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KNOWLEDGE MANAGEMENT IN PRODUCTION NETWORKS: CLASSIFICATION OF KNOWLEDGE REUSE TECHNIQUES

Sandkuhl K., Smirnov A.V. **Knowledge Management in Production Networks: Classification of Knowledge Reuse Techniques.**

Abstract. Many studies in the field of knowledge management indicate that enterprises and organizations establishing systematic sharing, transfer and reuse of knowledge can expect substantial benefits. Although sharing and transfer of knowledge requires a way to transfer or capture knowledge, not much work has been spent in investigating what kinds of reuse techniques are used in organizations. Starting from a classification of approaches to knowledge reuse, this paper investigates the state of knowledge reuse in production networks with a specific focus on networks of small and medium-sized enterprises (SME). The aim of the paper is twofold: for production networks, the intention is to investigate which kind of reusable knowledge, in terms of the classification developed, is most relevant for such networks; for the approach to the classification of knowledge reuse techniques, the aim is to further refine the approach and validate it in the field of production network research. The main contributions of this paper are (1) an analysis of reuse situations in SME networks, (2) evaluation of the proposed approach to the knowledge reuse classification for use in the reuse situations and (3) further refinement and validation of the classification approach.

Keywords: knowledge transfer, knowledge representation, production networks, SME networks.

1. Introduction. In the field of knowledge management, various studies have been carried out in order to determine preconditions, structures, procedures and best practices for successfully implementing systematic management of knowledge in organizations (see, e.g. [1-3]). The results of these studies indicate that enterprises and organizations establishing knowledge management structures can expect advantages and benefits, like reducing problem-solving time, faster delivery to market, cost reduction for specific activities [4], more effectivity in design for manufacturing [5], or better internal communication and increased staff participation [6]. The belief is that systematic development and reuse of knowledge will contribute to improving competitiveness of an enterprise [7]. Methods, tools and technologies used in this field stem from different areas of computer science and business information systems, among them knowledge engineering [8] and enterprise knowledge modelling [9] which offer means for capturing knowledge in defined representations in order to support the entire lifecycle of organizational knowledge management. Work presented in this paper focuses on a specific aspect of knowledge management and knowledge engineering: knowledge prepared for reuse.

The work brings together experiences in knowledge management for production networks and previous work on knowledge reuse and classification of reuse approaches [10]. Production networks in general are a cross-

enterprise organization structure implementing and managing distributed value creation and product/service delivery in a coordinated and often geographically distributed partner structure. Knowledge management for such networked structures has been investigated before which showed that specifics and needs for SME networks have not been extensively investigated (see Section "Background"). In this paper, the focus will be on such SME networks.

Experiences from industrial projects show that selecting the appropriate approach from the multitude of knowledge reuse techniques is difficult for practitioners (see, e.g. [11]). In our previous work we developed a classification of knowledge reuse approaches with clearly defined criteria motivated from industrial practice in order to assist selection of a suitable approach for a given knowledge reuse situation [10]. The aim of the paper is twofold: for production networks, the intention is to investigate which kind of reusable knowledge, in terms of our classification approach, is most relevant for such networks; for the classification approach of knowledge reuse techniques, the aim is to further refine it and validate it in the field of production network research. The main contributions of this paper are (1) an analysis of reuse situations in production networks with specific focus on SME, (2) evaluation of the developed knowledge reuse classification for use in the reuse situations and (3) further refinement and validation of the classification approach.

From a research method perspective, our work includes several stages for investigating the above research issue. The first stage is a literature review of knowledge management in production networks with the intention, to identify examples for knowledge reuse cases. The second stage is to apply the classification approach for knowledge reuse on the results of the literature study in order to evaluate its applicability and identify improvement potential. The third stage is to use the results of the classification in order to derive conclusions regarding the techniques for knowledge reused applied in SME production networks.

The remaining part of this paper is structured as follows: The next Section will give background information on production networks and knowledge reuse including different interpretations of the term as such. The third Section summarizes the classification approach for knowledge reuse developed in earlier work. It follows a Section that presents the results of the literature study on knowledge reuse in production networks and an example for knowledge reuse in an actual SME network. The literature study results and the example are analyzed from a classification perspective. In the fifth Section the classification approach is validated. The sixth Section contains a discussion about the kinds of knowledge reuse techniques considered most relevant for production networks. The final Section summarizes the findings and discusses future work.

2. Background. From a technological perspective, the background for this paper is work on knowledge reuse. From an application perspective, research in production network forms the basis. Both background areas are briefly summarized in this Section.

2.1. Production networks and SME networks. Globalization and increased competition on worldwide markets require new forms of organization and work support. Growing requirements to flexibility, lead time reduction or customization possibilities have caused a need to establish numerous collaborative partnerships between enterprises. Networked organizations, virtual enterprises, production and supply networks emerged [12]. Examples for such kinds of networks can be found in automotive industry. Typical car manufacturers that made 75% of product components 25 years ago now make only 25% of those components and 50-70% of product cost is with suppliers. Organizations of this form use information and communication technologies to extend their boundaries and physical location and form multiple links across the boundaries to work together for a common purpose. There is a rich body of knowledge about advantages, strategic drivers, organizational practices and other aspects for such networks (see, e.g. [13-15]). However, knowledge reuse and knowledge management practices in production networks have not been investigated in detail (cf. Section "Knowledge Reuse in Production Networks").

