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INTERPRETING KNOWLEDGE MAPS USING STRUCTURAL CRITERIA

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ABSTRACT
Companies have to develop their knowledge to provide more complex products to fulfill changing market‘s requirements. We have chosen a Multiple-Domain-Matrix (MDM)-based knowledge mapping approach to visualize companies' knowledge distribution, which divides company knowledge in three areas: tasks, knowledge and employees. From knowledge maps, weaknesses and strengths of knowledge distribution can be derived. In literature, only methods of graphical visualization were suggested to interpret such knowledge maps. These criteria are used to identify certain characteristics of knowledge structure. The developed methodology was applied in a department of a mechanical engineering company and critical knowledge elements were identified.

Keywords: knowledge management, knowledge maps, structural analysis, multiple-domain matrix

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1 INTRODUCTION

The increasing complexity and functionality of products generated by customer requirements and new technologies lead to an increased need of knowledge for the product development. Furthermore, rising staff fluctuation and demographic change lead to knowledge drain. To meet the challenges mentioned, the continuous development of the company's knowledge is necessary. The starting point of developing knowledge is the current knowledge distribution within the company. Therefore, the identification of current company's knowledge distribution is necessary to start the progress of knowledge.

In this paper, we use a Multiple-Domain-Matrix (MDM)-based approach including three domains: knowledge, tasks and persons. The MDM contains the knowledge distribution, which consists of domain-related elements and their relations. One approach of visualizing knowledge distribution is knowledge mapping (Eppler 2002). To build a knowledge map for the MDM-based approach, knowledge belonging to one or more persons and relations between knowledge, tasks (what the knowledge is used for) and persons (who possess the knowledge) were acquired within interviews. Using knowledge maps for this MDM-based approach, indirect relations between two tasks can be related if the tasks require the same knowledge to be accomplished. From these maps, advantages and disadvantages regarding the current knowledge distribution can be derived. An exemplary advantage identified by analyzing knowledge maps could be that the project manager has the same distance to every other employee in the visualized form of a knowledge map. Then, the project manager is closer to some employees and may neglect problems of the other employees. An exemplary disadvantage identified by analyzing knowledge maps could be that employees who need results from each other are not linked sufficiently enough. In this case, employees cannot work efficiently because the results of the other employees may not have the required quality.

A structural criterion is a metric for analyzing structures (Lindemann et al. 2009). In this paper, a methodology is built for interpreting knowledge maps using several structural criteria in terms of the knowledge distribution considering the employees and tasks within a company. Using these criteria, some findings were derived regarding the knowledge-driven integration of employees in their department or the importance of knowledge elements and tasks.

2 BACKGROUND: INTERPRETATION OF KNOWLEDGE MAPS

According to Newman (2003), a structure or a network consists of elements called nodes and relations between them called edges. The type of a structure depends on the categories the nodes and edges belong to. The structure is called social if the elements are people and the relations are kinds of contacts (Scott 2012) while an information or knowledge network describes the structure of information or knowledge, for example the world-wide web (Newman 2003). Organizational networks are closely related to social networks and cover beside people like clients or employees also processes, functional boundaries or tasks (Novak et al. 2011). According to Burton and Obel (1984), an organizational model also concerns inner activities of the firm, which is provided by the domain tasks of our MDM-based approach. The sort of network we are dealing within this paper is a combination of social network, informational network and organizational network, because the elements are related to the domains knowledge (informational), persons (social) and tasks (organizational). As Chan et al. used knowledge mapping for social network analysis (2006), we will use knowledge mapping for our network. In literature a lot of knowledge mapping methodologies exist (Eppler 2002; Horn 1989; Howard 1989). They differ in different criteria, for instance the purpose, the content, the graphic form or the creation method (Eppler 2008). The knowledge map's purpose is to visualize a great quantity of elements and relations in a manageable form. A collection of layouts to visualize information is given in (Herman et al. 2000), for example a tree-map whereas the color of rectangular elements represents the level of hierarchy (Johnson and Shneiderman 1991). In the knowledge mapping approach, the knowledge to illustrate is divided in knowledge elements. The representation of these elements and their relations depicts the structure of knowledge. According to Eppler, a knowledge element can describe experts, written text, applications or lessons learned (2002). We define a knowledge element in the same composition as Eppler's definition but an element is always needed to fulfill a task. So, a knowledge element is a definite range of knowledge which is required to accomplish a task. In a development department of an automotive company, a knowledge element could be the understanding of the Diesel cycle or the contact to the marketing department if this knowledge is needed for a certain

