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Knowledge structure maps based on Multiple Domain Matrices

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Abstract

Knowledge is one of the key factors for company's success: Companies have to know which knowledge they have, who it has and how it is used within the company to protect and develop their company´s knowledge. Knowledge may be modeled within knowledge structure maps. This paper describes a procedure of how knowledge structure maps based on Multiple Domain Matrices (MDMs) can be created for companies. MDMs are used for analyzing complex systems based on their structural characteristics. The knowledge maps contain the domains knowledge, tasks and employees and their relations to each other. The procedure is evaluated based on a use case within an SME in the mechanical engineering sector.

1. Introduction

The knowledge of a company is one of the main factors for its success. Increasing fluctuation of employees, shortage of qualified staff as well as demographic change demand for adequate activities which maintain corporate knowledge. Furthermore, changing markets and technologies call for a continuous development of the knowledge. It is necessary to visualize the corporate knowledge, in order to evaluate it as a basis for measures to meet these challenges. One possible approach is knowledge maps.

This paper describes how the knowledge of a company can be translated into a knowledge map. In addition, this paper describes an approach for extracting knowledge from employees in order to document it in a knowledge map. Therefore we use the approach of Multiple Domain Matrices. That allows not just for documenting the knowledge but also modelling the relations between the knowledge elements and thus the knowledge structure. The methodology is evaluated in a use case within an SME in the mechanical engineering sector. In that use case, a knowledge map of a development project team has been established. The applicability of the knowledge maps as well as the approach for acquiring them has been validated with the project team.

2. State of research: Knowledge maps

Knowledge maps are tools applied in the field of knowledge management for structuring and visualizing knowledge or its references and relations. Since the employees' knowledge will be visualized in a knowledge map, the category of knowledge map which best suits this purpose has to be identified. A set of different knowledge map formats was specified to handle various kinds of applications and purposes. Because of this vast number of knowledge map types, there are several approaches to classify these maps.

In this section several knowledge maps are presented. One approach is given by Wexler [1] who classifies knowledge maps by the questions: “the who, what and why of knowledge mapping”. The who describes the user, the what targets the content and the why deals with the content of a knowledge map [1]. Eppler [2] apprehends this kind of classification and develops it to the taxonomy of knowledge maps using five criteria: The purpose, the content, the application level, the graphic form and the creation method. Each of these criteria describes a certain property of a knowledge map. Regarding the creation method, a knowledge map can be generated semi-automatically or created iteratively [2] for example. In [3], Eppler introduces a certain kind of knowledge maps which he calls knowledge structure maps. These maps focus only on knowledge and display the architecture and relations within knowledge. For this purpose, knowledge is divided into knowledge blocks which can be hierarchized to each other. This hierarchy is based on learning dependency: A high-level block can only be known after all of its lower-level blocks have been understood. Eppler illustrates these dependencies by choosing special shapes for the knowledge blocks, see figure 1 (left). In contrast, Gordon [4] uses the same kind of hierarchization for his knowledge structure maps but he depicts the connections by arrows or lines as shown in figure 1 (centre). Furthermore, Gordon allows these relations to be qualified and quantified, but only in the context of learning [4]. Maurer et al. [6] decouple the relations between knowledge blocks or knowledge elements from the context of learning. Accordingly, knowledge elements from the methods domain generate knowledge elements from the competences domain [6]. Moreover, Maurer et al. allow the connection of knowledge elements from different domains, while Eppler only provides relations between elements from the same domain. Domain-overlapping relations are also regarded in Gordon’s approach but Gordon uses the domains only to structure the elements in a hierarchy and not to categorize the knowledge elements in different areas. This categorization is provided in the approaches of Eppler [3] and Maurer et al. [6]. Maurer et al. [7] suggest different ways of visualizing the knowledge structure maps. The force-directed graph is one of them and is based on [10]. Such a graph depicts the quantity of a relation or multiple-domain graphs including knowledge elements and their relations from several domains, see figure 1(right).

