How to Analyse Specifications with Self Organizing Map

Jörg Feldhusen, Eliseo Milonia, Arun Nagarajah, Sebastian Schubert

Abstract— **This paper describes an approach to apply self organizing map (SOM) for the support of the developer to optimize the design process of adaptable products. The SOM is able to asses the similarity of requirement lists. Assuming that similar requirement lists lead to similar products, the SOM is able to identify the existing product, which has to be changed least to fulfill a new order. The emphasis is put on the preparation of the requirement list, so that it can be processed using SOM. Furthermore an approach for the visualization of the product data integrating the standardization for SOM and the applicability for the communication between Original Equipment Manufacturer (OEM) and supplier is shown.**

Index Terms— **Adaptable Products, Automotive Supply Industry, Engineering Design, Product Development Process, Self Organizing Map**

I. Introduction

In today's automotive supply industry a majority of the products are developed by adapting or varying already existing products. This kind of product development is named here as adaptable product development. An important reason for such a development is that the enterprises in the automotive supply industry are forced to reduce the development costs and time [1].

What is today's approach for an adaptable product development in these enterprises? For a new development order, the designers take the previous solution as the development base and adapt it to fulfill the new request. An important prerequisite for this approach is that the changes of the requirements compared to the product variant, which is used as the base for the development, have to be identified. Hereby, components of the base product variant, which have to be changed, are recognized. The aim of the designers is to minimize the changes and to reduce the cost and time for the subsequent processes like manufacturing, assembling, etc [2].

From numerous research projects in the automotive industry it can be concluded that the designer usually does not select the suitable parent product which will fulfill the new customer requirements to its best, but selects the last product version as a base for the new development. The reason for such a poor selection is that, this knowledge is not documented in a way, which is feasible to work with. For the documentation the product requirements should be associated with the product characteristics clearly. Such an allocation cannot be carried out, because not all of the product characteristics are defined by the designer explicitly. In this case an expert system, which supports him to identify the implicit allocation, would help. A rule-based system has little prospect of success, because these systems usually assume that information is available explicitly [3]. In this paper the data mining method "self organizing map" (SOM) is introduced for solving the problem. Data mining means extracting implicit, yet unknown information from raw data [4]. Therefore the computer have to be enabled to search automatically after regularities and patterns in data and to carry out abstraction to get the structures of the implicit assignment as the result.

An important prerequisite for the application of data mining methods is that there exists a sufficient data base. Therefore these methods can only be used partially for a new product development. But for an adaptable product development the data from previous versions of the product can be used. It is assumed that the type of the requirements in the supplier industry remains constant and only the expression (values) changes. Hence there is enough data to use SOM for adaptable product development.

Furthermore for the handling of the requirements in a SOM based system it is essential to subdivide the requirements into elementary-textual components and to quantify them, i.e. to describe them with an unequivocal numerical value for representing in computer. For a new development order, which is given mainly by a change of values, the SOM is able to identify the requirement list with the most potential to fulfill the new order.

II. The Approach of the Research Project

For a successful procedure of this research, it is necessary to divide the main goal into the following sub goals:

1. The first aim is to define the requirements from the specifications of the Original equipment manufacturers (OEM) in elementary components and prepare them applicable for SOM
2. The second aim is the development of a SOM that supports the developer in a meaningful way with the accomplishment of the adaptable product development for a new order, which should be suitable for the intended requirements.

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A. Procedure for the creation of basic requirement components

In this project, specifications of different OEMs for bonnet locking systems (Fig. 1) have been analyzed. First all requirements have been extracted in original phrase and listed in a table. Not all specifications contain the same requirements. Care is taken that redundancy of describing similar requirement is avoided. Further the information which requirements are contained in each specification is documented. The acceptable thresholds of quantifiable requirements, like a maximum tolerance, which provides a secure functioning of the product, are varying in the specifications, so this information is also stored (Fig. 2). Qualitative requirements need to be stored in numerical values to be processable for the SOM. In a first approach these numerical values are determined by experts in workshops. Later a fuzzy-set will be applied to determine these.