Especially in small and medium sized enterprises (SME), the competitiveness and future market position of an enterprise is closely related to the ability of cooperating with partners in SME networks or supplier organizations. SME networks are communities or associations of enterprises based on common economical and value-creation objectives. They pro-actively form co-operations for joint development or project work. These co-operations typically are temporary, dynamical with respect to the members, geographically distributed, flexible and quick responsive to market demands.

SMEs usually have a number of internal knowledge sources which should be used more systematically and intensively in cooperation projects. Although most knowledge exists in the heads of employees, there usually is a substantial amount of externalized knowledge, i.e. stored electronically in documents, databases or information systems. Furthermore, corporate knowledge represented in work processes, organization structures or best practices also is an important knowledge asset. All these knowledge sources of specific importance in complex work processes with a number of distributed partners, high competence requirements and a lot of rules and guidelines to be obeyed. In these situations it is important to discover the exactly "right" knowledge source, to find it "in time" and to get access to it fast. During the last decade, a number of knowledge reuse, knowledge sharing and knowledge supply cases in industrial application scenarios were report-

ed (see, e.g., [16, 17] and [50]). The majority of these cases stems from large companies, or from IT-intensive middle-sized or small enterprises. Existing studies about IT use in SMEs, like [18], do not cover knowledge reuse techniques sufficiently. Drawing conclusions from experiences of larger enterprises with regards to SMEs is not appropriate, as SMEs have their own characteristics [19]: SMEs often belong to the ”late adopters” of new technology, i.e. they prefer mature technologies, which are easy to deploy, use and maintain. SMEs show a clear preference for to a large extent standardized processes and solutions. Innovation projects in SMEs typically have to contribute to business value within a short time frame.

2.2. Knowledge Reuse in Knowledge Management and Knowledge Engineering. Research in knowledge reuse is performed in various disciplines including economic sciences, psychology, engineering sciences or education sciences. In the scope of this paper with its focus on IT-related approaches and techniques, we will focus on computer science and business information systems. It is important to understand related areas in order to position knowledge reuse with respect to related work. Many approaches for knowledge reuse either originate from research on knowledge management or from knowledge engineering. Both areas aim at supporting the “lifecycle” of knowledge from inception to use and both include technological and methodical approaches.

The most relevant areas related to knowledge reuse are

– Knowledge management systems from an organizational perspective. These systems describe how to establish systematic knowledge management in an organization in terms of activities and organizational structures required. Well-known approaches sin this area are the “building block” model proposed by Probst et. al. [20] and the SECI model [21],

– Knowledge management systems from a technology perspective, i.e., IT-systems supporting organizational knowledge management, organizational memory [51] and decision support [48]. In this area, Maier et al.’s architecture proposal [22] for such systems and the differentiation between various knowledge services as components of this architecture is often applied.

– Knowledge representation techniques defined how explicit knowledge should be stored, e.g. as a knowledge base for different applications. [23] provides an overview to such techniques from computer science.

– Knowledge fusion addresses the question how to create new explicit knowledge from various knowledge sources [49], which often have different abstraction levels. [24] includes an overview to existing techniques in this field.

– Organizational situations for knowledge reuse were identified my Markus [25]. Knowledge about these situations supports the design of knowledge representation techniques and organizational practices.

– Evaluation of knowledge and knowledge management systems aims at deciding whether knowledge is useful for an organization and what the value is. Two selected approaches in this field are Delone and McLeans's IS success model [26] and Jennex and Olfman's approach [27].

Our past research work included activities which contributed to both, the organizational aspects of knowledge management and knowledge representation, and the technical aspects of these fields. Regarding the organizational aspects, this included capturing organizational knowledge in enterprise models [28], enterprise knowledge models or organizational knowledge patterns [29]. The more technology-oriented work was in the field of ontology patterns [30] and ontology engineering practices [31].

During our previous work on knowledge reuse techniques, we performed an analysis of related work for the organizational aspects of knowledge reuse and for the more technology-oriented aspects of this field. During this related work analysis, which is published in [31-34], many different techniques were discovered which either explicitly stated that they were designed for knowledge reuse or which due to their application context have to be considered as part of this field.

3. Criteria for Comparing Knowledge Reuse Approaches. The different perspectives and the variety of approaches for knowledge reuse discussed in the previous Section were an important motivation for the development of a classification approach for knowledge reuse techniques, which was first published in [10]. This approach is based on the analysis of literature in the field of knowledge management and knowledge engineering (see previous Section), on own work in developing knowledge reuse techniques and methods and experiences in industrial application of knowledge reuse. This Section summarizes the proposed such a classification which consists of a number of criteria for comparing knowledge reuse approaches. The main purpose of these criteria is to support interested researchers and practitioners in navigating through the wealth of reuse approaches being published in the scientific literature.

The proposed criteria are discussed in the following parts of this Section:

- Reuse techniques
- Reuse situations
- Capacity of knowledge representation
- Addressee of knowledge
- Scope of the knowledge
- Phase of solution development
- Validation status

The selection of the above criteria was guided by the intention to represent different and complementary aspects of knowledge reuse from an organizational and a technological perspective. The criteria reuse situation,

addressee of knowledge, validation status and phase of solution development are directed towards organizational aspects, whereas reuse technique, capacity of knowledge representation and scope address technological aspects. This set of criteria probably is not exhaustive, i.e., definition of additional criteria is possible and application of the criteria set is expected to show what additional ones are recommendable (see also Section 5).

All criteria aim at sorting knowledge reuse approaches into categories with respect to the criteria under consideration, i.e., all criteria contain a list of categories to be used. In case none of the given categories is applicable when using one of the criteria for a certain reuse approach, the additional category "other" should be used. Such a case would call for a discussion about an extension of the above classification scheme.