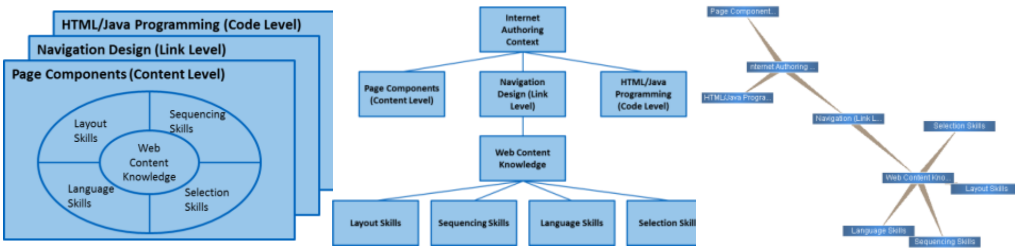

Figure 1: Visualization of a knowledge structure map, according to Eppler [3] (left), Gordon [4] (centre) and Maurer et al. [7] (right)

Gordon’s approach has already been used by an aerospace company to review the information flow from a former project. Within this project, other organizations participated and the company did not have an overview of which information was being shared with other organizations [5]. Using Gordon’s methodology, knowledge

clusters were showed, high-risk knowledge was identified and the Knowledge Structure map was used as a reasonable basis for the discussion of the relevance of the knowledge for the company.
In [6], the approach of visualizing knowledge was applied to knowledge transfer in Small and Medium-Sized Companies (SME). First, the tasks, competences and their relations to an employee were acquired in interviews. Then a graph was applied to show the entire network of tasks, competences and relations. The knowledge receptors of the knowledge transfer used this graph to identify knowledge issues which were confusing for them [6].
Another visualization suggested by Maurer et al. [8] is the usage of a matrix. Advantages of a matrix are the easy construction and the opportunity of using the matrix for a calculation. However, matrices are not as intuitively accessible as the kinds of visualization already mentioned. Furthermore, a matrix is only able to depict the elements and relations of one or 2 domains. A matrix which includes only one domain is called a Design Structure Matrix (DSM) and a matrix including elements from two domains is called a Domain Mapping Matrix (DMM). For more than two domains, it is necessary to use more than one matrix, which makes work with systems including more than two domains more complex. This complexity is made more easily comprehensible by using a Multiple Domain Matrix (MDM) [8]. An MDM is a symmetrical matrix which arranges the domains and illustrates the relations between the domains as shown in figure 2.

	Components	**People**	**Data**	**Processes**	**Milestones**
Components	Component impacts component	Person works on component	Component represented by data		Component completed at milestone
People			Person generates data		
Data	Data required for component	Data required by person		Data required for process	Data available at milestone
Processes		Person works on process	Process generates data	Process information transfer	Process completed at milestone
Milestones					

Figure 2: Example of a multiple-domain matrix, adapted from [8]

Danilovic et al. [9] use such an MDM for managing a multi-project environment. They considered four projects and built one DSM on a task-task level for each project and combined these DSMs into a MDM including the DMMs which represent the inter-project relations, and called this method DSM-analysis.
This kind of MDM for visualizing employees' knowledge is already being applied in a real situation. On the level of DSM and DMM, this method is suitable for knowledge acquisition from employees because it is easy for employees to understand how to fill the relations between knowledge elements in a matrix. But it is not easy for people to understand the structure of knowledge if it is depicted as a matrix. For this purpose, the matrix can be converted to a force-directed graph, according to Maurer et al. [7]. This kind of knowledge maps makes it possible to understand the structure of employees' knowledge. Furthermore, this has already been applied in SMEs to transfer knowledge from one employee to another. However, these methods for visualizing knowledge were only applied for

individuals and not for a whole company department. Within this paper, the MDM and the force-directed graph will be used to illustrate the structure of more than one person. From these notations of knowledge, characteristics of the knowledge structure will be derived which are relevant for the department.

3. Methodology: MDM-based knowledge maps

This section describes the methodology for creating an MDM-based knowledge map for companies within the engineering sector. The application of this methodology was proven in an SME project team and is described in the following section.