Real products have a high number of requirements. Employability of SOM always needs a complete set of requirements. To determine missing requirements a structuring of requirements would be reasonable. Therefore classes containing requirements belonging together have to be found. On the one hand in small classes missing requirements are easier to detect. On the other hand the classification supports like a checklist not to miss a whole domain of requirements. Furthermore the handling of a high number of requirements is simplified.

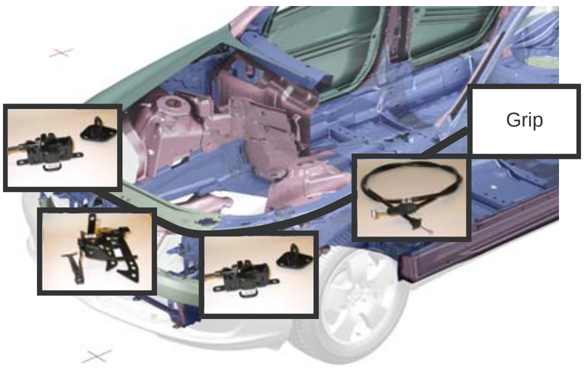

Fig. 1: Bonnet locking system

Anforderungsliste (Funktionale- und nicht Funktionale Anforderungen)	Theoretische Vorgabe	Einheit	Minimum 01	Maximum 01	...	Anteilige Gewichtung [%]	Variante 01	Variante 02	B 03		Variante 12	Variante 01	Variante 02	Variante 03	...	Variante 12
Eindruckkraft Motorhaubenverschluss	<25	N	-	24	...	50	36	25	25	14	4	67	96	96	171	600
Auslösekraft Verschluss	<33	N	-	31	...	30	10	5	15	20	5	310	620	207	155	620
Betätigungsweg	<7.5	mm	-	7.3	...	20	6	6	8	5	5	122	122	91	162	146
Kosten	<12.6	EUR	...	...	...	...										
Akustik beim Auslösen	<inf	sone	-	inf	...	0						0	0	0	0	0
Eindruckkraft Motorhaub A luss	<38	N	-	37	...	55	25	36	25	14	4	148	103	148	264	925
Auslösekraft Verschluss	<33	N	-	31	...	25	5	10	15	20	5	620	310	207	155	620
Betätigungsweg	<6.5	mm	-	6.3	...	20	6	6	8	5	5	105	105	79	140	126
...	...	...	...	...	...	...										
Akustik beim Auslösen	<5	sone	-	4.8	...	0			C			0	0	0	0	0
Eindruckkraft Motorhaubenverschluss	<45	N	-	44	...	30	25	36			4	176	122	176	314	1100
Auslösekraft Verschluss	<24	N	-	23	...	40	5	10	15	20	5	460	230	153	115	460
Betätigungsweg	<7.5	mm	-	7.3	...	10	6	6	8	5	5	122	122	91	162	146
...	...	...	...	...	...	...										
Akustik beim Auslösen	<6	sone	-	5.8	...	20		5	5	4		0	109	116	145	0
Eindruckkraft Motorhaubenverschluss	...	...	-	-	...	0						0	0	0	0	0
Auslösekraft Verschluss	...	...	-	-	...	0						0	0	0	0	0
Betätigungsweg	...	...	-	-	...	0						0	0	0	0	0
...	...	...	...	...	...	...										
Akustik beim Auslösen	...	...	-	-	...	0						0	0	0	0	0

Fig. 2: Table containing requirements in original phrase (German) (A), different requirement lists (B), quantitative thresholds (C)

A reasonable approach to classify the requirements is by comparing their interference with each other using a matrix method. They belong to the same class; if they have a strong positive interference with each other, e.g. the requirements specifying the forces needed for locking and opening of the bonnet have such positive interference. To analyze these interactions a matrix is built up, which contains every requirement twice, once in a heading of one column (A) and once in a heading of one row (B) (Fig. 3). In every cell of the matrix a number is put down to describe the interaction between the requirement in the heading of the column and the requirement in the heading of the row. A positive interaction between these requirements is marked with a „1", a negative with a "-1", no interaction with a "0".

Subsequently the requirements are rearranged in that way, that the requirements interacting with each other are closest together. The matrix after the rearrangement is shown in Fig. 4. Thus the classes are visible: A high number of "1" is recognizable close to the diagonal of the matrix. These are grouped in blocks (C). Requirements belonging to one block constitute a class. Interactions between classes are noticeable by a "1" or a "-1" outside the mentioned blocks (D).