task. Eppler (2002) visualized knowledge maps by building different shapes for different kinds of knowledge elements. Gordon (2000) hierarchized the knowledge and developed accordingly a visualization with knowledge elements on different levels. The force-directed graph was applied for displaying knowledge distribution by Maurer et al. (2009). In this approach, knowledge elements and relations between them were shown while numbers of relations determine distances between elements. In these cases, the interpretation of a knowledge map happened by analyzing the knowledge map's visualization. This kind of interpreting a knowledge map is reasonable and useful for a vast quantity of elements and relations, but not accurate. Another approach to handle a great quantity of data without being inaccurate is the use of structural criteria, which were used to manage complexity in engineering context. These criteria derive findings from system's structure. For this, outgoing and incoming relations between elements or elements concerning relations are considered. An exemplary structural criterion is the element's active sum, which is the number of outgoing relations. It describes the influence to other elements (Lindemann et al. 2009). We will use a similar criterion to analyze our knowledge structure. Since active sum is only suitable for single domain structures, we cannot use active sum for multiple domain structures of our MDM. We will consider relations from an element to elements of other domains.
The application of these criteria on knowledge maps will show results, which are not deducible from the knowledge maps' visualization. For example, element's ability to change impacts in the structure cannot be extracted by analyzing a knowledge map's visualization but by calculating the element's criticality. To gain results, which cannot be generated by analyzing a knowledge map's visualization, several structural criteria were applied on a knowledge map to obtain characteristics of the knowledge structure.

3 METHODOLOGY: APPLICATION OF STRUCTURAL CRITERIA ON KNOWLEDGE MAPS

This section describes the methodology for interpreting knowledge maps regarding the development of company knowledge. The methodology is developed for a company within the engineering sector. We have chosen an approach for knowledge mapping based on an MDM because this approach allows the consideration of relations on and between the different domains. The above-mentioned challenges: staff fluctuation or more complex products - affect the knowledge through the employees and in the company's arising tasks. Accordingly, the MDM includes the domains' tasks, employees, and knowledge.

3.1 MDM-based knowledge map

The knowledge map implies the domains' tasks, employees, and knowledge. The domain tasks includes all tasks, which are executed by the regarded company. The domain employee includes all employees who work in the regarded company. The elements of the domain knowledge are the knowledge which are necessary for accomplishing tasks and which are possessed by employees. The relations between these domains are depicted in figure 1. Employees use knowledge to process tasks. Every cell of figure 1 describes a relation between two domains and can be presented by a Domain Mapping Matrix (DMM). A DMM depicts the links between the elements of two different domains. During the knowledge acquisition, it is sufficient to create three DMMs: One DMM shows which knowledge is necessary for which tasks, another depicts which employee process which task and the third DMM includes information about which employee possesses which knowledge. Other DMMs can be calculated by transposition.

	Tasks	Knowledge	Employees
Tasks		Require	Require
Knowledge	Necessary for		
Employees	Process	Possess	

Figure 1. Domains of the knowledge map

A high number of knowledge elements reduce the clarity of the domain knowledge. To make the domain knowledge also clear for a high number of elements, we split the domain knowledge in sub-domains. This makes the categorization of knowledge elements possible. The number of knowledge elements per subdomain can be used to analyze the domain knowledge. Maurer and Kesper (2010) defined the three knowledge sub-domains: competences, methods and networks. Since our case study was referred to a research and development department, we adopted the knowledge domain networks and added three further domains according to Wickel et al. (2013). Therefore, the domain knowledge is divided in following sub-domains:

- Fundamental or expert technical knowledge (firm-nonspecific knowledge)
- Knowledge of procedures (firm-specific knowledge)
- Knowledge of products (firm-specific knowledge)
- Internal and external networks (firm-specific knowledge)

A knowledge element of the subdomain network is an element the employee accesses indirectly by knowing another division of the same company (internal) or by knowing another company, e.g. a supplier (external). Fundamental or expert technical knowledge is the knowledge employees have learned during their education at the university for example. Knowledge of procedures refers to the processes and procedures within the company and is firm-specific knowledge. The knowledge of products is also firm specific and implies properties about the products provided by the company. Knowledge elements of these four knowledge subdomains occur in mechanical engineering companies. Other companies or organizations need the definition of other knowledge subdomains (Wickel et al. 2013).

