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PRE-ACQUISITION CLUSTERING OF REQUIREMENTS – HELPING CUSTOMERS TO REALIZE WHAT THEY WANT

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ABSTRACT

This paper introduces a new method to group requirements according to different topics to create a catalog of requirement clusters, which lead to an easier and more complete process of requirement acquisition. The creation of the requirements list of is one of earliest and most important steps in the product development process. The quality and quantity of the requirements have a high impact on the costs, the time needed and the required iterative steps in the product development process. Standards for this process are hard to find, for every development project is inimitably and therefore happens under significantly different conditions. Up to now the clustering of requirements is only used to structure the product-requirements after the detection for further and more systematic use. The method presented in this paper will help to structure requirements before the process of acquisition to create specific clusters, which lead the customer to a more complete and more efficient acquisition process. These clusters help the customer to substantiate his wishes. Furthermore the generated clusters represent a storage of implicit knowledge, in which information is recorded.

Keywords: requirements, requirement clusters, requirement acquisition

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1 INTRODUCTION

One of the biggest problems in the process of requirement acquisition is overcoming communication problems between developers and customers. The use of different terms, as well as imprecise and non-standard words often lead to misunderstandings and produce incorrectly conceived requirements. In later stages of the product development process these errors and resulting decisions can only be corrected with great effort, which leads to significantly higher costs. As customer satisfaction has to be one of the highest priorities for a company, communication problems concerning requirements (Dutoit et al. 2006) should be prevented in the early phases of the product development process. Requirement clusters are a collection of various requirements assigned to a topic area and are supposed to facilitate the process of requirements acquisition. The incomplete acquisition of requirements leads to iterative steps and increased communication with the customer, which in turn increases costs. Up until now, the clustering of requirements appears only after the process of acquisition with the purpose of structuring them for the further development process. Röder et al. (2011) proposed a method to create a cluster catalogue before the process of acquisition for faster and more complete requirement acquisition. This paper introduces a method to create these requirement cluster based on a word mining approach. The basic method was tested in a small case study and showed potential to identify and clarify implicit and fuzzy requirements.

Once the basics of the overall requirement cluster method and other applied methods are introduced in Section 2, the method for creating clusters is described in Section 3. A short example of application and validation experiences with student groups is given in Section 4. A final conclusion and the outlook are given in Section 5.

2 METHOD OF REQUIREMENT CLUSTERS

The method of clustering requirements is a known concept, however, the approach described by Röder (Röder 2011) is fundamentally different from previous clustering methods. Clustering methods are used in the field of requirement management, meaning after the acquisition process. They are used to structure identified requirements using a given hierarchy. Therefore, their aim is to improve clarity in subsequent processes. The methodology of requirement clusters by Röder is designed to improve the process of requirement acquisition. Thus, general requirements are clustered and saved in the form of a requirement cluster catalogue that can be used for the requirement acquisition of a specific project. Naming one requirement or a defined term during the process of requirement acquisition can activate other requirements that belong to the same cluster as the initial input, meaning they have some kind of connection. The activated, standardized and project-specific requirements are given to the customer, who can specify a target value for the requirements or add their necessary requirements. The requirement list that is created afterwards consists of the standardized, product-specific requirements and those that have been added by the individual customer. This method tries to improve the acquisition of requirements by identifying relevant requirements by using requirement clusters and reducing the time needed due to the standardized procedure.

An integrated requirement model has been developed to categorize and describe the different kinds of requirement clusters. The different spaces of the model imply different types of requirement clusters so that a complete description and classification of all possible cluster types is possible. Besides the categorization of different requirement cluster types, the model can be used to derive methods for the creation and usage of the different cluster types. Due to the wide range of requirements and requirement sources the integrated model combines the key elements of various other models to cover all requirement types that can occur. The key elements of the integrated model are the product pyramid model in the variation by Sauer (Sauer 2006); the common idea to divide requirements in a solution and a problem space category; approaches for an algorithm-based product development process leading to the systematic restriction of the solution space (for example, Wäldele 2008); the concept of process modeling by Heidemann (Heidemann 2001); and the basic utility theory of economics. These model elements are combined to give an integrated view over the range of possible requirements and their connections to derive the requirement cluster. The complete integrated requirement model can be seen in Figure 2. After a short survey of the model it is used to classify the method described in this paper in the overall context of the requirements cluster methodology.