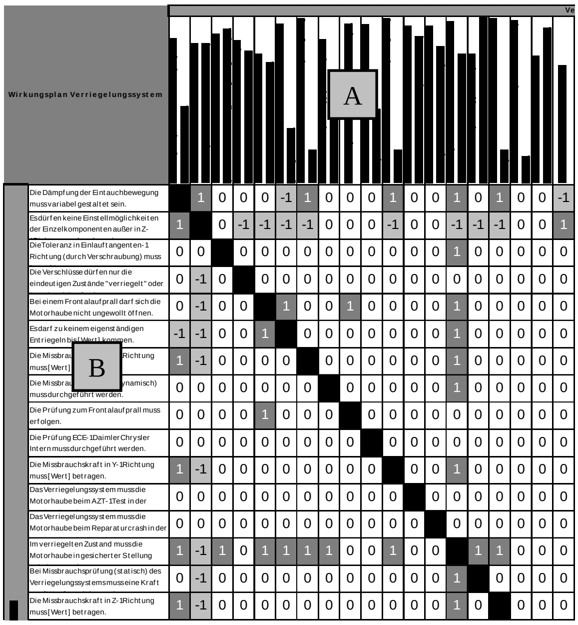

Fig. 3: Matrix showing interference of requirements (A) and (B)

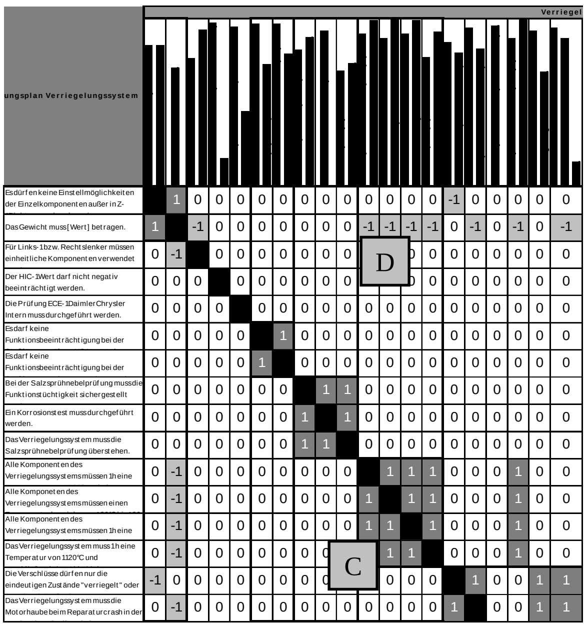

Fig. 4: Rearranged matrix showing classes (C) and interaction between classes (D)

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For the communication between OEM and supplier the textual describing of requirements is not convenient. Therefore the visualisation of the requirements could be helpful. SysML is a domain-specific modelling language developed as a variant of UML for the specifying, analysing and designing a broad range of technical products [5]. Thus a second description of the same product is introduced, imaginable like a visualisation of the same product in different layers (Fig. 5). On the SysML layer the product is modelled in a use case schema. The changes, which occur during the communication with the OEM, can be adapted directly in the use case schema. The use cases in the first layer are connected with the class diagrams in the second layer. In this layer the properties, functions, and attributes of the classes are described by the changes of the use cases.

