GATHERING AND ANALYSING EXTERNAL INFLUENCES ON THE PRODUCT DESIGN - A CASE STUDY

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Abstract

The early phase of each development process is characterised by severe decisions under great uncertainty. To facilitate these decisions, it is crucial to know the (external) influences on the product and the corresponding product development, to offer as large a base of information as possible. There is a broad variety of factors influencing the product and the associated development, which may include legislative changes or mutating customer behaviour. To help the developers make the right decisions it is essential to provide a vast number of information to support this task.The results presented in this paper provide the basis for the approach of including the prognosis of external influencing factors into the planning procedure of products or product-service systems. At first, a literature review was conducted to identify relevant external influencing factors for product and product development. In the following within the framework of the cooperation with an industry partner an approach was elaborated and evaluated.It supports selecting the most important factors for the product or the company, determining the interrelations between them and for weighting their specific impact.

Keywords: Product-Service Systems (PSS), Information management, Knowledge management, Design process

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1 INTRODUCTION

Companies in an industrial environment face a multiplicity of challenges. Global and rapidly changing markets as well as constantly rising costs for putting innovations on the market increase the competitive pressure. In combination with shortening the product lifecycle, and thus a need for shorter design periods and faster innovation processes, high time and cost pressures are significant characteristics of the competitive field of manufacturing companies (Kersten, 1999; Cooper and Edgett, 2005). In that manner, companies must improve their innovation processes in order to cope with the complexity of today's products and corresponding services (Hepperle et al., 2012). Moreover, they have to attain high variability in anticipating and reacting to the stakeholders' needs in order to adapt to the dynamic markets and customer needs (Hepperle et al., 2010). This is aggravated by the fact that changes and corresponding change propagations along the lifecycle have to be considered early in the development to prevent redundant costs that grow exponentially the later unintended changes are made within the lifecycle (Ehrlenspiel et al., 2007). In this context, it is important to anticipate the whole product lifecycle and external influences on the lifecycle to allow fast responses to influences from the environment and moreover to adapt the complete portfolio and the associated processes to the latest conditions with respect to content and time (Georgantzas and Acar, 1995). This puts a challenge to the planning and development departments of a company to assign the proper characteristics to a product within a reasonable amount of time (Hood and Wiebel, 2006). Especially the early phase of the development, the planning phase is characterised by severe decisions under great uncertainty. In order to facilitate these decisions, it is crucial to know the (external) influences on the product and the corresponding product development, to offer as large a base of information as possible, because the goal of each decision throughout a product development is the selection the best out of a set of alternatives (Schenki et al., 2013).

2 INITIAL SITUATION: PRODUCT PLANNING BASED ON FORECASTING

As companies find themselves situated in a dynamic surrounding, they need to adapt and react to this condition. There is a broad variety of factors influencing the product and the associated development. Those factors could be legislative changes, mutating customer behaviour or proceeding technological innovations. They have great impact on the decisions in the product development. To enable the developers and decision makers take the right decisions it is essential to provide relevant information. In this context, a variety of information can be called in, which include, inter alia, past development data or usage data. For this purpose, a model was developed to depict, manage, organize, and store this planning information (Kammerl et al. 2016). It is a tool for supporting the planning activities in the early phase of the innovation process and helps the designer to concretize the requirements all the way to the resulting product structure. The knowledge obtained throughout the product planning can be structured and depicted graphically. The model serves as a decision support and facilitates the deduction of products from a portfolio. In a next step, the model shall be expanded to include the progression of external influencing factors and their prognosis. Based on the past progression of those factors, the future progression shall be estimated by means of various forecast procedures. This allows the designer to anticipate the future development of certain influences and react to this at an early stage. The aim of this paper is an abstract list of external factors and a methodology to visualize and analyse them. The results of the analysis are beneficial for designers to better manage design projects based on a better understanding of external factors and how they influence the product and the company.

The results presented in this paper provide the basis for the approach of including the prognosis of external influencing factors into the planning procedure of products. In the next subsection, the result of a literature review is presented, aiming at the identification of external influencing factors relevant for products and product development. In the following a procedure for selecting the most important factors for the product or the company, for determining the interrelations between them and for weighting their specific impact is presented. It was evaluated within the framework of the cooperation with an industry partner.