The overall model space is divided into a solution neutral space, a solution specific space and a restriction space. A basic rule of requirement acquisition states that the customer should define

solution-neutral requirements to prevent unintended and unnecessary limitations in the field of possible solutions. However a customer must always have the opportunity to define non-solution-neutral requirements, although they should be scrutinized. Requirement clusters of layers of the solution specific space should primarily be defined by the development team before and during the development process. Some of these clusters are a non-solution-neutral transformation of the solution-neutral requirements, transferring them out of the solution neutral space.
The top layer of the pyramid model describes a Pareto-inefficient condition of the customer. An idea or information triggers a process through which the customer realizes that there is a target condition state (S2) that he prefers to the current condition state (S1) based on his aggregate individual utility preference function (U). At this layer, requirement clusters describe a relative deficit of the customer. The current condition and the preferred target condition can be described using property vectors (Gramlich 2013). The customer has a unique preference (p) for each property vector, which valuates the attributes and different values of a vector. The mathematical description can be seen in the formula below.

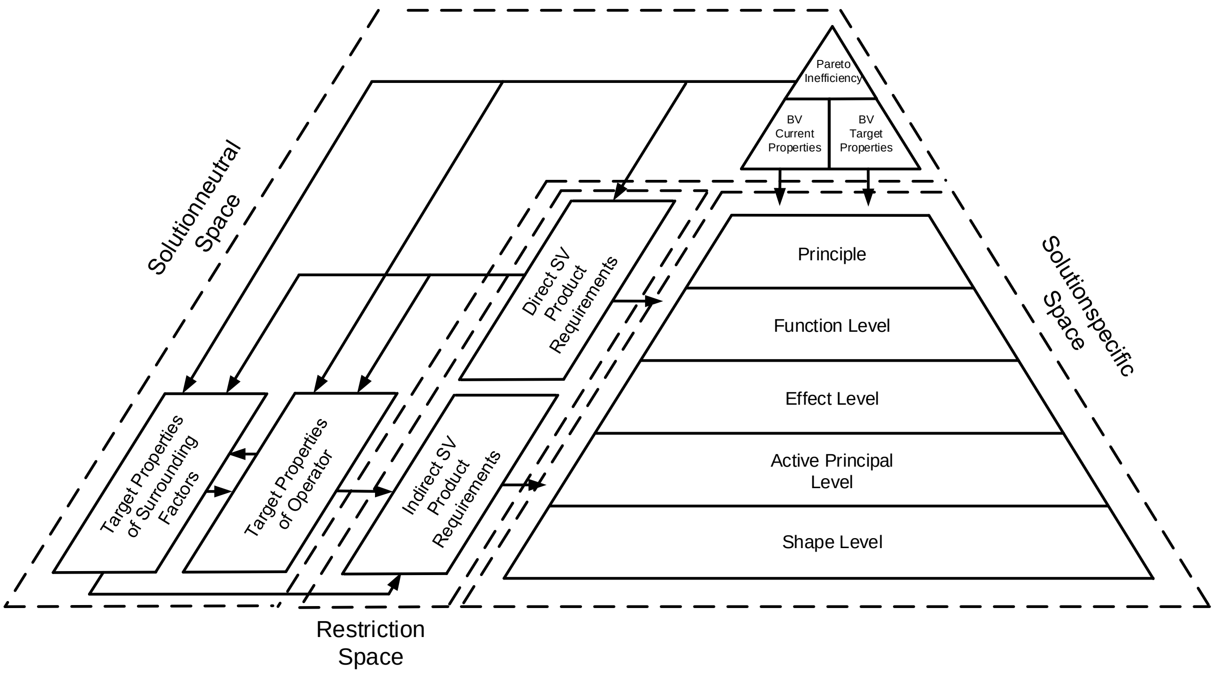

Figure 1: Integrated model for requirement categorization

Thus property vectors can be ranked and brought to an ordinal order based on the overall utility function. Regarding requirements, the property vectors (E) can be divided into base vectors (BV) and side vectors (SV). Base vectors describe the core target property vectors that cause the Pareto inefficiency and describe the desired target state by which the customer can achieve a higher level of utility. The base vector describes the current and desired state of the operand in the process of usage. If the desired properties of the base vector are not achieved through the development process, the entire development process is unsuccessful. The basis vectors of the current state and desired target state define the solution space of the development project.

$$\begin{pmatrix} E_1 \\ E_2 \\ E_3 \end{pmatrix}_{S_1} p_{BV} + \begin{pmatrix} E_4 \\ E_5 \end{pmatrix}_{S_1} p_{SV} = U_{S_1} \leq U_{S_2} = \begin{pmatrix} E_1 \\ E_2 \\ E_3 \end{pmatrix}_{S_2} p_{BV} + \begin{pmatrix} E_4 \\ E_5 \end{pmatrix}_{S_2} p_{SV} \qquad (1)$$