In addition to the localization of knowledge in a company (i.e., what knowledge is located with which person/employee - knowledge carriers), the MDM-based knowledge map contains information about the network and structure of a company's knowledge. Therefore employees (knowledge carriers), their knowledge and also their tasks are integrated as domains in the MDM-based knowledge map. Information about which knowledge is necessary for which task and which person(s) provide(s) and support(s) this knowledge in the company is recorded. The knowledge structure map makes complex relationships and networks between the domains of knowledge, tasks, and employees transparent and thus more accessible and usable for companies. To analyse the MDM-based knowledge map regarding different kinds of knowledge, the domain knowledge is again split into the following subdomains:

- Fundamental or expert technical knowledge
  Technical knowledge is universally applicable and not company- or product-specific. Engineers acquire that knowledge typically within their education and expand it during their professional life. Examples are knowledge about engineering mechanics or numerical simulation.
- Knowledge of procedures
  Knowledge about technical and organizational, (mostly) company-specific processes such as development processes, manufacturing processes or certification processes
- Knowledge of products
  This knowledge is related to the product such as applications, functions, design principles and design rationales. It embraces all experience and information about the company specific product and service portfolio.
- Internal or external networks
  Knowledge of other departments of the company as well as suppliers etc.

Networks represent the indirect knowledge of a person, i. e. the knowledge that is accessed through collaboration with a supplier or engineering service providers. Internal networks are those within the company, external one are those outside the company.

The MDM-based knowledge structure map of a company is built by three steps shown in figure 3.

Within the first and second step the particular knowledge maps of the employees were built. While the acquisition of the first employee begins from scratch (first step), the acquisition from further employees is built on the knowledge and tasks named by the employees already interviewed (second step). In a third step the particular maps of the employees can be merged to one knowledge map of a company or group of employees.