This MDM-based knowledge map serves as system for structural analysis, which is performed within the next sections. Another option to analyze this MDM is the interpretation of the visualized knowledge map, which was already performed in (Wickel et al. 2013). Our methodology deals with the structural characteristics of a network. Other network's characteristics are focused on the relations' quality, the transactional content (Tichy et al. 1979), or the relations' strengths between two elements, the nature of the links (Tichy et al. 1979). Since our MDM-based approach does not imply different relations' qualities, consideration of these qualities will not give a benefit. Furthermore, the MDM-based approach does not provide different strengths for relations, analyzing this relations' characteristic will be also senseless for our case.

For the analysis of the knowledge maps' structure, we identify six structural criteria. The dimension of every criterion describes the current situation of the knowledge distribution within the company and is an interpretation of the knowledge map. These six criteria will be applied on the knowledge map of the case study in section 4.

3.2 Number of tasks per employee

The more tasks an employee has to handle, the lesser tasks can be accomplished, i.e. if the employee originally assigned to perform the task, is absent. This number can be seen as a measure for the employee's importance for the company. However, only the quantity of tasks is regarded, not the quality. If an employee has many tasks, and as far as the company is concerned; the terms of quality is not as important as the other tasks, this number negates the importance of the employee.

3.3 Number of knowledge elements per employee

This number is a measure for the knowledge-driven integration of an employee in the company. The more elements are available for an employee, the more tasks can be fulfilled by the employee, and the more knowledge can be brought in tasks by the employee. The number of knowledge elements an employee provides correlates with the difficulty of substituting this employee. If an employee retires, the lost knowledge elements will have to be brought in by other or new employees. The more knowledge elements lost, the more new employees have to be hired or the more knowledge has to be gained by other employees. If the quantity of knowledge elements is regarded, and not the quality, then this number is not a measure of the importance of an employee for the company. Furthermore, it is also a question of knowledge elements' quality in determining how difficult the issue of employee's substitution is.

3.4 Knowledge subdomains of employee

The knowledge elements every employee carries in belong to different knowledge subdomains. Depending on the allocation of employee's knowledge elements to these subdomains, the employee's role in the company can be identified. This role can refer to the technical department of the company for example. The substitution of an employee with mainly firm-specific knowledge is more difficult than the substitution of an employee with mainly firm-nonspecific knowledge: firm-nonspecific, technical knowledge is taught in universities and schools while firm-specific knowledge can be only taught in the company. So, a newly-hired employee may have acquired all technical knowledge from his education or from the previous he has worked for, but he still has to attain the firm-specific knowledge.

An employee belonging to a technical division may deviate from this regarding knowledge subdomains. Especially because elements of the subdomain network describe that the employee has only indirect access to the knowledge. An employee having contact with a supplier of control software does not necessarily make him an expert in control software.

According to Krauss and Fussell (1990), a common knowledge basis of the employees improves the communication in a multidisciplinary team. The broader this knowledge basis is the easier it is for employees to understand employees from other disciplines.

3.5 Number of tasks per knowledge element

The more tasks are affected by one knowledge element, the lesser tasks can be accomplished regularly if this knowledge element is lacking. So this number can be used as a measure of the importance of a knowledge element. However, this kind of importance does not focus on the knowledge element's quality. The lower this number is, the easier is the elimination of a knowledge element. If a knowledge element is removed which is needed for a lot of tasks, every task has to be outsourced or an external network has to be found as a source for that element. Accordingly, it is easier to remove a knowledge element, which is used for only one task. In this case, only one task has to be outsourced.

3.6 Number of employees per knowledge element

This criterion represents the knowledge element's availability in the company. The fewer employees bringing in a knowledge element, the higher is the probability for lack of the knowledge element. It is not always necessary to increase this number. Such an increase always needs efforts, and in some cases only one expert per company is needed for a certain knowledge area. However, if this number is low or only one employee provides a knowledge element, this element can be graded as a critical element. So for future decisions, a determining factor is that there has to be enough employee(s) to provide the critical elements.

3.7 Criticality of knowledge elements

Combining the number of tasks per knowledge element and the number of employees per knowledge element makes the identification of critical elements possible. This criticality refers to the knowledge element's availability. Analogous to the availability of resources in market economy, this criticality depends on supply and demand. Low supply means that only a few employees possess the knowledge element, and high demand means that the knowledge element is needed for many tasks. As low supply and high demand raises the resources' price in market economy, the knowledge elements' criticality rises.