The properties of a side vector can also increase the utility level, but only in combination with the transformation of the base vector to the desired state. Side vectors can be divided into two categories. Direct side vectors of product requirements are non-solution-neutral requirements describing the product itself and are directly named. Indirect side vectors of product requirements are non-solution-neutral requirements derived from process requirements following the idea of Schott. On the other hand solution specific requirements can result in solution neutral (process) requirements. (Schott

1997). Requirement Clusters are a helpful tool to support both transformations. Side vectors always limit the solution space.
The core of the solution space is the product model pyramid. From each possible solution at each layer a connected requirement cluster can be derived. These requirement clusters gather the essential properties which define the specific solution. Connected to that can be the fixation or ranging of connected values.
Using the vector model of target properties, various types and phenomena in requirements can be described. Implicit requirements can be described as a set of property vectors for which the customer knows their preference and the properties but does not mention them or mentions only some of the properties of the vector, but all of them are rated by the preference factor.
There are requirements which are only defined at a macro vector level. This means the customer knows their preference regarding the vector and can name the overall vector, but is not able to name the single properties of the vector. An example of this type of fuzzy requirement cluster is the requirement “design”. Everyone has certain preferences regarding the design of an object, but for most people it is hard to name the connected properties. Only long interviews and the comparison of different designs of the same product can help to extract the properties influencing the design and so belonging to the vector. In many cases these vectors are product specific too. For example, for a smart phone a property of the design vector could be the radius of the corners, which is not a relevant property for the design vector of cloths.
In this paper a method based on the idea of word mining will be introduced to generate requirement clusters and help extract the properties of fuzzy target property vectors or incomplete target property vectors leading to implicit requirements.
The foundation of being able to extract factual content of texts and relationships from unstructured textual data with mathematical and statistical methods for cluster analysis is provided by the method of text mining by Heyer et al. (2006). Heyer says “Text mining indicates computerized procedures for the semantic analysis of texts, which support automatic or semi-automatic structuring of especially large texts”. For this proposed application these fundamental steps have been modified to cluster requirements. The core steps to cluster requirements are the same as used in the basic concept of text mining. The steps have been modified and the concept of text mining has been put in an overall process to fit the special requirements and circumstances of the method of requirement clustering. A detailed guide of the steps of the newly developed method is given in Section 3.
This paper does not give final evidence about how efficient fuzzy and implicit requirements can be identified, but introduces the general method and shows an initial indication in a small case study, which implies the identification of fuzzy properties and implicit requirements through this method. As a first approach, this paper will explain the overall method and show some results based on student groups. These results show initial logical implications through which fuzzy and implicit requirements can be identified.

3 METHOD

The sequence of the method "Pre-Acquisition Clustering" is illustrated as a flow diagram in Figure 2. The method consists of six steps, one of which is the adapted text mining method. The engineer is involved in all stages of the creation of the cluster catalogue, but with a different impact at each step.

3.1 Creation of the checklist and definition of preambles

The basis for the selection of the key words used in the interviews is a checklist such as the one proposed by Pahl et al (2007). The engineer decides which key words of the checklist are relevant for the creation of the product specific clusters. These key words are defined as preambles. The intuitive extension of the checklist with more useful preambles is possible. Ideally no more than 15 preambles should be defined to focus the interview. The checklist is required to be able to execute comparable interviews to standardize them. The preambles form keywords to which the test recipients can name their requirement orientated associations.

3.2 Definition of boundary conditions

The interview must be standardized to ensure similar conditions for all test persons. Only with the exact same process can the respondent answers be compared. For the interview boundary conditions the following issues have to be clarified. The number of interviews which will be executed: With an increasing number of interviews the representativeness of the results is improved. Consequently, the generated clusters gain objectivity. Another is the age and the background of the test persons, for example, the sex, occupation or the financial situation have to be set. The socio-demographic factors have to be set specifically for the customer and the product. Also, it has to be clarified which role the interviewee occupies (buyer, obtainer or user). This depends on whether the product is for consumption or is an investing item. Finally, it has to be decided whether there is an opening question or not. The use of an opening question depends on specific knowledge of the customers and is meant to facilitate the entry into free speech.