3.1. Reuse Techniques. In general, a technique denotes "practical method or art applied to some particular task". In the context of knowledge reuse, we propose to consider techniques form computer science developed as means to facilitate reuse. Based on the literature search mentioned in the previous Section, we identified four techniques frequently used in knowledge reuse which are summarized in Table 1.

Table 1. Reuse techniques distinguished in the classification approach

Reuse Technique	Description
Module based techniques	a module is a self-contained component of a solution with defined interfaces hiding the actual implementation. The module has to be used „as is", i.e., without changing it, and often will be composed together other modules to a solution
Reference Architecture based techniques	architectures in general identify the main building blocks of a system with their interfaces and dependencies. Reference architectures are architectures reflecting the common building blocks for a defined domain which were agreed on by the stakeholders in that domain. Reference architecture can be considered as technique for knowledge reuse „in the large".
Template based techniques	a template is a gauge to be used as a guide in making something accurately for a defined purpose. A template defines the structure but not the content; usually no behavioral aspects included
Pattern based techniques	a pattern provides solution principles (and how to implement them) for a recurring problem in a specific context by abstracting from actual application. A pattern exposes the core elements of the solution (structure and behavior) and consequences of using it. A pattern cannot be used as it is (unlike a module) but always has to be adapted for the purpose at hand

The question to be answered for this criterion when classifying a knowledge reuse approach is: "What knowledge reuse technique is used by the knowledge reuse approach?"

3.2. Reuse Situations. The concept of reuse situations was proposed by Markus [25] as a way to characterize typical situations in organization where a demand of knowledge reuse arises. The reuse situations identified by Markus are shown in Table 2.

Table 2. Reuse situations in the classification approach

Reuse Situation	Description
Shared work procedures	this situation exists when people work together on a team, either with the same roles or tasks or with different functions (cross-functional) and reuse work procedures earlier developed by themselves, i.e., they are producers of knowledge for their own later reuse
Shared work practitioners	when people in different organizational or geographical settings do similar work and share knowledge between each other in order to support their work. These people are not part of a team, but they have similar tasks. They are producers of knowledge for each other's reuse
Expertise-seeking novices	people with an occasional need for expert knowledge that they do not possess and do not need to acquire themselves because they need it rarely can be called expertise-seeking novices. Thus, this situation is given when a task has to be performed just once and the knowledge is required for this task only
Secondary knowledge miners	people who seek to answer new questions or develop new knowledge can be considered as "mining" for new knowledge. Through analysis of records or documentation produced by other people for different purposes, they aim to reuse knowledge

The question to be answered for this criterion when classifying a knowledge reuse approach is: "For what knowledge reuse situation has the knowledge reuse approach been designed?"

3.3. Capacity of the Knowledge Representation. This criterion is based on Alan Newell's work on knowledge levels. For Newell, knowledge is that which an observer ascribes to an intelligent agent (human or machine) that allows the observer to construe the agent's behavior as rational, i.e. behavior that allows the agent to achieve its perceived goals [35, 36]. Newell emphasizes that knowledge is an abstraction that cannot be written down. Data structures that we might use to encode knowledge in a computer knowledge base are not equivalent to the knowledge (the capacity for behavior) that those data structures represent. We are able to use data structures (symbols) to represent knowledge in a knowledge base, but those symbols cannot generate intelligent behavior – unless some process is applied to those symbols. This means we have to distinguish the symbols in a knowledge base (knowledge representation) from the knowledge (capacity for rational behavior) that the symbols can be used to generate.

Sharing and reuse of knowledge according to Newell requires specific preconditions. Knowledge bases have meaning only when they are processed by some interpreter - either by a computer program or by our own minds. We cannot share and reuse knowledge bases if we do not also share and reuse the inference engines (or mental processes) that bring our knowledge bases to life. Although we may speak of transferring "knowledge" from one site to another, we can at best transfer knowledge bases. We design our knowledge bases so that they can be processed to produce intelligent behavior. According to Newell, the area of problem solving is one of the application fields for sharing and reuse of knowledge. Sharing knowledge about problem solving requires a format for knowledge representation; a shared vocabulary; a conceptual model; and a process to be performed by the interpreter using the knowledge base.

Capacity reflects how much of a problem solving task can be represented by the knowledge reuse approach under consideration, i.e., how "powerful" is the reuse approach when it comes to capturing all parts of the relevant knowledge. Regarding the capacity of the knowledge representation the levels summarized in Table 3 are distinguished.

Table 3. Capacity of reuse distinguished in the classification approach

Capacity	Description
knowledge representation format	a knowledge representation format only defines how to represent the knowledge when explicating it. Often this includes syntax and semantics of records in knowledge bases, information structures in databases or languages to represent knowledge
reusable lexicon / shared vocabulary	in addition to the knowledge representation format, capturing knowledge usually requires the definition of what terms and concepts may be used for representing knowledge and what their meaning is
shared conceptual model	the relations between different concepts of the shared vocabulary has to be captured in order to represent knowledge. A knowledge reuse approach with the capacity to express a shared conceptual model usually allows for the definition of hierarchies, taxonomic relationships, classes of objects, characteristics of classes, etc.
process reuse	according to Newell, the knowledge representation alone is not sufficient to capture knowledge but there has to be an interpreter (which can be a machine or the mental process of the human) using what is represented. If the knowledge reuse approach allows for representing the process to be performed by interpreter independent of knowledge representation format but dependent on the interpreter, it has the capacity of process reuse
problem solving reuse	the highest capacity level is reached, if the process to be performed by an interpreter can be represented independent of the knowledge representation format and independent of the interpreter

It should be noted that the above levels of knowledge representation are building on top of each other, i.e., "reusable lexicon / shared vocabulary" requires "knowledge representation format"; "shared conceptual model" requires "reusable lexicon / shared vocabulary" and "knowledge representation format"; etc.