4 CASE STUDY

The methodology described in section 3 was applied in a mechanical engineering company. An exemplary group of employees from this company were selected, which we call in the following "pilot department". This group consists of seven employees and they are together in a project team and connected by tasks. Concentrating on these seven employees, we are able to build a knowledge map only for these employees. To get the knowledge map of the entire company, all company's employees would have to be interviewed. The execution of these interviews is described in (Wickel et al. 2013). The number of seven employees guarantees a lucid knowledge map and makes it possible to get an overview of the knowledge structure of these employees. The more employees we have, the more difficult it would be to keep track of the employees' knowledge. As an important aspect, the knowledge within a department has to be considered; so the number of interviewed employees should be close to the number of employees in their actual departments. Therefore, we took an average number and interviewing seven employees suits the purpose. To ensure a broad distribution of knowledge they were chosen from different disciplines, which is shown in Table 2.

Table 2. Disciplines of selected employees

Employee	Employee 1 and 3	Employee 2	Employee 4	Employee 5 and 6	Employee 7
Technical discipline	Mechanical engineer	Process engineer	Testing	Software engineer	Project manager

The duration of each interview was four hours and the interview's proceeding was conducted in the same manner: At first, the employee spoke about his tasks in the department. This was done by showing the tasks of the other employees who had been interviewed, or the employee being interviewed using storytelling. The method storytelling implies that the employee tells a story about his everyday work and identifies his tasks from this story. After all tasks were acquired, the employee listed for every task the needed knowledge elements. To support this, he was asked for every task: "Which knowledge elements are necessary for you to execute this task?" During this procedure, the relations between tasks and knowledge elements were set in the MDM for the interviewed employee. If he mentioned a new knowledge element, it was added to the MDM. For every member of the pilot department an own knowledge map was built. The knowledge map of the whole group was generated through matrix addition of these individual knowledge maps. In total, 57 tasks and 99 knowledge elements were identified. Some of the relations between the elements of different domains were acquired by interviews and some of them were generated by matrix transposition, see figure 2.

	57 Tasks	99 Knowledge elements	7 Employees
57 Tasks		Calculated by transposing	Calculated by transposing
99 Knowledge elements	By interview		
7 Employees	By interview	By interview	

Figure 2. Multiple-Domain Matrix for acquired information of the case study

Furthermore, the domain knowledge was divided in four subdomains, which are shown in table 3. Most knowledge elements are allocated to one of these subdomains. Some knowledge elements are assigned to two knowledge domains because a clear allocation to one subdomain was not possible.

Table 3. Knowledge domains

Knowledge domain	*Number of allocated knowledge elements*
Fundamental or expert technical knowledge	42
Knowledge of procedures	32
Knowledge of products	23
Internal or external networks	11

After creating this knowledge map, the methodology explained in section 3 was applied on this map. The results of this structural analysis are described in the following sections. Since the selected characteristics are expressed by a number for each element, we visualized these result via bar charts to compare the elements in terms of the characteristics.

4.1 Number of tasks per employee

Figure 3 shows the number of tasks for the seven employees of the pilot department. Employee 1 and 2 have 24 tasks while employee 7 has 9 tasks. Accordingly, the absence of employee 1 or 2 is more critical for the company than the absence of employee 7. However, this result is based only on the quantity of tasks and not on its quality. If employee 7 is responsible for the most important tasks, his absence is more critical. So, this structural criterion can be used only if the quality of tasks is also taken into account. Using this criterion another structural characteristic of the company can be analyzed: the distribution of tasks. The average of tasks per employee is 17. To have a reasonable distribution, all employees on the same hierarchy should have the same number of tasks as soon as every task has the same range. The employee 7 was the project leader of the team and this criterion showed that he has the less number of tasks. This can be interpreted as a weakness of the task distribution - that the person with the most responsibility has the less number of tasks.