In the next section the results of the literature review and the methodical background are presented. Section four describes the methodology for selecting, interconnecting and weighting the influencing factors. The methodology is applied in section five on an industrial application case.

3 STATE OF RESEARCH

Several authors have dealt with the topic of factors influencing the product, the product-service system or the manufacturing company itself. The result of a structured literature analysis in the field of product development and product design is presented in the following. Firstly, we start by shortly explaining the surrounding work of the publication and after that we describe the categories deduced from the corresponding work. The first kind of literature source are books covering the complete product development or innovation process. The second kind are specific publications from the field of engineering.

Related approaches

A literature review revealed several approaches which deal with the analysis and prognosis of external influences of with the topic of scenario analysis. Among others, Gausemeier et al. (2007), Gausemeier and Plass (2014), Götze (2013) and Wilms (2006) work in the field of scenario technique (further authors dealing with scenario technique can be found in Köpernik (2009)). The scenario technique differentiates from traditional planning by taking scenarios into account. The future is described by means of complex pictures described by independent influencing factors. These pictures describe the development possibilities of a certain inspection area. Mercer (1995) proposes a simplified scenario planning approach which at the same time retains the ability to handle uncertainty. He tries to amplify the designer's viewpoint and their planning horizons beyond the short term. All scenario technique approaches from literature have in common that the focus on non-cyclic factors. In contrast to those approaches we are not restricted to those factors but also take cyclic factors into account.

Influence factors

Ehrlenspiel (2009) deals with the process of product development from planning until the usage of the product. He offers methodical support for the product designer and addresses the whole development process. From his work, factors regarding the construction process, the product development and costs could be deduced.

- Construction process (e.g. market maturity, competitive situation, demanded complexity).
- Product development (e.g. labour market, location factors, innovations).
- Costs (e.g. materials, suppliers, production processes).

Lindemann (2009) as well as Ponn and Lindemann (2011) describe methods for supporting the designer in order to be more efficient and effective. Pahl et al. (2013) authored the standard reference in construction methodology. They offer and structure a set of methods and tools for systematically finding new solutions for technical problems. From their work a set of boundary conditions could be deduced.

- Supplier market, competition, environment (Lindemann, 2009).
- Customer needs, sustainability, globalization (Ponn and Lindemann 2011).
- Conditions of use, laws, society (Pahl et al., 2013).

Vogel-Heuser et al. (2014) work in the scientific area of cycle management. They offer support for the task of innovation management. From this work factors out of the field of innovation and further boundary conditions could be deduced.

- Innovation (e.g. strategy, knowledge, technology).
- Boundary conditions (e.g. politics, resources, society).

Cooper et al. (2002) focussed on enhancing the generation of new product ideas and better selecting projects as well as building more efficient decision points moving towards portfolio management. From their work factors regarding targeted marketing could be deduced.

- Targeted marketing (e.g. strategic orientation, legislation, market attractiveness).

Langer and Lindemann (2009) dealt with external context factors for product development. They elaborated a model for classifying these factors and determined the cyclical behaviour of these factors. From their work influences on the design and management of development processes as well as further external influences could be deduced.

- Influences on the design and management of development processes (e.g. technology cycles, legislation, society).
- External influences (e.g. environment, market, company interfaces).

McQuater et al. (1998) present the main findings of the examination of the management of design and new product development. From this work, external influences on development and design as well as unpredictable natures could be deduced.

- External influences on development and design (e.g. environment, demography, customers).
- Unpredictable natures (e.g. market, government, technology).

Moehrle and Isenmann, 2007 are dealing with the topic of technology road mapping. Hence, they offer technological companies to develop strategies for the future. From their work factors in future development and periphery could be deduced.

- Future development (e.g. science, politics, competitive behaviour).
- Periphery (e.g. wealth, demography, technology).

Reymen et al. (2006) developed a domain-independent descriptive design model and investigated its application in the design process. From this work factors influencing the design task could be deduced.
Design relevant factors (e.g. competition, standards, statutes)
The identified external influencing factors were selected, consolidated and structured and could thus be the basis for the approach described in the next section.