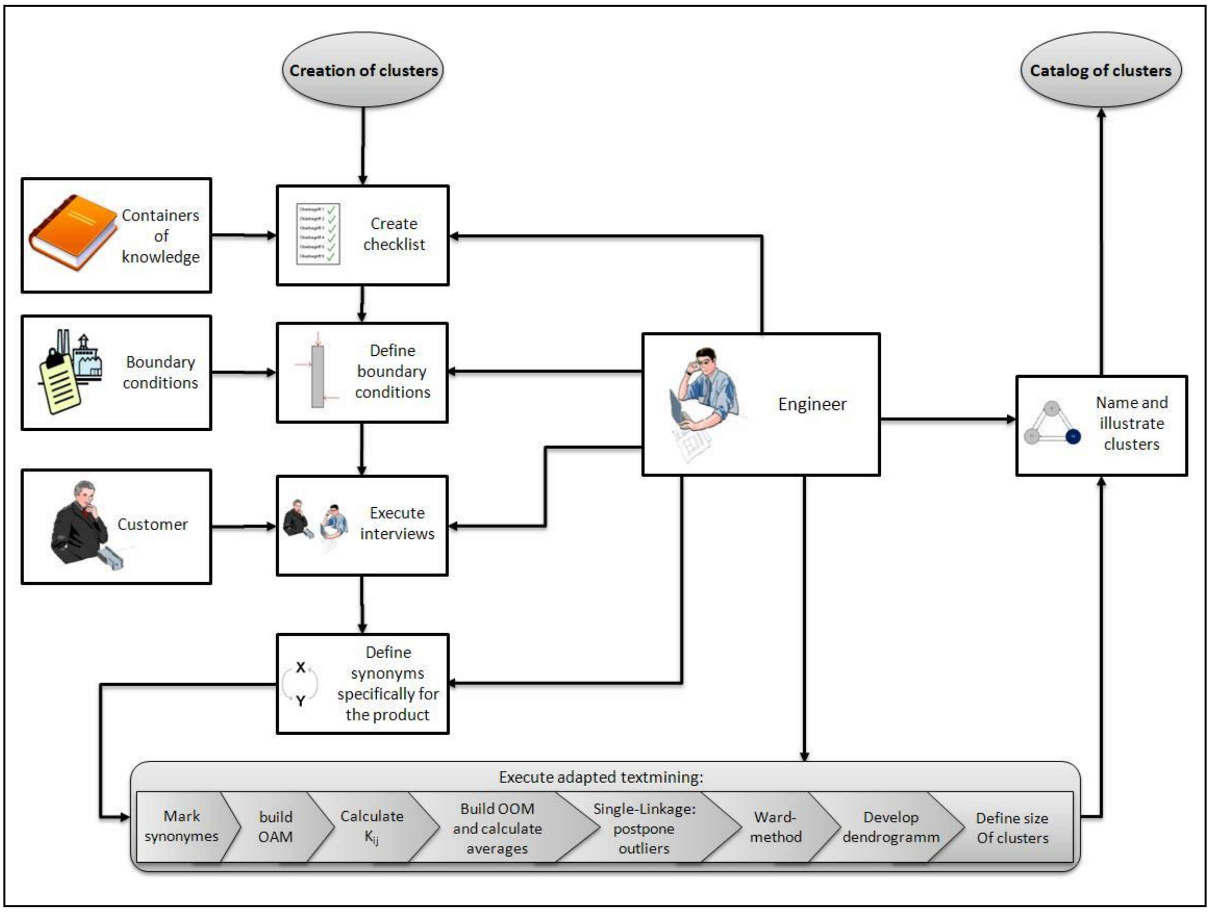

Figure 2: Schematic representation of the method Pre-Acquisition Clustering

Interviews are always product specific. The answers given cannot be generalized. As already mentioned, the answers given for the design of a smart phone cannot be used to design any other object. In special cases the interview part of this method could be replaced with a latent sematic analysis. This has to be thought through by the user. For this study, interviews have been chosen because they deliver satisfying results in all product fields.

3.3 Execution of interviews

As a basic document for the adapted text mining process, the interview has to be documented in written form. Therefore they may be recorded and typed afterwards or may be written down directly by computer programs. If an opening question is used the interview will start there. Then, regardless of the answer, all the preambles of the checklist are asked in order, while the interviewee must take position and name requirements and associations to each. The structure of the interview thus consists of a free section and then one paragraph each for all generic terms. The interviewee is not allowed to take notes or use any other records, because the answers are to be given spontaneously. The first idea thought of should also be said first. The answers should be formulated as freely as possible. Likewise during the conversation sketches are prohibited, because the method can’t extract the information given by them. The interviewer behaves predominantly passively and may only provide assistance if the preambles are misunderstood. Any influence shall thus be avoided, so the interviewee is not primed.