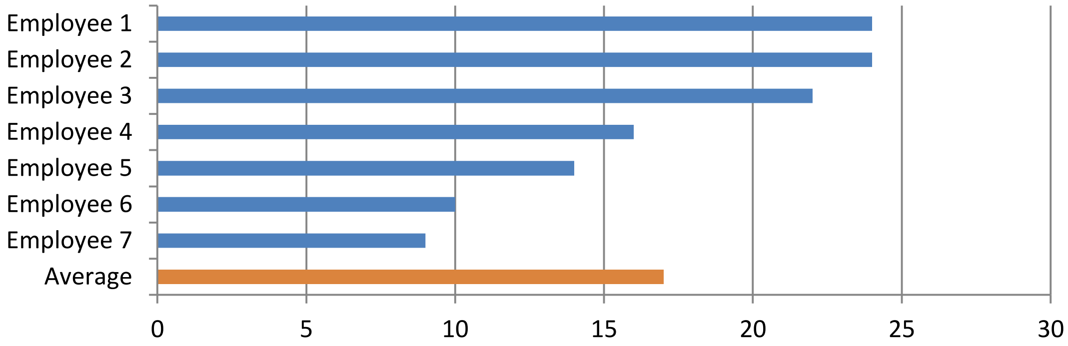

Figure 3. Number of tasks per employee

4.2 Number of knowledge elements per employee

The knowledge elements and their knowledge domains for every employee are depicted in Figure 4. The department can be divided in three parts regarding this number: The first part is employee 3 who has most elements, the second one is the midfield and consists of employee 4, 2, 6, and 1 and the third part includes employee 7 and 5. Employee 3 carries in most knowledge to the project, so this employee has a special role in the department. The number of knowledge elements of the second part is close to the average and most of employees are part of it. It is a strength of the pilot department that most of the employees possess an equal amount of knowledge for the project. The focus has to be set on the third group, employee 7 and 5. If the project manager's function is only to monitor project, it is sufficient for the project manager to possess less knowledge than the other employees. Since the manager's work is not on a technical level, employee 7 does not have to bring in as much knowledge as the other employees. The number of knowledge elements of employee 5 who is a software engineer shows that this employee has to be integrated more into the group.

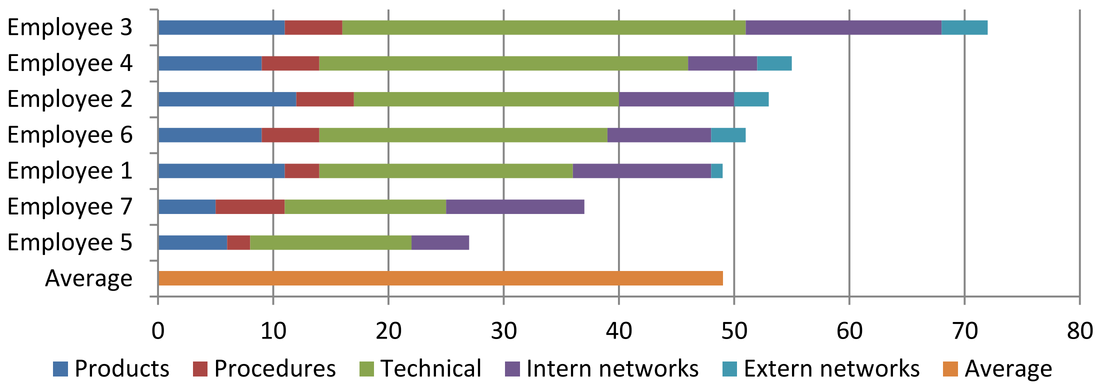

Figure 4. Knowledge elements per employee

4.3 Knowledge subdomains of employees

Figure 4 shows additionally to which knowledge domains employees' knowledge elements belong. Except for the external networks, shares of knowledge domains are similar for every employee. Technical knowledge is the biggest part, which can be seen as an advantage, because the pilot department is a development division. If the department was a marketing division, this structure should look differently. It has to be mentioned that employee 1 and 5 have partial less knowledge of procedures than the rest. This could be a risk for the future. The five knowledge domains can be summarized in two: technical knowledge and firm-specific knowledge (knowledge of products, procedures and networks). While technical knowledge can be acquired in a variety of ways like in the university, firm-specific knowledge can be taught only within the company. So, the substitution of employees with a lot of firm-specific knowledge is more difficult in terms of the knowledge because new employees will still have to learn all firm-specific knowledge. Furthermore, a substitution of too many employees with firm-specific knowledge can represent a risk because too much knowledge can be lost through that substitution.