4 METHODOLOGY: ANALYSING AND VISUALIZING DYNAMIC INFLUENCE FACTORS

Throughout the product design, external influences must be connected to the product properties to be able to determine possible changes in the product architecture or in the platform design. This process is established in many companies and often used for setting up the basic platform strategy. To make sure the product architecture will meet the market needs, Kraus (2005) developed a standard procedure for platform system design. In the first step the internal and external requirements must be gathered. In the following step the platform attributes and their respective values have to be derived (Elezi et al., 2015). To ensure a robust platform during the complete lifecycle the attributes need flexibility to react on future dynamic influence factors (DIF). Therefore, Elezi et al. (2015) integrated the planned flexibility to Kraus's (2005) procedure.
This way, a new step is anchored between platform strategy definition and platform architecture design, which enables systematic identification of the product variant structure under consideration of future trends of DIFs. One key element is the so-called change priority indicator method (CPI), which is used to quantify the effect of these influence factors on platform system. CPI is used as a quantitative measure of the necessary capacity for platform system flexibility (Elezi et al., 2015). The concept of CPI is a variation of the FMEA method. In this case the degree of required product flexibility is assessed instead of the risk of failure. CPI is applied in an interdisciplinary workshop with experts of product management, sales and development.
Resulting these workshops, the DIF are connected to attributes and CPIs are determined. By analysing the CPIs the attributes can be rated as stable or flexible because of anticipated changes caused by DIF. Based on this analysis, the platform strategy and the platform design can be deduced. A great problem when carrying out the workshop is an inefficiency due to too many DIF which in consequence can lead to changes caused by irrelevant DIFs. These DIFs have low CPIs and therefore are not relevant for the flexibility estimation. To improve the CPI method, it is necessary just to use the key dynamic factors relevant for the most significant changes.
This paper introduces a procedure based on scenarios-technique and structure complexity management to identify these key factors. Figure 1 shows the 3 steps to connect dynamic influence factors and to identify key factors. The scenario-technique was chosen as a basis for the introduced procedure because it also includes future in a systematic way (Gausemeier et al., 2001).To build scenarios and alternative future prospects, we used about 20 key influence factors. These key factors are identified out of a set of influencing factors in the so called scenario field analysis (Gausemeier et al., 2001). Gausemeier et al. (2001) use the direct and indirect influence analysis to choose the 20 most relevant influence factors.
Hence, in the initial step (0) the main factors are determined. For this purpose, in the run-up to the workshop the complete list of influencing factors is sent to the participants and by means of a questionnaire they must select their top 20 factors which have an influence on the product or the development. In the next step (1) the influence factors are connected by the experts of the CPI-workshop in the direct influence analysis. Therefore, each pair of influence factors must be evaluated, whether they influence each other or not. For this end, each participant of the workshop must fill out an extract

of the complete matrix. Thus, not a single designer but several ones are responsible for the up to 400 cells of the matrix. If there is an interdependency between two DIFs, the result is documented in a so-called influence matrix. If the influencing factor of a row influences the influencing factor of a column, the cell contains a "1". A matrix which sets a relation between objects of the same category can also be called a design structure matrix (DSM), (Browning, 2001).
Each questionnaire contains three columns of the influence matrix, which should be filled by the participants. After the DSM is filled completely, the sum of the rows (active sum) and columns (passive sum) can be computed. The activity of an element is a ratio for comparing different nodes regarding their relative tendency towards an active or passive behaviour in a system (Lindemann et al., 2008). By putting the active sum on the horizontal axis and the passive sum on the vertical axis the so-called influence-portfolio can be generated that can be divided into different sectors. Namely there are four sectors with active, passive, inert an critical elements (Lindemann et al., 2008, see Figure 3). Active elements have a huge effect on other elements. On the one hand, critical elements possess active links on many other elements, and are on the other hand affected by many other elements, (Lindemann et al., 2008). Lindemann (2009) proposes that critical and a selection of active influence factors represent key factors. To confirm the result of the first step the second step uses another indirect influence analysis of the used DIF in the CPI-method.