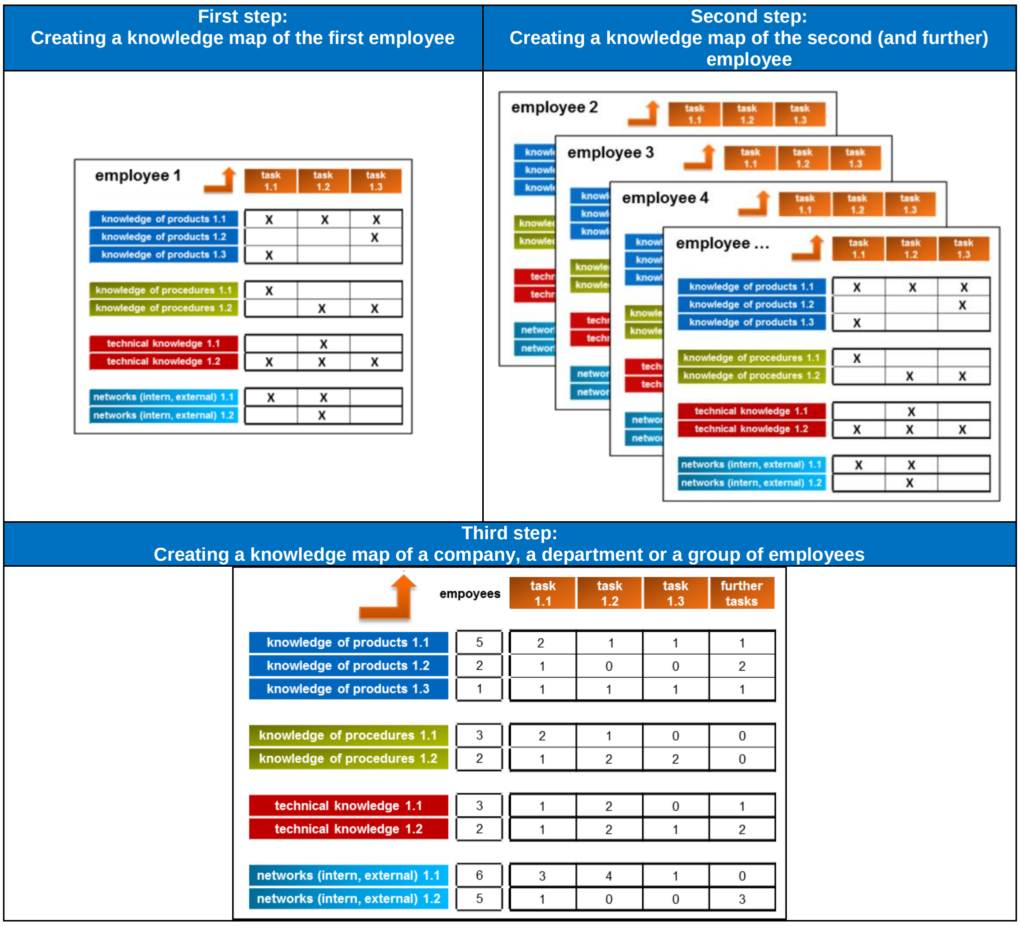

Figure 3: Methodology overview for creating MDM-based knowledge maps

First step: Creating a knowledge map of the first employee

With the first employee, acquisition begins from scratch and thus determines the level of abstraction of the knowledge and tasks. Therefore it is important for the first employee to be selected well; he should be experienced in his job, have a good overview over the whole tasks and have a large proportion of the entire knowledge and tasks within his team (or company).
The data stored in the knowledge map is acquired by interviews. The interview with the first employee about his tasks and knowledge is done by using the "story telling" method. The interviewer asks the employee about his tasks along his work process:

- If the employee is active in day-to-day business, he tells the tasks along his daily work.
- If he works in a project, he tells the tasks similar to the project process.
- If he works in a development department, he tells his tasks along the development process.

Thus the tasks of the employee can be recorded systematically and completely. Also an interview guide with a set of structured questions supports the interview of the employee in sustaining tasks which are done rarely or appear less important to the employee. These tasks can be very important for the company as well. The

tasks are named and then written down openly during the interview by the interviewer.
After all the tasks have been listed, details of the knowledge which the employee brings into the particular task in order to execute the task successfully are acquired. Hereby the knowledge and the relationship between task and knowledge are filled in the MDM. An interview guide again provides support in the systematic procedure with a set of questions on various types of knowledge. The procedure of the knowledge acquisition is shown graphically in figure 4.

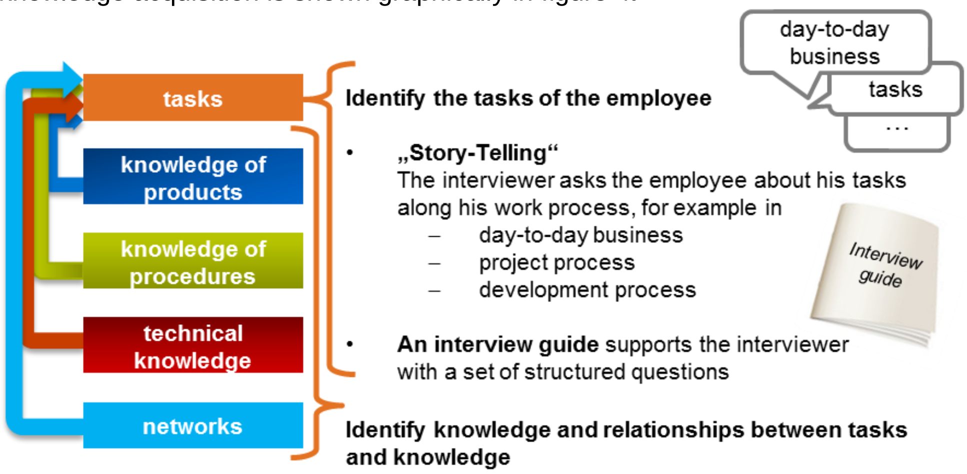

Figure 4: Procedure of creating a MDM based knowledge map for an employee

The following figure shows an exemplary knowledge map of an employee in form of a matrix.

	task 1.1	task 1.2	task 1.3
knowledge of products 1.1	X	X	X
knowledge of products 1.2			X
knowledge of products 1.3	X		
knowledge of procedures 1.1	X		
knowledge of procedures 1.2		X	X
technical knowledge 1.1		X	
technical knowledge 1.2	X	X	X
networks (intern, external) 1.1	X	X	
networks (intern, external) 1.2		X	

Figure 5: Exemplary knowledge map of one employee

Second step: Creating a knowledge map of the second (and further) employee

The acquisition of the second (as well as further) employee(s) is built up on the knowledge matrix of the first employee in order to use the same terminology and deduce the same tasks and knowledge elements. The procedure is divided into three stages:

- The employee goes over the tasks of the first (respectively the previous employees) consecutively with the interviewer and specifies whether or also performs the task. The assessment is binary, i.e. the employees can only decide whether he does the task or not. Afterwards the procedure is exactly the same for the assessment of the knowledge elements.