The question to be answered for this criterion when classifying a knowledge reuse approach is: "What capacity does the knowledge representation underlying the reuse approach provide?"

3.4. Addressee of knowledge. The addressee of knowledge captured by a reuse approach can be considered as the target group which is supposed to use the knowledge.

Most reuse approaches capture knowledge which is meant to be used by an individual in her/his work context, but there are also knowledge reuse approaches suitable for organizational knowledge only. With this criterion, we aim to distinguish whether the knowledge reuse approach under consideration is meant for. The potential addresses are summarized in Table 4. The questioned to be answered for this criterion when classifying a knowledge reuse approach is: "What is the main target group of the knowledge provided by the reuse approach?"

Table 4. Addressees of knowledge distinguished in the classification approach

Addressee	Description
Individual	the knowledge is meant for an individual when performing tasks as part of his/her organizational role
Group of people	the knowledge is not meant or not to be used or not possible to use by an individual on its own, but it usually does not happen within an organizational context
Organization	the knowledge can only be reused in an organization with an organizational context in place
Several organizations	the knowledge concerns several organizations cooperating with each other (inter-organization)

3.5. Scope of the knowledge. In the context of knowledge management, approaches for reusing knowledge often focus on specific perspectives of enterprise knowledge, like knowledge about processes or about products. The criteria "scope of knowledge" addresses this fact and aims at classifying knowledge reuse according to these perspectives. We propose to base this criterion on work from enterprise knowledge modelling. In general terms, enterprise modelling is addressing the systematic analysis and modelling of processes, organization structures, products structures, IT-systems or any other perspective relevant for the modelling purpose [37]. Enterprise knowledge modelling combines and extends approaches and techniques from enterprise modelling. The knowledge need-

ed for performing a certain task in an enterprise or for acting in a certain role has to include the context of the individual, which requires including all relevant perspectives in the same model. Thus, an essential characteristic of knowledge models are "mutually reflective views of the different perspectives included in the model" [9]. As a best practice for capturing such mutually reflective views, the POPS* perspectives were proposed: the enterprise's processes (P), the organization structure (O), the product developed (P), the IT system used (S) and other aspects deemed relevant when modelling (*) [38].

Based on this best practice, the criterion is supposed to capture, what the main scope of the knowledge in the knowledge reuse approach is. The different options are shown in Table 5.

The questioned to be answered for this criterion when classifying a knowledge reuse approach is: "What is the scope of the knowledge captured by the knowledge reuse approach?"

Table 5. Scope of knowledge distinguished in the classification approach

Scope	Description
Product	the knowledge concerns about a product. It should be noted that a product of an enterprise does not have to be a physical product but can be a service provided to a customer, i.e., it can be a "service product"
IT solution or artefact	the knowledge is related to an IT solution or artefact within the solution development process
Process	the knowledge is explicitly addressing a process or a way to perform certain activities in an organization e
Organization structure	the knowledge is about organization structures, e.g. how to implement certain roles, positions or structural characteristics

3.6. Phase of solution development. Both in knowledge management and in knowledge engineering, the introduction or development of systems or solutions to given problems happen in a systematic way, which is reflected in development phases. Many knowledge reuse approaches were designed for a specific development phase. The purpose of the criterion is to determine in which solution development phase the knowledge reuse approach under consideration is supposed to be useful or applicable. We distinguish between 7 traditional phases, which for example are reflected in software engineering approaches, like Boehm's spiral model [39]. These phases are explained in Table 6.

The questioned to be answered for this criterion when classifying a knowledge reuse approach is: "For what phase of the solution development process situation has the knowledge reuse approach been designed?"

Table 6. Phases of solution development distinguished in the classification approach

Phase of solution development	Description
Analysis	Knowledge relevant for solution development when analyzing requirements or application contexts for the envisioned solution
Specification	Knowledge which is reusable when specifying the expected structure and behavior of the envisioned solution
Design	Knowledge which is reusable when designing the solution in the large (architecture) or in detail (component design)
Implementation	Reusable knowledge for implementing the solution
Verification and Validation	Knowledge relevant for validating and verifying the solution including test designs and data
Operation	Knowledge relevant during operations and execution
Maintenance	Knowledge for detecting or avoiding problems during operations

3.7. Validation Status of the Approach. The validation status of the reuse approach is considered an important criterion in order to, e.g., judge the suitability of the approach for use in industrial practice. Our assumption is that the more an approach has been validated in theory and practice, the more mature and useful it is. Among the many scientific approaches for validating research results, we base our proposal for judging the validation status on the work of Lincoln and Guba ([40], p. 289 ff.) on "naturalistic inquiry". On the one hand, we distinguish between theoretical and practical validation. Theoretical validation means assessing an approach within the theories of the domain the approach is part of or supposed to contribute to. In the context of knowledge reuse, this means to assess the soundness, feasibility, consistency within the body of knowledge in, for instance, knowledge management and knowledge engineering. Practical validation encompasses all kinds of application of the approach for validation purposes, which requires defined procedures and documenting results.

This could be simple lab examples illustrating the approach, controlled experiments in a lab setting, application in industrial cases, etc.