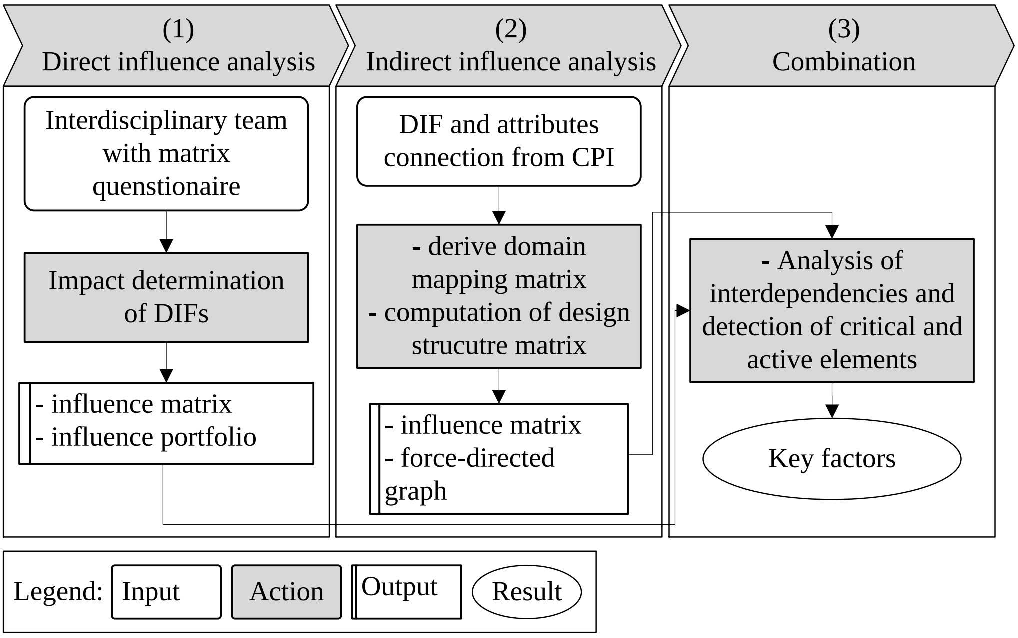

Figure 1. Procedure to identify key factors

This indirect influence analysis follows in step (2). Gausemeier and Plass (2014) use the existing DSM to compute the square matrix and identify loops. In this work, the indirect influence analysis is created by means of a different information basis.
While anticipating, and rating the flexibility of attributes there also arises a connection between attributes and influence factors. If objects of two categories are connected in one matrix it is called domain mapping matrix (DMM) (Lindemann, 2009). By multiplying the DMM (A) with the transformed DMM the resulting DSM (B) could be computed. The formula for calculating the DSM is as follows:

$$A*A^T = B \quad (1)$$

In this matrix, the influencing factors are connected to each other. Figure 2 shows the idea of the indirect dependency. Two influence factors are linked (without direction) when they cause a change on the same attribute.

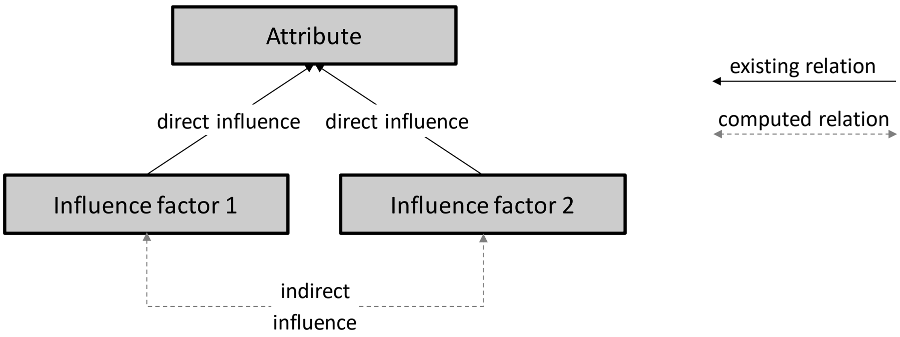

Figure 2. Indirect dependency of two influence factors

In contrast to the direct influence analysis the influence portfolio is not significant in this case. All influence factors will be arranged on an angle bisector because the matrix is symmetric. Thus, a third tools, the force directed graph is employed (see Figure 3). In a graph of that kind factors are represented as nodes and the connection to other influence factors is represented by edges. Nodes can be considered as magnetic monopoles which repel each other. The edges can be considered as springs which compel each other. In that manner, highly interconnected nodes will be arranged in the centre of the graph and elements with low interconnectedness at the border. Moreover, the size of the nodes can show the amount of indirect dependencies. Thus, big nodes in the centre of the graph represent relevant influencing factors.