- Then the employee completes the tasks and knowledge elements of his own which are still missing. The interviewer supports this process by using the interview guide according to the first employee. Subsequently a comprehensive list of all his tasks and knowledge elements exists.
- The tasks and knowledge elements of the employee are linked together in the MDM knowledge map. This is done according to the usage of knowledge in the particular tasks.

This procedure is used for the second as well as for further employees in the procedure of acquisition.

Third step: Creating a knowledge map of a company, a department or a group of employees

In a final step the MDM-based knowledge map of the company (or several employees) is created by addition of the particular MDMs of the employees (see figure 6). This DSM can be used for the analysis of the knowledge as well as its structure.

4. Case study

The methodology described in section 3 was carried out at a medium-sized company within the mechanical engineering sector for one selected exemplary group of employees, in the following called "pilot department". The members of the pilot department were established by the head of the R&D department of the company at a first meeting. When choosing the members of the pilot department several points were taken into account:

- The employees should be together in a project team or department and therefore connected by tasks.
- The employees should be from different disciplines to ensure that a wide network of knowledge is created.
- The size of the pilot department is limited to 5-10 employees due to the restricted personal capacity of the department.

For the pilot department seven employees were selected who were involved in a new product development project. The seven employees came from four different technical disciplines: mechanical design, software development, testing and process engineering, and the project manager was also part of the pilot department.

Knowledge acquisition procedure for the pilot department of the company:
The knowledge acquisition procedure for the employees of the pilot department was carried out according to the procedure described in section 3b). The interviews with the employees took place within 32 hours, see table 1.
During knowledge acquisition the interviewed employee, a representative of the company and two interviewers (one doing the interview and the second one for the documentation) were always present. The session started with a short presentation about the goals of the project and the procedure of how to create MDM based knowledge maps from the interviewers. Afterwards the representative of the company informed the employee of the confidentiality of the data and the usage of the collected data.