4.4 Number of tasks per knowledge element

Figure 5 shows the seven knowledge elements with the highest number of allocated tasks (knowledge element 1 – 7) and the 14 knowledge elements with the lowest number of allocated tasks (knowledge element 86 – 99). Knowledge element 1 – 7 are needed for 35 or more tasks, so each of them affects more than 60% of the tasks. Knowledge element 86 – 99 are required for only two or one tasks, so each of them affects less than 4% of the tasks. This number takes only the quantity of tasks into account and not its quality. But this great difference in the numbers – 60% against 4% – allows the statement, that element 1 – 7 are more important than element 86 – 99. Derived from this, knowledge element 1 – 7 should be available for more than one employee and further education in these knowledge elements should also be, for the entire department or company; such would be more reasonable than further education in knowledge element 86 – 99. It is sufficient for element 86 – 99 to be available for a few employees even if these elements are qualitatively important for the company. The minor need for tasks means for the knowledge elements, that it is sufficient if only a few employees hold them on a high level.

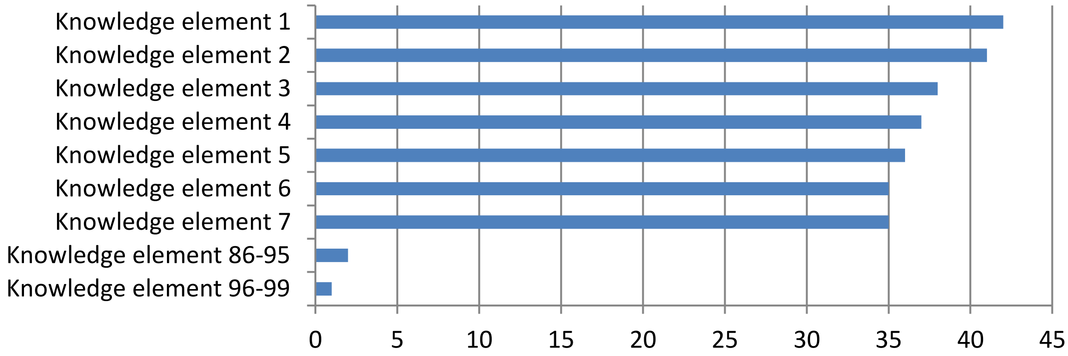

Figure 5. Number of task per knowledge element

4.5 Number of employees per knowledge element

Most of the knowledge elements are available for two or more employees while 30% of them are available only for one employee. The knowledge elements possessed only by one employee represent a risk for the future because the element will fail if the employee fails. If such a knowledge element is required to fulfill one or more important tasks, additional employees should be equipped of such knowledge. Figure 6 shows the number of employees per knowledge element for these knowledge elements which have the highest number of allocated tasks (see also Figure 5). Except for knowledge element 6 all elements are available for five or more employees. These elements are already very stable and they do not represent a risk for the future. However, knowledge element 6 is possessed only by 3 employees but is needed for 35 tasks. Because of this low number of employees for such a frequently used knowledge element; it can be risky for the company, so such knowledge should be taught to more employees.

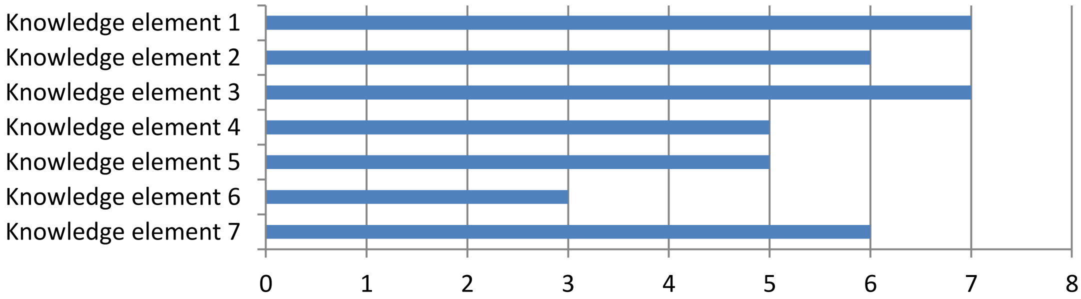

Figure 6. Number of employees per knowledge element for element 1 – 7

4.6 Criticality of knowledge elements

To measure the knowledge element's criticality, the number of tasks per knowledge element and the number of employees are combined. Figure 7 shows a graph of all knowledge elements whereas the abscissa describes the number of employees and the ordinate the number of tasks. In this graph, every knowledge element is depicted as a dot. The more left and the further up a dot is placed in the graph, the higher is the knowledge element's criticality. In this case, knowledge element 6 is the most critical element because it is needed for 35 tasks but possessed only by three employees. So, if these three employees fail to perform, more than the half of department's tasks cannot be fully accomplished.