On the other hand, we consider the context of validation and distinguish between validation by the developers of the approach in their internal environment, validation by the developers outside the internal environment, and validation by other actors than the developers. Combining these two perspectives leads to a two by three matrix, which is depicted in Table 7. The cells of this Table show typical ways of validation for the different combinations of the two perspectives.

Table 7. Validation steps according to Lincoln and Guba

Validation steps	Theory	Practice
Internal, development team	Validation against state of research, internal consistency checks	Prototype implementation for checking feasibility, test in lab environment
External, in validation context	Peer-review of publications describing approach and concepts, comparison to known best practices of the domain	Case studies with application partners using the artifacts for evaluation purposes Application of the developed artifacts in cooperation / under instruction from developers
External, in application context	Development of extensions or enhancements of the concepts and approaches by external actors Application of the artifacts for creation of new theoretical knowledge Comparison with related approaches	Use of the artifacts developed (e.g. algorithms, methods, software components) for solutions

Using the above matrix, information about the knowledge reuse approaches has to be used to determine where to position the validation status for the reuse approach in the matrix. Usually, validation starts on the "internal, development team" level with validation in theory followed by validation in practice, and proceeds "downward" in the matrix with alternating theory and practice validation to "external, in application context". Thus, the highest validation status would be reached if all cells in the matrix were covered.

The questioned to be answered for this criterion when classifying a knowledge reuse approach is: "What validation status does the knowledge reuse approach have?"

4. Knowledge Reuse in SME Production Networks. This Section focuses on an analysis of knowledge reuse situations in production networks in general and networks of small and medium-sized enterprises (SME) in particular. This analysis consists of two parts: in the first part, a literature analysis regarding knowledge reuse is described. In the second part, an example for an industrial network is presented and analyzed.

4.1. Literature Analysis. The literature analysis performed for this paper followed a systematic process described by Kitchenham [41]. Starting point was the definition of research questions guiding the systematic literature analysis. In our case the main questions were:

– RQ1: What scientific work has been done on knowledge reuse in production networks?

– RQ2: Using the classification approach presented in the third Section, what knowledge reuse techniques have been described in the published work?

In the next step, the literature sources to be analyzed had to be defined. Since knowledge reuse and knowledge management are interdisciplinary subjects, literature sources from computer science and information systems were included. We analyzed SpringerLink, IEEE xplore, AISeL and ScienceDirect. In the search term we included knowledge management and not only knowledge reuse to make sure that papers were selected which did not explicitly mention the term reuse. Furthermore, in addition to production network, we also included terms commonly used as a synonym or generalization. The final search term used in all literature databases was as follows:

("Knowledge Management" OR "Knowledge Reuse") AND ("Production Network" OR "Manufacturing Network" OR "SME-network" OR "SME-cluster" OR "SME network" OR "SME cluster" OR "Networked Organization" OR "Networked Organization")

The search was performed in title, abstract and keywords or metadata. The list of hits in each literature database was analyzed paper by paper. In this step, only those papers were selected which described a knowledge reuse technique or examples, organization structures or practices for reuse. Table 8 shows the number of papers retrieved.

Table 8. Number of papers retrieved in the literature analysis

Literature Source	No. of hits for the search term	No. of relevant papers
IEEE xplore	28	3
SpringerLink	17	3
AIS electronic library	22	0
Total	67	6

At the end of this process, only 6 papers remained for further analysis. Many hits had to be excluded because they were not addressing production networks but single organizations or because they used knowledge management and knowledge reuse only as a motivation for the development of a very specific system or technology without showing applicability or real-world use. Table 9 presents the papers which were analyzed in detail.

Table 9. Papers retrieved in the literature analysis

No.	Paper	Source
1	Y. Zhang and Y. Jin, "Research on Knowledge Management for Group Enterprise in Cloud Manufacturing," *Computer Science & Service System (CSSS), 2012 International Conference on*, Nanjing, 2012, pp. 1946-1950.	IEEE xplore
2	Chunli Yang and Hao Li, "A framework of product knowledge management supporting product agile customization design," *Service Operations and Logistics, and Informatics, 2008. IEEE/SOLI 2008. IEEE International Conference on*, Beijing, 2008, pp. 308-313.	IEEE xplore
3	M. Takahashi, J. I. Oono, K. Saitoh and S. Matsumoto, "Reusing makes it easier: manufacturing process design by CBR with KnowledgeWare," in *IEEE Expert*, vol. 10, no. 6, pp. 74-80, Dec 1995.	IEEE xplore
4	G. Bruno, D. Antonelli, R. Korf, J. Lentes, N. Zimmermann (2014) Exploitation of a Semantic Platform to Store and Reuse PLM Knowledge. Advances in Production Management Systems, Volume 438, IFIP Advances in Information and Communication Technology, pp 59-66. Springer.	Springer Link
5	R. Furian et al. (2013) Knowledge Management in Set Based Lean Product Development Process. Advances in Production Management Systems, Volume 397, IFIP Advances in Information and Communication Technology, pp 368-375, Springer.	Springer Link
6	M. Bricogne, F. Belkadi, M. Bosch-Mauchand, B. Eynard (2010) Knowledge Based Product and Process Engineering Enabling Design and Manufacture Integration. Advances in Production Management Systems, Volume 338, IFIP Advances in Information and Communication Technology, pp 473-480, Springer.	Springer Link

Analysis of the retrieved papers focused on identifying the knowledge reuse technique described in the paper and classifying it with the approach presented in the third Section. The result of this classification is shown in Table 10.