3.4 Definition of synonyms

Synonyms for each preamble of the checklist must be established and documented. Up until now, this has been done manually by the authors of this method. Rolland (1992) shows some basic approaches to identifying synonyms in an automated way. Her ideas could be adapted to achieve a higher level of automation, but leads to the same result.

Either way, all interviews must be analyzed concerning the wording and the connected statement. For example, it is conceivable that the interviewee wants a good ratio of value to costs and names the word “price”. In this case, price would then have to be defined as a synonym for costs so that this information is properly allocated and therefore not lost. For the following analysis, it is essential that all preambles are identified in the interviews. Before the interviews are evaluated, the synonym list should be complemented and therefore adapted to the development of the interviews. Each synonym must be clearly assigned to a preamble.

3.5 Adapted text mining

The synonyms list in connection with the recorded interviews is used as a basis for the adapted text mining (Figure 3). Up to step six (the creation of a dendogram), the adapted text mining is very close to the text mining proposed by Heyer et al. (2006) and other advanced text mining methods. The original text mining is only put in the context of requirements and slightly modified. Thus in the first step paragraphs are analyzed instead of sentences, and preambles are compared to all of the words of the sentences analyzed. The mathematical operators of the next steps are used almost identically. Only the last step, which sets the cluster size, is a new procedure fitting the requirements of the overall cluster method. The text mining has been adjusted to the requirements analysis.

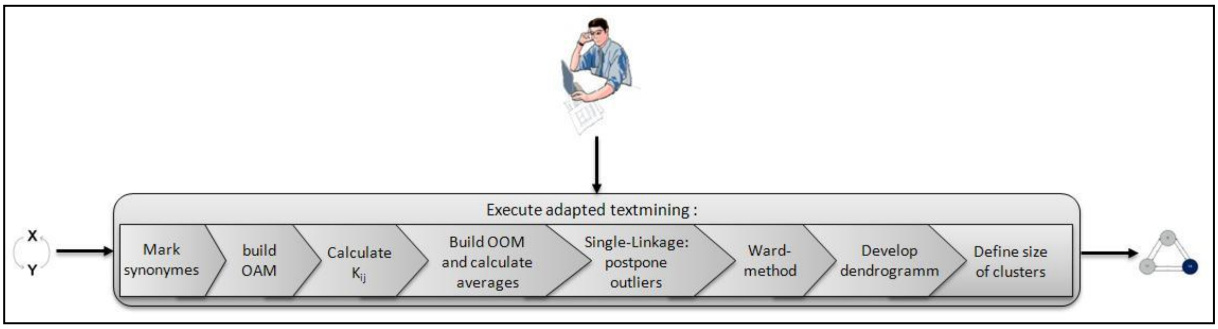

Figure 3: Schematic representation of the text mining

During text mining the following steps have to be accomplished:

All synonyms in the paragraphs have to be found and marked. In comparison to the original text mining after Heyer et al. (2006) which analyzes only individual sentences, each paragraph of the interviews will be analyzed for the presence of preambles by using the synonym list. It is helpful to note the identified preambles at the side edge to facilitate the creation of the OAM.

In this preamble paragraph matrix (OAM), the preambles of the checklist are noted in the columns and the individual paragraphs of the interview are noted in the rows (see Heyer et al.(2006)). If a preamble is found in one paragraph, one or several times, a one ("1") is entered in the corresponding cell; if it is not found, a zero ("0") is entered. Consequently, it is irrelevant how often synonymous of the preambles are found in a paragraph. Additionally, by summing up the columns, the values of K_i are calculated for each preamble.

For the calculation of all K_{ij} a symmetrical matrix of the preambles is created. This matrix is used to register how often two terms occur together in the same paragraph. The foundation to be able to enter the values of K_{ij} is the OAM. Whenever a one ("1") is indicated in a paragraph for two different terms respectively, the value increases by one for K_{ij}. This matrix is not binary; higher integer values can be calculated. Although the actual processing steps of this operation are trivial, experience has shown that the manual implementation of this step is very prone to errors.