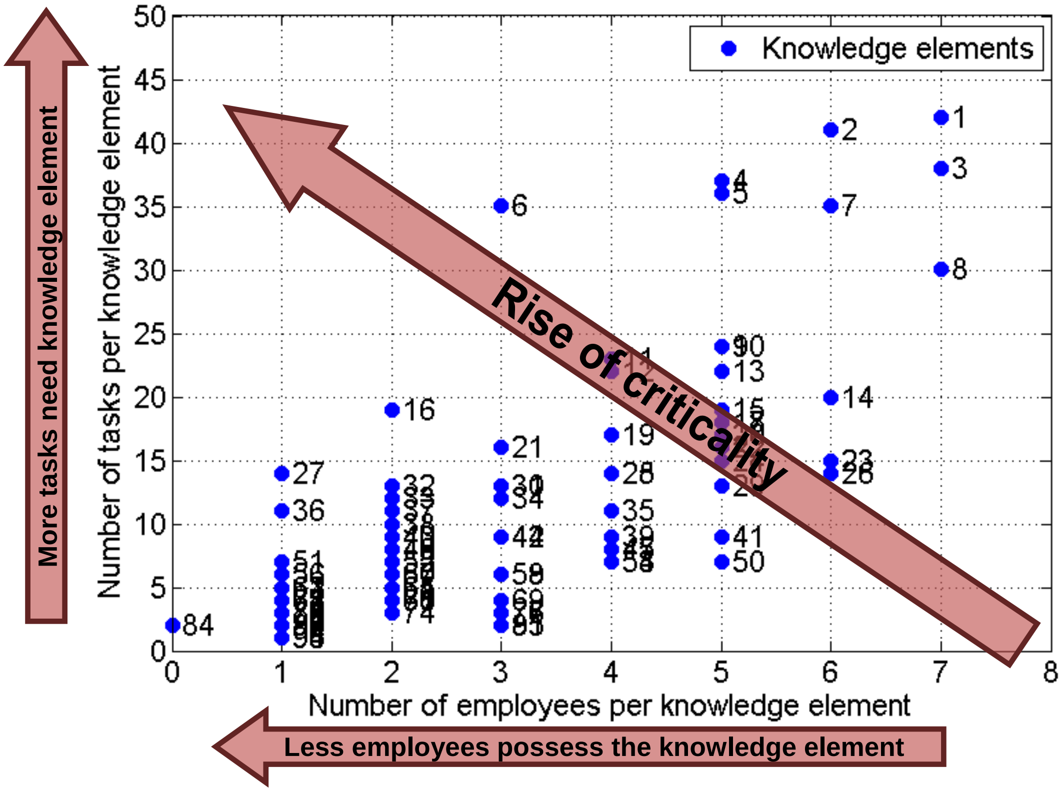

Figure 7. Knowledge elements' criticality

5 CONCLUSIONS

The findings of the structural criteria cannot be more far-reaching than the data gained for the knowledge map. This is the reason for one weakness of this methodology. Since no qualities of tasks or knowledge elements were gathered, these qualities could not be used to identify weaknesses or strengths of the company concerning knowledge distribution. Today no methodology exists that elicits valuable qualities of tasks or knowledge elements. This method has to be developed before structural criteria can be used for studies in the area of knowledge elements' qualities.

Another limit also depends on knowledge map. To compare tasks and knowledge elements with each other, they should be defined at the same level of abstraction so their granularity should be the same. It is difficult to guarantee same granularity of all elements during creation of knowledge maps.

Since different employees were interviewed for the knowledge acquisition, and because they have different beliefs regarding the granularity, not every knowledge element or task has the same range. Furthermore, the educational background of the interviewers is crucial to the knowledge map. In the case study both interviewers were mechanical engineers and they had problems in understanding the non-mechanical engineering employees. Since it was a mechanical engineering company but a multidisciplinary team, mechanical engineers were the most suitable interviewers for this company, but they could not conceive all knowledge which is needed in this multidisciplinary team.