The most important finding of the literature review is that there is not much research available on knowledge reuse in production networks (RQ1). Only 68 papers as a result of the search is quite a low number. The same is true for the 6 papers found relevant. The published approaches focus on framework or module development, which in most cases have not entered the validation phase yet. The dominant scope considered is product knowledge.

Table 10. Classification of knowledge reuse techniques in the papers resulting from the literature review

Criterion	Classification of papers from literature review					
	#1	*#2*	*#3*	*#4*	*#5*	*#6*
Reuse Techniq.	Fr.work	Fr.work	Module	Fr.work	Module	Fr.Work
Reuse Situation	Shar. work proc.	Exp.-seek. nov.	Exp.-seek. nov.	Shar. work proc.	Exp.-seek. nov.	Exp.-seek. nov.
Capacity of KR approach	Shar. conc. mod.	Shar. conc. mod.	Shar. conc. mod.	Shar. conc. mod.	Shar. conc. mod.	Shar. conc. mod.
Address. of knowldg.	Organ.	Organ.	Indiv.	Organ.	Indiv.	Organ.
Scope of the knowldg.	Product, proc.	Product	Product	Product	Product	Product, proc.
Phase of solution develop.	Design	Design	Spec.	Spec.	Spec.	Design
Validat. status of approach	Internal	Internal	Internal	External, valid. cntxt	Internal	Internal

4.2. SME production network example. In order to illustrate the use of the classification approach for investigating knowledge reuse approaches in SME production networks, this Section will briefly introduce an example of such a network. The example was one of the industrial case studies on distributed product development in the MAPPER project [42] and is based on a networked organization from automotive supplier industry. The network consists of independent companies in the automotive domain who cooperate in product design and development and also coordinate their activities for production and delivery. Organizations of this form use information technology to extend their value creation possibilities [43] and establish various links across their organizational boundaries to achieve the joint objective [44].

The leading partner in the example network is a first tier automotive supplier from Sweden with its business area “seat comfort systems and components”, working with development and manufacturing of products for trucks and cars world-wide. The products considered in the example are seat comfort products, like seat heater, ventilation for seats, lumber support and head restraint. Typical development processes of products in this business area encompass elicitation of system requirements based on requirements from car or truck manufacturers; functional specification; development of product architecture (logical and technical components); co-design of hardware, software, elec-

trical and mechanical components; component and integration testing; and production planning including production logistics, product line and floor planning.

The first tier supplier performs this process in a geographically distributed setting, which involves engineers and experts at different locations in Scandinavia, which also includes SMEs. Many seat comfort systems and components are developed in product families, i.e., various versions exist and have to be maintained and specialized for different product variations made for different customers. In this context, fast and flexible engineering processes and the possibility to concurrently perform forward-engineering processes for different product variants is of crucial importance. In this context, information sharing and smooth reuse of knowledge from earlier product versions and network partners are key factors for efficient processes.

Figure 1 shows a typical collaboration set-up for engineering seat comfort components in the example network. The customer for a new variant of a seat heater is an OEM (Original Equipment Manufacturer) for cars or trucks. The first tier supplier receives the order for engineering and manufacturing the seat comfort sub-systems for a new vehicle model. From the first tier supplier perspective, this order usually leads to a new variant in a product family. Several sub-suppliers and partners are involved in the engineering and production network, with responsibility for specific components, like the carrier cover and carrier material or the copper wires for the heating coil, or for selected services, like the controller design or manufacturing of the relay unit. The first tier supplier organizes and monitors the overall design process, contributes own components and engineering steps, and is responsible for the system integration.

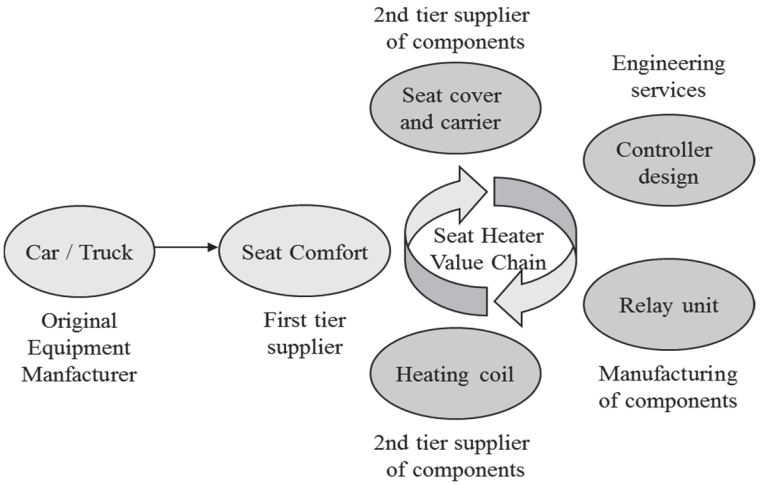

Fig. 1. Example supply network in collaborative product engineering

Enterprise engineering frameworks, such as GERAM [45], recommend using enterprise models or partial enterprise models for capturing proven structures of how to organize processes, what actors and roles are required, and the specific resources needed for a certain task. One of the problems encountered when representing relevant knowledge of production network members with partial enterprise models for each network member is to identify the integration points between the individual partial models, i.e. the processes where collaboration takes place and what actors and resources are involved.

In this context, the concept of a "connector view" was developed with the intention to contribute to solving the problems with interconnecting collaboration processes and give a "network-wide view" of the collaboration. As a complement to the partial enterprise models, the connector view is a model which captures collaboration elements, i.e. a model solely focused on processes, actors and resources which constitute collaborative situations. For a defined partnership in a production network, the relevant partial enterprise models are integrated with help of the connector view which results in a model for the collaboration of the established partnership with cross-enterprise collaboration processes and information flows (see [46] for more details).