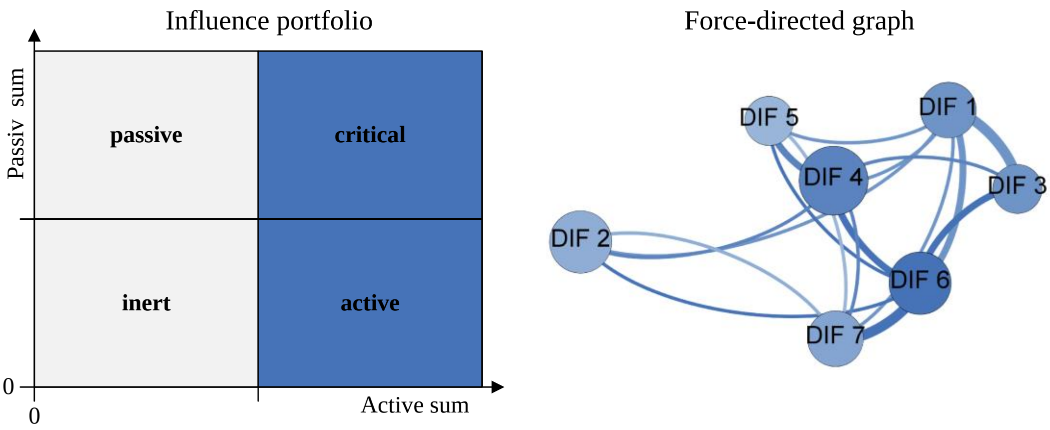

Figure 3. Influence portfolio and force-directed graph to visualize influence matrices

In the last step both matrices (A, B) can be combined to determine matches or differences. This can be achieved by subtracting the second matrix from the first one. As a preparation, the first matrix is multiplied by two. When subtracting the two matrices, in the delta matrix (Δ) we get entries from the range of -1, 0, 1 and 2. The resulting formula can be seen in the following:

$$2*A - B = \Delta \tag{2}$$

A 0 in a matrix field indicates that both fields are empty, a 1 indicates that both matrix fields are filled. A 2 indicates that only the first matrix has an entry and likewise a -1 indicates that only the second matrix has an entry. Thus, the differences in the two matrices can be recognized easily.

5 CASE STUDY: PLATFORM STRATEGY OF A MANUFACTURING COMPANY

To evaluate the methodology, the complete procedure to identify key factors was applied in an industrial environment. At a manufacturer of planetary gearheads, nine experts from departments of product management attended the CPI workshop.

In preparation for this workshop two experts from product management reduced the number of 90 DIFs to 23 DIFs. They selected the relevant factors for their market and the company situation, like product lifecycle, technology or market influences.
With this number of influencing factors, the CPI workshop was held. After all changes were anticipated and rated via the CPI method the workshop participants answered the split-matrix questionnaire for the impact of one influence factor on each other. By computing the active and passive sum of the resulting influence matrix an influence portfolio could be computed. It is shown in Figure 4. It shows six critical and eight active influencing factors.