During the interviews for creating knowledge maps employees pointed out some weaknesses of the company. These statements were always non-scientific subjective opinions from the view of a certain employee. Results of the structural criteria were used to determine which of these statements were true and which were false. So, these results can be used as a proof of employee's statements regarding the current situation of knowledge distribution or of the employees.

Further findings were identified from structural criteria, for example tasks' importance or knowledge elements' importance concerning their integration into the company. Such results can be found only using structural criteria because other kinds of criteria to interpret knowledge maps deal with the visualization of the distribution of all knowledge elements or tasks. But structural criteria focus on single elements and make the interpretation of single elements and the identification of elements with a special character possible.
Structural criteria provide additional findings, which are helpful in analyzing knowledge structure; especially the identification of critical knowledge elements, depending on the number of employees possessed by the company and the tasks allocated. In comparison, visual interpretation of knowledge maps could not provide such findings, because to establish findings, a visual analysis of the knowledge map will not suffice.

REFERENCES

Burton, R.M. and Obel, B. (1984) Designing efficient organizations modelling and experimentation. North-Holland; Sole distributors for the U.S.A. and Canada, Elsevier Science Pub. Co., Amsterdam, New York, U.S.A.

Chan, K. and Liebowitz, J. (2006) The synergy of social network analysis and knowledge mapping: a case study. *International Journal Management and Decision Making*, 7(1), pp. 19-35.

Eppler, M.J. (2002) Making Knowledge Visible through Knowledge Maps: Concepts, Elements, Cases. In Holsapple, C.W., ed. *Handbook on Knowledge Management 1: Knowledge matters*, pp. 189-205 Heidelberg, Berlin, Springer.

Eppler, M.J. (2008) A Process-Based Classification of Knowledge Maps and Application Examples. *Knowledge and Process Management*, 15(1), pp. 59-71.

Gordon, J.L. (2000) Creating Knowledge Structure Maps to support Explicit Knowledge Management. In *ES 2000.* Peterhouse College, Cambridge, UK. pp. 34-48 Springer.

Herman, I., Melan, G., #231, on and Marshall, M.S. (2000) Graph Visualization and Navigation in Information Visualization: A Survey. *IEEE Transactions on Visualization and Computer Graphics*, 6(1), pp. 24-43.

Horn, R.E. (1989) Mapping Hypertext: Analysis, Linkage, and Display of Knowledge for the Next Generation of On-Line Text and Graphics. *The Lexington Institute*.

Howard, R.A. (1989) Knowledge Maps. *Management Science*, 35(8), pp. 3-22.

Johnson, B. and Shneiderman, B. (1991) Tree-Maps: a space-filling approach to the visualization of hierarchical information structures. *Proceedings of the 2nd conference on Visualization '91*, San Diego, California, pp. 284-291.

Krauss, R.M. and Fussell, S.R. (1990) Mutual knowledge and communicative effectiveness. In Jolene, G., Robert, E.K. and Carmen, E., eds. *Intellectual teamwork*, pp. 111-145 L. Erlbaum Associates Inc.

Lindemann, U., Maurer, M. and Braun, T. (2009) *Structural Complexity Management*. Springer London, Limited.

Maurer, M., Braun, T. and Lindemann, U. (2009) Information visualization for the Structural Complexity Management Approach. *19th Annual International Symposium of the International Council on Systems Engineering (INCOSE) 2009*, 2, Singapore, pp. 939-954.

Maurer, M. and Kesper, H. (2010) Knowledge transfer applying the structural Complexity Management approach. *International Conference on Information Retrieval & Knowledge Management (CAMP'10)*, Shah Alam, Selangor, Malaysia.

Newman, M.E.J. (2003) The structure and function of complex networks. *SIAM review*, pp. 58.

Novak, D., Rennaker, M. and Turner, P. (2011) Using Organizational Network Analysis to Improve Integration Across Organizational Boundaries. *People & Strategy*, 34(4), pp. 32-37.

Scott, J. (2012) *Social Network Analysis*. SAGE Publications.

Tichy, N.M., Tushman, M.L. and Fombrun, C. (1979) Social Network Analysis for Organizations. *The Academy of Management Review*, 4(4), pp. 507-519.

Wickel, M.C., Schenkl, S.A., Schmidt, D.M., Hense, J., Mandl, H. and Maurer, M. (2013) Knowledge structure maps based on Multiple Domain Matrices. *Innovation through Knowledge Transfer*, Derry, Londonderry, Northern Ireland, pp. 5-16.