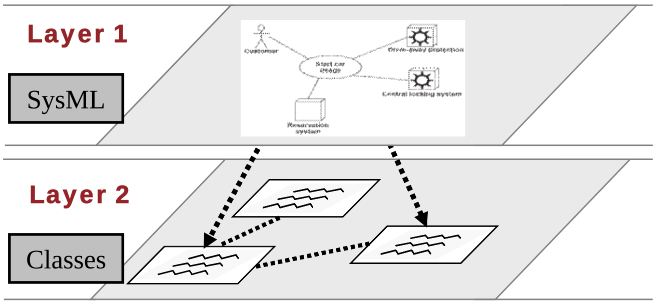

Fig. 5: Layers of product description

Before setting up the product model according to SysML, the requirements have to be standardized linguistically. Requirements contained in specifications are normally written in prosaic text, so different OEMs are phrasing their requirements differently. Hence the requirements have to be transformed in unambiguous and clear textual components. The elementary textual components of the requirement should be described according to the VDA-reference (German Automotive Association) [6].
The VDA has developed a guideline which aims for describing unambiguous and complete specification of a product, which is necessary for a precise communication between OEM and supplier. Therefore all requirements are formulated consistently in clear elementary textual components, by what the quality of the specification is improved and errors due to the large space for interpretation are avoided. This translation of the requirements into the standardized textual components enables the requirements to apply them to SOM.
The elementary textual components, which should consist of subject, object and predicate should be set-up especially for the automotive industry and should be stored in a database. The user uses these defined components to describe the requirements. In addition there is a “weak word-list” containing words not to be used. An example for a translation follows: The requirement in direct quotation of the specification is “In case of a front impact, the bonnet must not be opened unintentionally.” Transformed according to the VDA standard the requirement will be “For a front impact (condition) the locking system (subject) have to (demand-word) keep the bonnet (object) closed (keep ... closed = action) (Fig. 6).

B. SOM basics

SOM is a special data-mining-method, which is used to identify and furthermore to visualize complex numerical coherences.
The generic term 'data-mining' includes a great number of so called 'knowledge-generating' methods. These methods are mainly used to detect complex coherences in data, mainly in those cases where common statistical tools will not generate satisfying solutions [4].
Based on historical data of a product, for example, real reasons for quality-defects of that product can be detected, even though these causes are hidden in the data [4].
Several powerful methods and algorithms were developed, each with specific capabilities (random-forest, support-vector-machines, neural networks, etc.) [7]. The correct use of these and other methods will finally result in an expert-system which can be used for classification, approximation and prediction [4].

[Precondition] – optional — For a front impact
Temporal aspect. State of the system or the environment.

[Subject] — the locking system
The executive element, e.g. System, Subsystem, User etc.

[Demand-word] — have to
Have to, ought to, can; refers tothe subject

[Action] — keep... closed
Verbs

[Object] — the bonnet
In the action involved elements

Fig. 6: Basic requirement components

The SOM is a special architecture of artificial neural networks. Neural networks are information processing structures, which have been built up with the knowledge of the function of the human brain. They consist of a large number of highly interconnected elements, called neurons. Between the neurons, there are connection weights, which are established through the learning process. Through the adjustment of connection weights, such a network is able to in to recognize structures and to generalize them. Basically there are two kind of learning methods: supervised and non-supervised. In a supervised learning method a training record including the desired results is given. The network has to learn the relationship. For a non-supervised learning there is no desired output. Networks with this learning method are used for clustering. SOM belongs to the non-supervised learning systems. This makes them suitable for the mapping of the requirements.

C. Realisation of SOM for adaptable product development

The first step is to create a fitness matrix based on the table shown in Fig. 2, in which the original requirements are substituted by the standardized requirements. Next a non-supervised learning is carried out: The existing requirement lists of realised product variants are applied to SOM. SOM is able to determine whether two requirement

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lists are similar to each other or whether they are different and further to quantify this by a fitness value. In case of a high degree of similarity the fitness value is “1”, in case of no similarity the value is “0”.

To gain a high reliability of the SOM, it has to be trained with high number of requirement lists. A sufficient number of requirement lists is higher than the number of requirements. In case the number of available requirement lists is insufficient, the number of requirements has to be decreased. It is currently checked, if the application of modules and therefore a lower number of required training sets on SOM is sufficient. A main problem is the non-consideration of the interactions between these modules. It has to clarified, how this can be compensated.

The following example shows how for a new order and therefore for a new requirement list (AL04) the suitable variant can be chosen. In Fig. 7, the fitness values for the requirement lists "ratngv05", "ratngv06", "ratngv07", "ratngv08" are displayed. A fitness value close to “1” stays for a high fitness value and therefore for a high suitability of the product variant to be chosen as the development base. From this figure it can be derived that the variant "rangv06" is the most suitable for the new order.