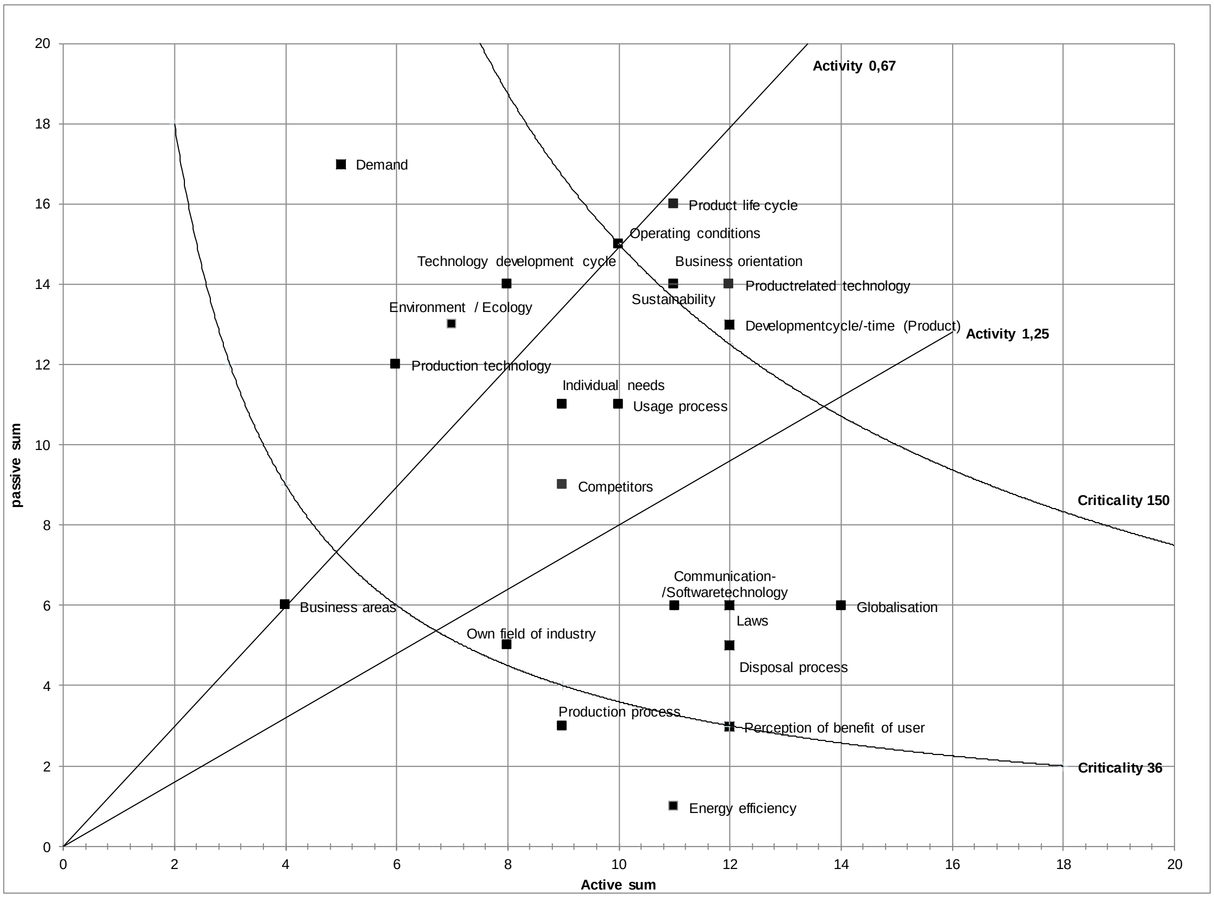

Figure 4. Influence Portfolio

In the indirect influence analysis, the results of the CPI-Method were used, where the influencing factors were combined with 19 product attributes. The resulting DMM was derived to an undirected DSM with 23 influencing factors and weighted dependencies. The force-directed graph was depicted with the open source software gephi. The resulting graph is shown in Figure 5.