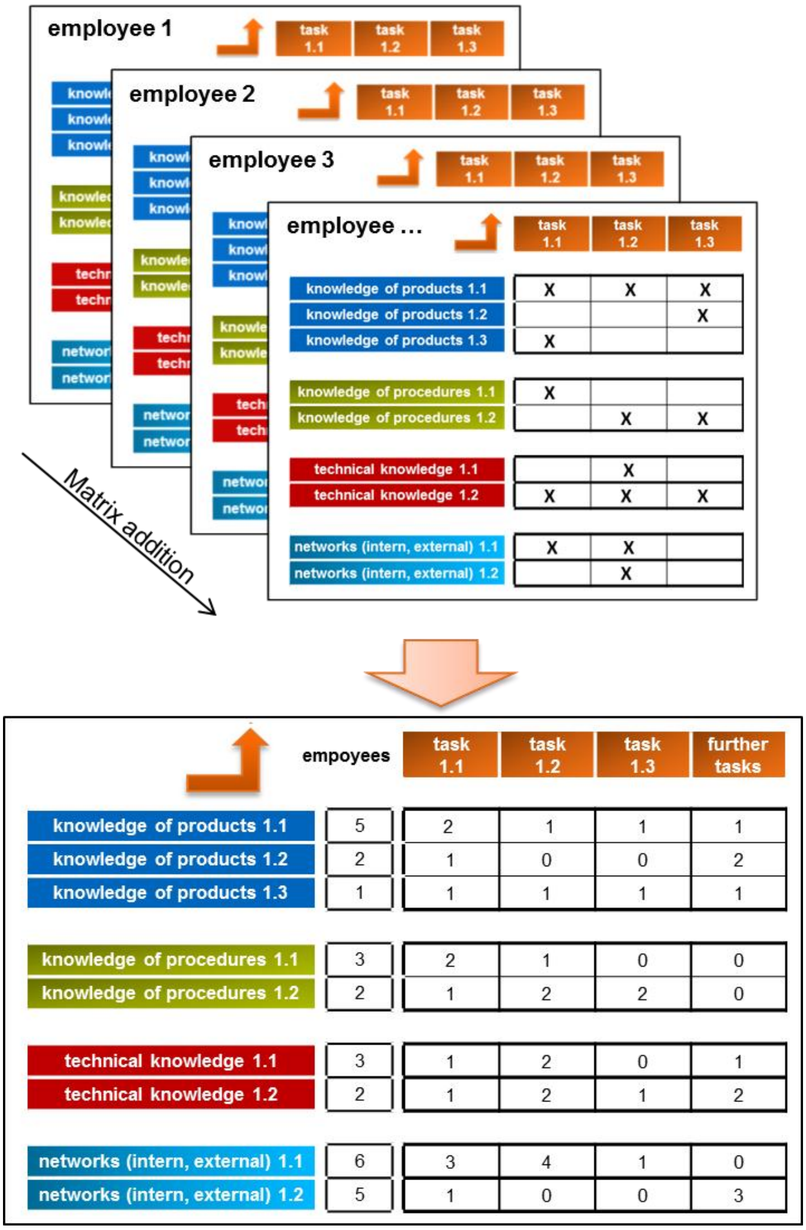

Figure 6: Creating a knowledge map of a company by addition of MDMs

Table 1: Duration of knowledge acquisition for the pilot department

Employees/ sequence	*Technical disciplines*	*Duration of the interview*
employee 1	Mechanical engineer	8 h
employee 2	Process engineer	4 h
employee 3	Testing	4 h
employee 4	Software engineer	4 h
employee 5	Software engineer	4 h
employee 6	Mechanical engineer	4 h
employee 7	Project manager	4 h

First step: Creating a knowledge map of the first employee

Within the knowledge acquisition the first employee was interviewed about his tasks within the new development project. The tasks were simultaneously recorded, chronological to the progression in the project in order to achieve better clarity and overview of the tasks. In a next step the employee named the knowledge, which he needed to execute the tasks. In the field of technical knowledge the interviewer asked explicitly if the employee has fundamental or expert knowledge. In a final step the interconnections between knowledge elements and tasks of the employee were registered together with the employee in a DMM.

Second step: Creating a knowledge map for the second to seventh employee

The knowledge acquisition of the second to seventh employee of the project team was carried out analogously to the procedure described in section 3. Depending on the employees' individual working field, numerous or less common tasks and knowledge elements between the employees were identified. Generally speaking, all employees have unique and common knowledge elements. Unique elements, which only they use for the project and common knowledge elements which several employees of the company's project team share.

One DMM was completed for every employee with the relation between tasks and knowledge. The interconnections in individual DMMs show that different employees bring different knowledge elements into the same tasks. This means that several employees work together on one task and the knowledge of the different employees is necessary to execute this task.

Third step: Creating the knowledge map of the project team

The knowledge map of the whole project team could be generated through matrix addition of the individual knowledge maps of the employees. The knowledge map consists of 57 tasks, 77 knowledge elements and 32 networks. Figure 7 shows the knowledge map, comprising the 7 employees and their knowledge elements (pictured as numbers).

The knowledge map of the project team (figure 7) depicts which knowledge is unique to a particular employee and which knowledge is held by several employees of the project team. The unique knowledge is located on the edge of the knowledge map, while the mutual knowledge is in the centre of the map and strongly linked to employees of the project team. The position of the employees in the knowledge map highlights which employee is how close to which other employee in terms of the knowledge. The Mechanical Engineer 2, the Process Engineer and Testing are close to each other and located in the centre of the map. This means that they have a lot of mutual knowledge but also slight knowledge of the other employees: they have central knowledge of the project and the best overview over the project team's knowledge. In contrast, the Project Manager is on the edge of the knowledge map and has less mutual knowledge. The knowledge map makes knowledge structures of the project team transparent. The impact of the structures has to be discussed in the context of the project team and company.