In the next step, the preamble preamble matrix (OOM) has to be created and the averages have to be calculated. The OOM is created by calculating the Dice coefficient, as shown in Equation 2:

$$sig_{dice}(t_i,t_j) = (2 * k_{ij})/(k_i + k_j) \quad (2) \tag{2}$$

with k_i= number of paragraphs containing the preambles t_i; k_j= number of paragraphs containing t_j; k_{ij}= number of paragraphs containing t_i and t_j.

If several interviews are being executed, an individual OOM has to be created for each interrogation. The values of all OOMs will be averaged after all interviews are done in just one averaged OOM. This final matrix is the basis for the following steps.

Then, in a preliminary step, outliers have to be reset. The single linkage method is used to create a first dendrogram. With the help of a dendrogram the results of the previous steps can be shown in a graphical form. For this step the use of statistical software is recommended, especially to automate the resetting of possible outliers. These can easily be identified in the dendrogram: outliers are the last to be combined with the other clusters and often have a larger separation from the other clusters. The outliers must then be deleted from the average OOM, which is formed from the average values of all interviews. The outliers reset in this step are the basis for a separate cluster. Special attention has to be paid to the outliers because these are requirements which are either implicit requirements or often forgotten by the customer.

Once the outliers are removed from the data set the Ward's method can be applied. The high computational complexity at this point requires the usage of statistical software. As a distance measure the Squared Euclidean distance is selected to be able to do the amalgamation by using the Ward's method. The Ward's method provides a classification overview in which the order of the individual preambles are fused. This process is then graphically represented in a dendrogram. The numbering (Num) of the dendrogram represents the preambles.

Finally, the last step can be realized in two ways: static with the elbow criterion or dynamically, depending on the user. The elbow criterion, when combined with the classification overview from the Ward's method, can show the development of the measure of heterogeneity associated with the number of clusters in a graphical representation form. If there is a bend in the graph ("elbow"), the optimal number of clusters – after the criterion – is found. The disadvantage of this method is that the curve can run very smoothly and therefore it can be very hard to impossible to identify a bend. The elbow criterion does not distinguish between users. The more knowledge a user possesses of a certain topic, the greater should be the size of the cluster. A more experienced user can identify the connections between requirements and knows how the adjustment of one requirement will affect other requirements. The variation of the cluster size with adaptation to the user is called "dynamic cluster sizing". After determining the number of clusters the specific arrangement of the clusters can be made.

3.6 Naming and representation of clusters

The existing OAM and the final dendrogram are used yet again. Each resulting cluster forms a mind map (Figure 4). First, all preambles are listed for each cluster. While neglecting the first paragraph, how often the preambles are mentioned in the other paragraphs is further investigated. The specific number is noted on the connection arrows. It may occur that the numbers of arrows coming in and going out take on some very different values. When the mindmap is created, the sum of the inputs and outputs is formed. The one preamble with the largest sum is eponymous for the cluster. In the example shown in 5 this would be the term "Ind. C "with a total sum of 20.

The parting results in different levels of the clusters. The naming of the sub-cluster stays the same. Two or more preambles are considered and the compounds are evaluated. Again, the preamble with the largest sum of arrows coming in and going out is eponymous for the sub-cluster. When naming a cluster which consists of only two preambles, the summation inevitably falls off. In this case the preamble with the larger output is eponymous.

4 CASE STUDY AND DERIVED RESULTS

This chapter shows the influence of the experience of the interviewees on the cluster size using a small case study. As stated before, this case study gives no final evidence about the efficiency of using the method to acquire fuzzy and implicit properties of property vectors, but shows the functionality of the basic method and sets the foundation for future research.

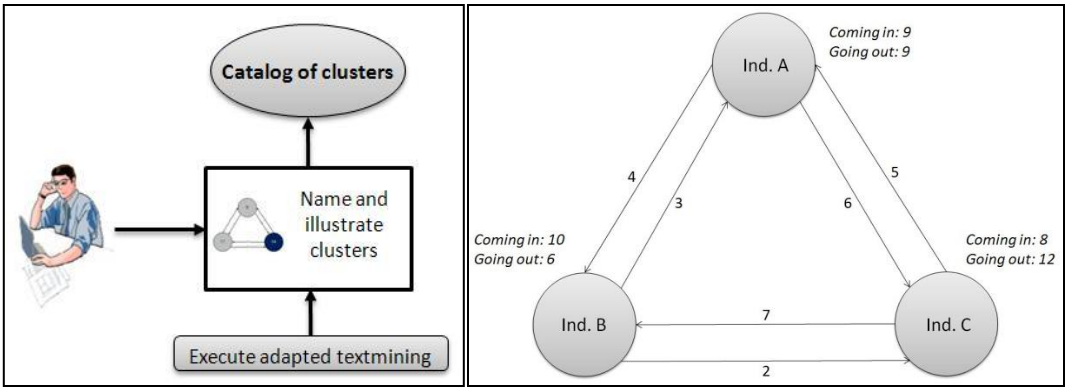

Figure 4: Schematic representation of the naming of the clusters (left) and a mindmap of a cluster