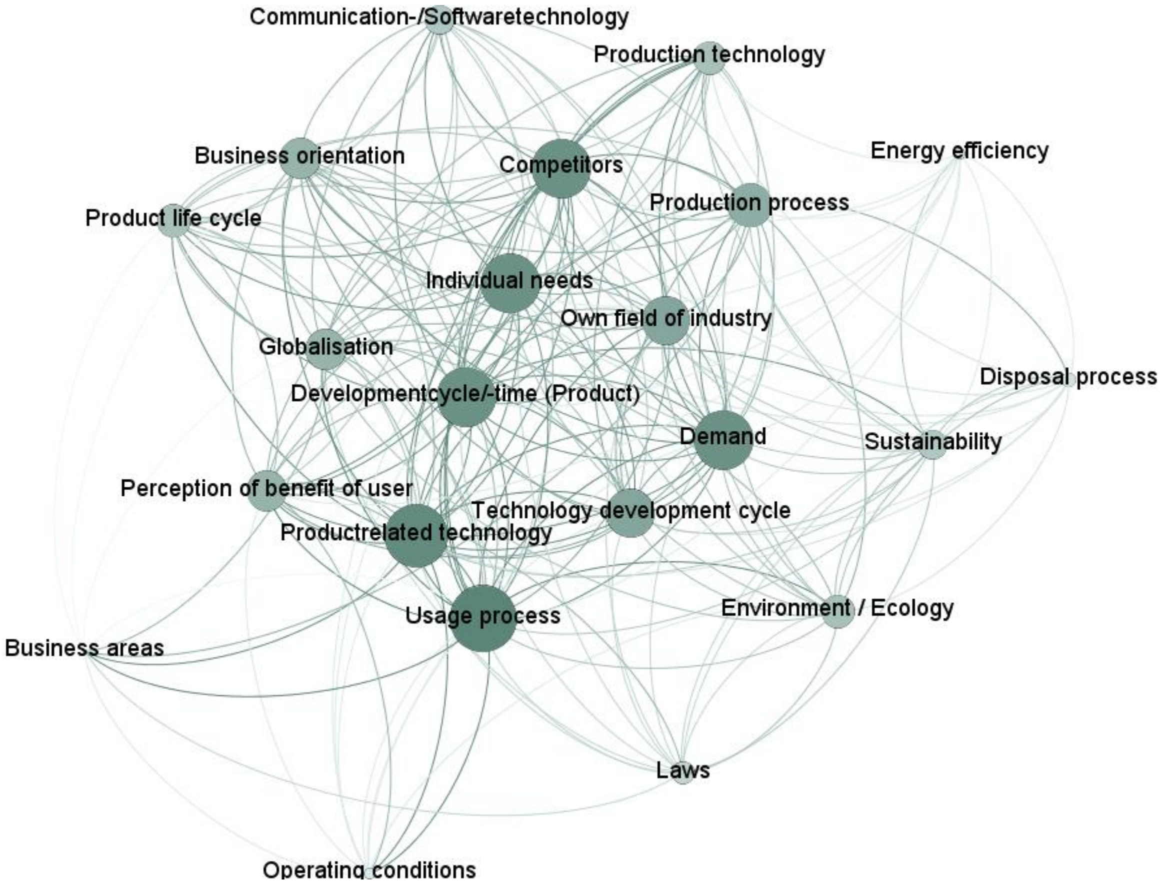

Figure 5. Force-directed graph

It can be determined, that the critical as well as the active influencing factors are sorted around the centre of the graph. Vice-versa the other influencing factors are out of the centre, so they are not part of this figure. Concluding, the indirect influence analysis underlines the results of the direct analysis.

Those results were presented to and discussed with the head of product department and the general management of the company. They consider the identification and the assessment of external factors as essential for the success of the platform strategy. The general management used those figures to discuss the relevance of single factors. They asked for the underlying reasons of some factors because they have expected different results for some cases. The complete approach was considered very helpful by the general manager and the sales manager.

6 CONCLUSION AND OUTLOOK

The dynamic surrounding companies are situated in poses great challenges to each development process. The factors which can have a vast influence on the development process and the corresponding decisions range from legislative changes, mutating customer behaviour to proceeding technological innovations. To enable the designers, take the right decisions throughout the development process, it is essential to provide the relevant information to support this task. In this context, a variety of information can be called in, which include, inter alia, past development data or usage data and especially external influencing factors.

In this paper, we presented an approach for selecting and connecting the most important influencing factors for the current company situation. We started our research by conducting a literature review to identify relevant external influencing factors for product and product development. In cooperation with an industry partner, a procedure for selecting the most important factors, for determining the interrelations between them and for weighting their specific impact was elaborated and evaluated. The approach was presented exemplarily in a use case, carried out in the company.

In future research, the results presented in this paper will serve as the basis for an approach for calculating and estimating the future development of the external influencing factors. For this purpose, the past development of these influences - if at hand - will be analysed and projected into the future by means of different simulation methods. If no past data is available, the calculations require the use of assumptions. Among others these simulation approaches contain Monte-Carlo-Simulation or Fuzzy Logic. In a next step, future scenarios shall be deduced from these predictions to help the designer anticipate future developments or trends and react to them premature. Finally, these scenarios will be integrated into a model for the support of product and product-service system planning for documentation and to support the designer make better decisions.

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