When classifying partial enterprise models and the connector view with the approach presented in the third Section, it shows that basically two techniques are used: the partial enterprise models are reused by instantiating them, i.e. they have to be considered as patterns; the connector views are blueprints for what to integrate in creating collaborative processes, which makes them templates.

Since partial enterprise models and connector views are meant for sharing experiences between enterprise engineers about how procedures or tasks should be designed, the reuse situation is "shared work procedures". These patterns are meant to capture not only a conceptual model, but all information for problem solving, which shows the capacity of the approach. Partial enterprise models will be used in organizations engaging in a collaboration, which makes organizations the primary addressee of the knowledge. The scope of the knowledge is "process" and "organization structures", as partial enterprise models are used to describe these two aspects of organizations. The use of the knowledge for designing the way of collaboration indicates that the development phase addressed is "design". As partial enterprise models and connector views were used in a number of real-world application contexts by people external to the development teams, the validation status of the approach is "external, in application context". The result of the classification is shown in Table 11.

Table 11. Classification of reuse in the sample SME production network

Criterion	Classification of knowledge reuse approach used in SME network
Reuse Technique	Pattern and template
Reuse Situation	Shared work procedures
Capacity of knowledge reuse approach	Problem solving reuse
Addressee of knowledge	Organization
Scope of the knowledge	Knowledge about processes and organization structure
Phase of solution development	Design
Validation status of the approach	External, in application context

5. Validation of the Classification Approach. Already in Section 4 the knowledge reuse classification approach (Section 3) was applied when categorizing what knowledge reuse approaches are relevant for SME production networks. However, in the previous Section the developers of the categorization applied the approach, i.e. it was an internal validation of the approach. In contrast to the previous Section, this Section will take an external perspective when validating the classification approach, i.e. persons from outside the development team will use and evaluate the approach. The purpose is to check whether the knowledge reuse classification is applicable when practitioners investigate reuse in SME production networks.

In previous validation attempts [10], the classification criteria have been applied for technological and organizational approaches from computer science and business information systems. If we want to meet our ambition to support practitioners in selecting the right technique, the criteria have to be understandable even in this context. At the same time, performing the classification will – at least for the given selection of papers – show what knowledge reuse techniques actually are in use in SME networks and which potentially should receive more attention.

The validation requires that the approach under consideration is applied and evaluated by actors which were not involved in developing it. Thus, the evaluation of knowledge reuse approaches in SME networks was performed in two seminars at different occasions with different student groups in different educational settings. The first seminar was organized in autumn 2014 in a master course on Knowledge Representation at Rostock University, Germany. Participants were 12 master students, all of them with a Bachelor in Business Information Systems. Seminar 2 took place as part of a summer school in spring 2015 at Berlin University of Technology. Participants were more than 20 PhD students and master students. Both seminars followed the same set-up and work process:

– a 4 hour time frame was arranged, which consisted of 1,5 hours lecture, 1,5 hours group work and one hour discussion of the group work results;

– the lecture introduced the term knowledge reuse, related areas from knowledge management and knowledge engineering, examples for knowledge reuse techniques and the classification approach, i.e., the lecture basically had the same content as the first four Sections of this paper;

– the group work part had the task for each group to use the classification approach for investigating and classifying the technique of knowledge reuse applied in a given SME network. Each of the SME networks to be investigated was documented in a scientific publication. The participants formed groups of two or three students and selected themselves which SME network to work on. No group was allowed to take the same paper as another group. The papers selected for the group work are listed in Table 12;

Table 12. Papers on SME networks selected for the seminars

No.	Paper
1	Corso, M., Martini, A., Paolucci, E. and Pellegrini, L. (2003), ‘‘Knowledge management configurations in Italian small to medium enterprises’’, Integrated Manufacturing Systems, Vol. 14 No. 1, pp. 45-56. Dominant approach: inter-personal relationships
2	Wenger, E. (1998), Communities of Practice: Learning, Meaning and Identity, Cambridge University Press, Cambridge.Dominant approach: technical and organizational infrastructure and self-organization in the community
3	Dyer, J.H. and Nobeoka, K. (2000), ‘‘Creating and managing a high-performance knowledge sharing network: the Toyota case’’, Strategic Management Journal, Vol. 21, pp. 345-67. Dominant approach: establish learning processes and knowledge sharing structures
4	Sandkuhl K., Smirnov A., Henoch B. (2004) “Towards Knowledge Logistics in Agile SME Networks - Technological and Organizational Concepts”. In: Dolgui A., Soldek J., Zaikin O. “Supply chain optimisation: product/process design, facility location and flow control”. Kluwer Academic publishing, ISBN 1-4020-8081-6. Dominant approach: use application ontology to capture competences of network partners
5	Sandkuhl, K. (2010) Capturing Product Development Knowledge with Task Patterns: Evaluation of Economic Effects. Quarterly Journal of Control & Cybernetics, Issue 1, 2010. Systems Research Institute, Polish Academy of Sciences.
6	Peças, P., & Henriques, E. (2006). Best practices of collaboration between university and industrial SMEs. Benchmarking: An International Journal, 13(1/2), 54-67. Dominant approach: best practice descriptions
7	Yew Wong, K. (2005). Critical success factors for implementing knowledge management in small and medium enterprises. Industrial Management & Data Systems, 105(3), 261-279. Dominant approach: implement management support and organizational structures
8	K. Sandkuhl, V. Tarasov (2010) Comparison of Approaches for Competence Demand Modeling in Flexible Supply Networks. Logistics and Supply Chain Management: German-Russian Perspectives, Proceedings of the 5. German-Russian Logistics Workshop. St. Petersburg, May 2010, ISBN 978-5-7422-2585-0. Dominant approach: competence descriptions