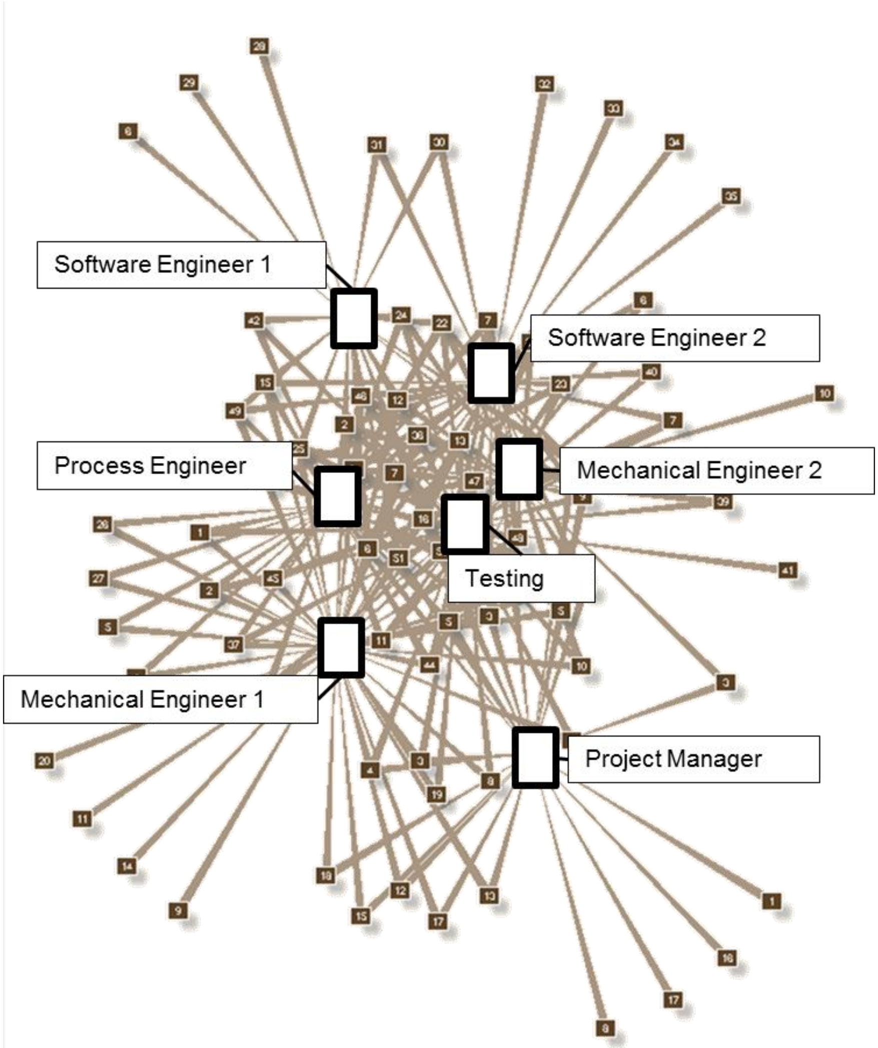

Figure 7: Knowledge map, comprising 7 members of a project team and their knowledge

5. Conclusions

The procedure has the advantage that a similar level of abstraction is achieved in naming tasks and knowledge elements. This is based on the transparency of the procedure; the interviewee sees the elements of the employees interviewed previously. Moreover the procedure saves time since the knowledge map does not have to be built up from scratch for every employee. The explicit relation of terminologies of different employees to knowledge and tasks already mentioned is another benefit.

The first employee has a special role in this project. Together with the interviewers, he defines the terminologies of the tasks and knowledge elements and thereby the fundamental level of abstraction of the knowledge acquisition. This means that he has a strong influence on the knowledge map. Thus the first employee should be selected systematically and deliberately. The first employee should have a broad overview in the department and should be integrated in many tasks.

