these issues, the next section shows starting points for further work to develop the approach concerning additional interesting dimensions.

5.2 Further work

Based on the current status, the presented approach of identifying goal interrelations will be improved concerning both the support of data handling as well as the refinement of planning oriented issues. In order to allow on the one hand a manageable analysis of goal interrelations and on the other hand to focus on the task of planning products, the selection of solutions and demands further to be analysed will be addressed. Besides implementing evaluation methods within the framework, guidance for companies to position themselves in the model of context factors is worked on. In order to address planning relevant issues further dimensions in respect to mid- and long-term planning horizons have to be focused. Issues like information availability, inaccuracy and fuzziness of information as well as consideration of occurrence probabilities play an important role. Furthermore, the integration of the developed approach within existing planning approaches is considered in further work. In this context case studies are planned in order to evaluate the applicability within industrial practice. In particular the interface of the approach to the steps of prioritising product concepts and timing these within the product roadmap will be elaborated on in this context.

ACKNOWLEDGMENT

We thank the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG) for funding this project as part of the collaborative research centre 'Sonderforschungsbereich 768 – Managing cycles in innovation processes – Integrated development of product-service-systems based on technical products'.

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