	Zielgrößen			
	ratngv05	ratngv06	ratngv07	ratngv08
SOM-Fitness AL04	0.34	0.85	0.67	0.54

Fig. 7: Fitness values for different requirement lists

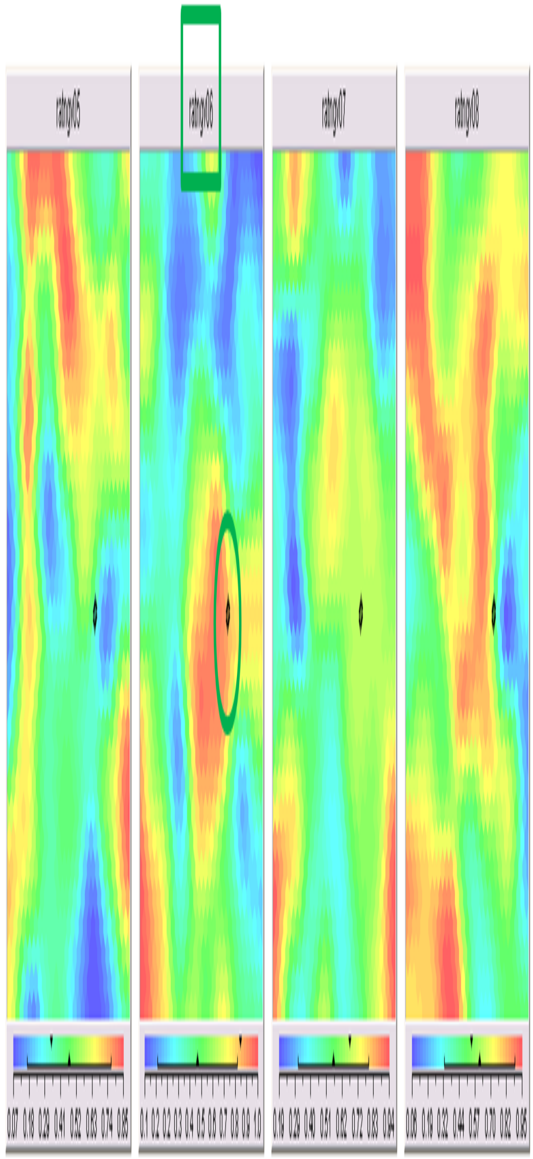

Fig. 8: Fitness landscapes of different requirement lists

The capability of existing requirement lists as a development base can also be visualized by a fitness landscape. Fitness values for sets of requirements, with all requirements varied, are displayed. In Fig. 8 the requirement list AL04 is displayed as a small black comb. It can be confirmed that the variant "ratngv06" has the highest suitability. In addition, the graphical representation as a fitness landscape has the advantage that the stability of the solution can be assessed. In case of two requirement lists assessed with a similar fitness value, the stability can be a further criterion for the selection of a requirement list. A comb in a large area indexing a high fitness value seems to be more robust against further modifications. Thus the selection of a variant with a high stability is more convenient.

In case of a slight modification of the requirement list AL04, the examination of the areas around the combs shows, "ratngv06" is still a suitable one, but the variant "ratngv08" could also be an appropriate solution, because an area indexing a high fitness value is close to the comb. Thus, the graphical analysis provides valuable insights and analysis capabilities.

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III. SUMMARY

The goal and the novelty of this research project are to apply a SOM based system to shorten the time for conceptual design of an adaptable product development. This can be achieved by the application of the SOM-based system to identify existing solutions that are suitable as a development base for a new product order. The selected product variant can be adapted with a minimal effort for the new product order. This increases the customer satisfaction, because the new product is based on an approved product.

To apply requirement lists to a SOM based system, requirements have to be quantified and standardised. The quantifiable requirements can be processed easily. The qualitative requirements are difficult to process; these have to be transferred by the designers into numerical values. In a later stage of this project, the aim is to apply a fuzzy set for the determination of these values.

The basis for the requirements to be processed with SOM is the description of the requirements in elementary standardized components. For this a VDA guideline can be used as a basis. Further a description of the requirements according to this guideline eases the communication between OEM and supplier due to the clear phrasing. This reduces the number of iteration loops and therefore the development time and costs.

Classification of the standardized requirements is necessary to detect missing one and to make a great set of requirements manageable. In combination with a use case schema modelled in SysML a product data model is established, which can be used for the communication between OEM and supplier and which can be applied directly on SOM.

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