Therefore a comparison between interviews of experienced subjects (PhD students) and subjects not familiar with the topic of product development (undergraduate students – referred to as laymen) is carried out. The experts are PhD students and work as research associates. The subjects without special knowledge in product development are undergrad students from unrelated disciplines. For the corresponding interviews the product example of a cinema poster stand made of welded, roll-formed elements is used.
The results using the Ward's method are shown in Figure 5. The elbow criterion provides a four-cluster solution for the dendrogram of the laymen. For the experts, the weakness of the criterion comes to the fore and provides no clear result. Although the classification is purely subjective, a four-cluster solution is chosen for reasons of comparison.

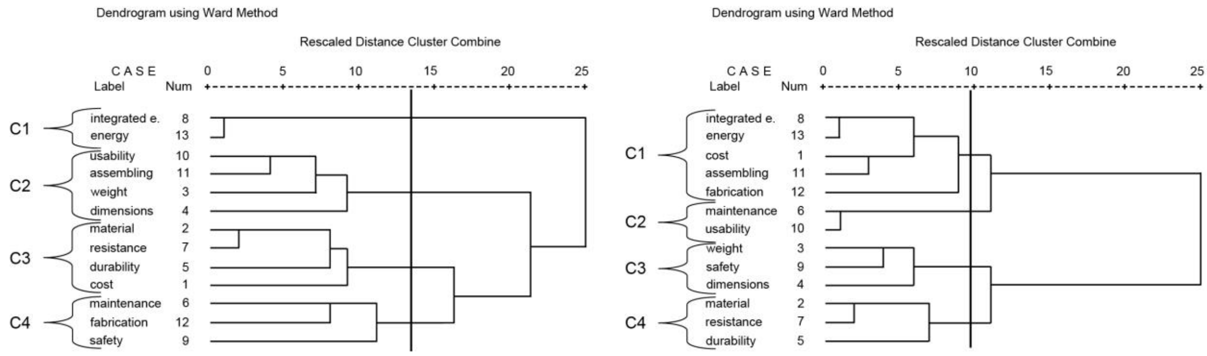

Figure 5: Ward's method applied on laymen (left) and experts (the line indicates the cluster sizes)

Five clusters, one of which is the outlier “recycling”, form. For experts as well as laymen, "integrated extensions" and "energy" are included in the first cluster. In addition "cost", "assembly" and "production" are associated with this cluster by the experts. The fourth cluster is almost identical for "material", "stability" and "resistance"; the laymen allocated "costs" to the cluster, which is put in the first cluster by the experts. The clusters two (laymen: ease of use, installation, weight, dimensions; experts: maintenance, ease of use) and three (laymen: maintenance, manufacturing, security; experts: weight, safety, dimensions) differ significantly. Recommendations for the use of requirement clusters in the process of requirement acquisition can be derived. A dynamic design of the cluster size according to the customer is essential. Laymen are advised to use smaller and more specialized clusters with a lower level of complexity because they are overwhelmed by too large clusters where preambles cannot be assigned. It is therefore advisable to provide larger clusters for experts. As experienced users recognize the connections between requirements and can oversee the consequences of adjusting values of requirements. The experts focus on essential requirements. There is rarely a preamble that does not cross-link to other preambles. The experts have dealt with checklists so often that most of the preambles appear in the free paragraph. The two groups differ clearly in their ability to associate context for the preambles. There are significantly more outliers for the laymen than for the experts, where only "recycling" has to be deleted. This indicates that the laymen do not have the ability to classify the named preambles in the process. The laymen had problems with the terms "installation", "production" and "maintenance". The differences have then been neglected in the interviews. In comparison there are none of these incomprehensibilities in the experts. Looking at all interviews it becomes visible that for "repair", interviewees often talked about "usability". Therefore when "usability" is said, "maintenance" is often meant, which has to be seen critically when evaluating the newly developed method. When interpreting the results it must be considered that only 40 interviews have been executed. The small sample may not be representative, yet tendencies are revealed. The usage of the dynamic cluster size is shown in Figure 5. Depending on experience and classifiable knowledge level, for example, by questionnaires or professional years, different sized clusters are presented to the customers. In this illustration of the dendrogram the preambles that cut the dotted line together form a cluster:

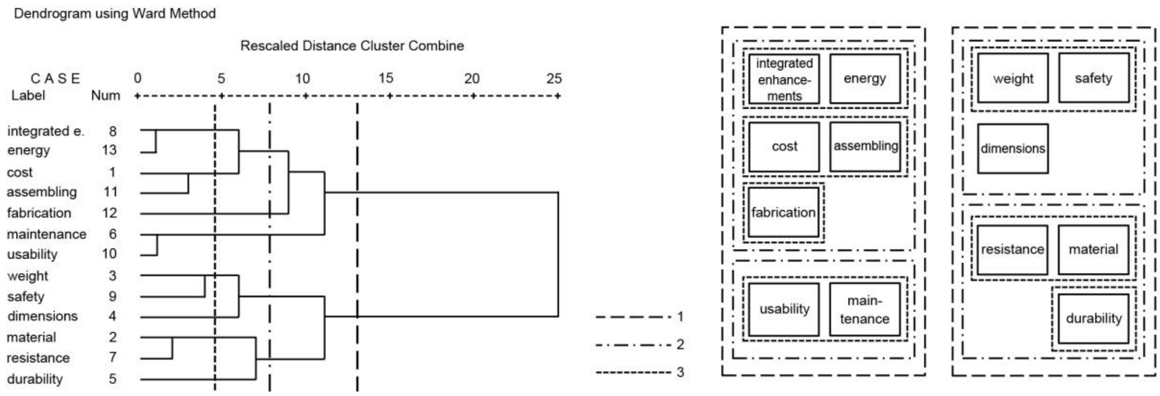

Figure 5: Dendrogram with dynamic cluster sizes (left) and the corresponding cluster levels

The allocation of the clusters with different limits is shown in Figure 8. The laymen would use clusters resulting in the cutting line number three, because those resulting clusters are smaller and well-arranged. The terms "assembly", "costs" and "production" are neglected in the laymen clusters, as these preambles have often been mixed up in the interviews. In this case the engineer would have to complete those clusters. Another advantage of the smaller clusters is the more specific naming. The process of naming is not affected by the variable cluster size. Again a mindmap of each cluster will be compiled. In this case the limits of the lines two and three are examined more closely. For each single limit different clusters are compiled. They can be divided into different levels. In this case, line three makes up level one, and line two equals level two. The bigger cluster (level two) would be used for experts, the smaller cluster would be suitable for the laymen.

Through this case study, some basic results can be derived.

Using the adapted word mining method, a reasonable requirement cluster can be created. The requirements in a cluster have a logical connection.

By averaging the results over many interviews, implicit requirements can be identified. Implicit requirements show up in the dendrogram as outliers. They are outliers because they are not often mentioned in connection with other requirements and/or not often mentioned at all regarding the average. An outlier can be either a requirement which is not important for the project or an implicit requirement. Further research has to be done on how outliers can be sorted into the two categories after identification. First results show that experts produce less outliers, meaning less implicit requirements. Integrating the outliers in the laymen cluster, following the structure of the expert cluster, could lead to less implicit requirements in the acquisition process of laymen.

This case study shows that an effective way to define fuzzy property vectors could be using the meta description of the fuzzy vector as preambles in the checklist. Through averaging it should be possible to define the main properties of the fuzzy property vector.

5 CONCLUSION AND OUTLOOK

In this paper a new method to cluster requirements of products before acquisition is proposed. The method is a tool for the overall methodology of requirements clusters by Röder et.al. Initial testing of the method Pre-Acquisition Clustering have shown promising and reasonable results. Iterative steps can be shortened and therefore money can be saved in the development process through the clustering of requirements. The cluster methodology leads to a more complete requirement list. The clusters made by the method not only simplify the communication between engineer and customer, but also function as an implicit knowledge base and therefore guarantee a more complete acquisition of requirements.

The acquisition of data happens in a subjective way by the customers. The analysis of the data is based on statistical methods, which objectifies the clustering. Additionally, the OAM is averaged over all interviews, which improves the results further. This method is a promising way to clarify fuzzy and implicit requirements, grouping them in logical clusters and, through this, offer a tool for an advanced and optimized requirement acquisition. The results have to be put in the context of the overall methodology. This method generates only a certain type of requirement cluster and only in combination with other cluster types can an optimal requirement acquisition be achieved through pre-acquisition requirement clustering.

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