Evaluation of applicability

After the knowledge acquisition with the employees, a series of telephone interviews was conducted concerning the applicability and further usage of the used methodology. The interviewees were the employees of the case study project team. The results of this evaluation show that the interviewed persons declared the methodology as useful and applicable for real situations in the company.
Furthermore, some of them identified a personal advantage they gained from the study: The interviews forced them to reflect past projects and the daily work. This reflection helps to keep track of the own tasks.

However, some restrictions and potential for optimization were mentioned. One of them is the binary character of the relations between knowledge elements and tasks or the relations between elements of other domains. The methodology used implies whether a knowledge element is needed completely to accomplish a task. But employees would have preferred to allocate only a part of the knowledge element to a certain task. As the relations can only be assigned the values 0 or 1, the quantity of the impact of a knowledge element on a task is not measured. This problem can be solved by allowing a number between 0 and 1. But in this case it will be difficult to compare these numbers to all others because employees feel differently concerning the quantity of a knowledge element. From this, it follows that it is not possible to build a consistent knowledge map using this kind of quantifying the relations. Another approach is to measure the relations by using a non-numeric scale. In the case of the relations between knowledge elements and tasks this scale can consist of the three levels “not needed”, “helpful” and “necessary”. Employees will be able to distinguish between these three terms and for further calculations, the three levels can be converted into numeric values, e.g. “not needed”=0, “helpful”=0.5, “necessary”=1.
Another point to be optimized is the effect of the employees’ sequence. The employee who is interviewed first has different boundary conditions than the employees who are interviewed afterwards because this employee has no access to the tasks and knowledge elements from the other employees. Because of this, the employees’ sequence has an effect on the quality of the knowledge map. An additional iteration of the interviews or a group workshop for all employees can eliminate this weak point. Two more reservations mentioned by the employees are the confidential use of the information gained and the additional value of the results compared to the time required for the interviews. These reservations of the employees can be eliminated by improving the process of informing the employees concerning knowledge management and the methodology used.

6. References

1. Wexler, M.N. The who, what and why of knowledge mapping. Journal of Knowledge Management, Vol 5:3, pp. 249-264 (2001)

2. Eppler, M.J. A Process-Based Classification of Knowledge Maps and Application Examples. Knowledge and Process Management, Vol. 15:1, pp. 59-71 (2008)
3. Eppler, M.J. Making Knowledge Visible through Knowledge Maps: Concepts, Elements, Cases. In: Holsapple, C.W. (ed.) Handbook on Knowledge Management 1: Knowledge matters. pp. 189-205. Springer, Heidelberg, Berlin (2001)
4. Gordon, J.L. Creating Knowledge Structure Maps to support Explicit Knowledge Management. In: Macintosh, A.M., Mike; Coenen, Frans (ed.) ES 2000, Peterhouse College, Cambridge, UK 2000, pp. 34-48.
5. Gordon, J.L. Creating knowledge maps by exploiting dependent relationships. Knowledge-Based Systems Vol. 13, pp. 71-79 (2000)
6. Maurer, M., Klinger, H., Benz, A. Applying the Structural Complexity Management to Knowledge Transfer in Small and Medium-Sized Companies. In: Howlett, R.J. (ed.) Innovation through Knowledge Transfer, vol. 5. Smart Innovation, Systems and Technologies, pp. 51-60. Springer, Heidelberg, Berlin (2010)
7. Maurer, M., Braun, T., Lindemann, U. Information visualization for the Structural Complexity Management Approach. Paper presented at the 19th Annual International Symposium of the International Council on Systems Engineering (INCOSE) 2009, Singapore, pp. 20-23 July (2009)
8. Maurer, M., Lindemann, U. Facing Multi-Domain Complexity in Product Development. CiDaD Working Paper Series, Vol. 3:1, pp. 1-12 (2007)
9. Danilovic, M., Börjesson, H. Managing the Multiproject Environment. Paper presented at the Proceedings of the 3rd Dependence Structure Matrix (DSM) International Workshop, Massachusetts Institute of Technology, Cambridge, USA (2001)
10. Di Battista, G., Eades, P., Tamassia, R., Tollis, I.G.: Graph Drawing Algorithms for the Visualization of Graphs. Upper Saddle River, New Jersey: Prentice Hall (1999)