– the discussion of the group work results consisted for each group of a short description of the publication analyzed and the classification reached. This classification was discussed with the other seminar participants. Furthermore, each group had the explicit task to reflect on suitability of the different classification criteria for the given purpose, on the applicability of the criteria, i.e., are the criteria described in a way which allows to clearly distinguish the different categories, and whether criteria or aspects for classification were missing or superfluous. In seminar 1, the participants had to summarize their results in a short report; in seminar 2, the results were captured during discussion.

The results of the group work in the three seminars are summarized in Table 13 regarding the classifications which were detected for each technique.

Table 13. Summary of the classification results from all seminars for the papers listed in Table 5

Paper no.	Reuse Technique	Reuse Situation	Capacity	Addressee	Scope	Phase of Development	Validation status of Approach
1	1: template 2: none	1,2: shared work practitioners	1,2: none	1,2: individual	1,2: process, artefact	1,2: all phases	1,2: external, in application context
2	1: template 2: template	1,2: shared work procedures	1,2: vocabulary	1,2: group	1,2: process, organization or artefact	1,2: all phases	1,2: external, in application context
3	1,2: none	1,2: shared work practitioners	1,2: none	1,2: organization	1,2: process, organization	1,2: all phases	1,2: external, in application context
4	1: model 2: template	1,2: expert seeking novices	1,2: conceptual model	1: organization	1,2: IT-artefact	1,2: analysis + design	1: internal, in validation context
5	1: pattern 2: template	1,2: shared work procedures	1, 2: problem solving	1,2: organization	1,2: process, org., product, IT	1,2: design	1,2: external, in application context
6	1,2: pattern	1,2: expertise-seeking novices	1,2: concept. model	1,2: individual	1,2: organization, process	1,2: analysis, design	1,2: external, in application context
7	1,2: none	1,2: shared work practitioners	1,2: one	1,2: organization	1,2: process, organization	1,2: all phases	1,2: external, in application context
8	1,2: template	1,2: expert seeking novices	1,2: conceptual model	1,2: individual	1: organization 2: none	1,2: analysis	1,3: external, validation context

Due to the different number of participants and due to the possibility for each group to select their publication to evaluate, some papery were classified by two different groups simultaneously. Regarding the suitability of the classification criteria, the participants of the seminar confirmed that it was possible to use the criteria for analyzing the characteristics of knowledge reuse techniques and to classify the techniques described in the provided papers.

The classification results discussed above and shown Table 13 support this impression. For the applicability, most criteria were perceived as sufficiently clear defined and applicable in practical use: reuse technique, reuse situation, capacity of knowledge representation, validation status, and phase of solution development. The criterion which received criticism in seminar 2 was the scope of the knowledge. The participants of this seminar expressed that the product and process perspective were not sufficiently distinguishable, which was solved by additional explanations by the teacher during the seminar. Seminar 1 did not raise this question, probably because they both had a solid education in enterprise modeling which emphasizes the distinction between product and process knowledge. The implication for the classification approach is that the aspect should be more clearly explained and illustrated with examples.

Criticism from both seminars was expressed regarding the target group criterion “addressee”. A knowledge representation technique suitable for an individual in his daily work also will be of use for the organization this individual is working with. On the other side, knowledge meant for the organization will usually be applied by the individuals in the organization. In order to : If the knowledge reuse technique cannot be applied by an individual alone but need organizational structures, like roles or processes, than the technique is to be classified as meant for organizations, not for individuals.

6. Discussion: Knowledge Reuse Types relevant for SME Production Networks. The example network presented in the third Section of the paper investigated the need for knowledge reuse of an industrial network in collaborative product engineering. The conclusion from this case was that the reuse techniques relevant for the network were “patterns” and “templates” with the purpose to capture “shared work procedures” as the reuse situation. The scope of knowledge to be reused concerned “processes” and “organization structures” with the addressee being the “organization” as such. The capacity required of the reuse approach is to support “problem solving”.

Although this situation concerns only the knowledge reuse in one specific production network, it can be used as a starting point or initial hypothesis what typical knowledge reuse needs of networks might be. Validation of such a hypothesis should be done by either studying existing infor-

mation about networks, or the currently existing networks themselves, or both. As studying the network themselves would not be realistic due to the efforts involved and the need to make all such networks cooperate, we propose to in the first step focus on published information.

In the previous Section, we studied the available information about knowledge reuse in such networks by identifying published work in the field and by using our classification approach. In this context, it was important not to ask the developers of the classification approach to evaluate the identified papers but to use analytically trained people from outside the development team, in this case two student groups.

The results of this work are summarized in Table 13 which shows the knowledge reuse classification for the identified papers. When evaluating the results from the perspective of our hypothesis, we put specific weight on papers and cases that have the maturity level of being applied in practice (i.e., "external, in application context"). Regarding the reuse technique, these papers confirmed the hypothesis from the industrial case that templates and patterns are relevant, but they also show that, in a number of cases, no technique at all is applied. In these cases of no visible technique, the capacity of knowledge reuse achieved also is "none" – which is not surprising but indicates that in these cases no reuse approach for explicit knowledge was used at all but that these cases basically address sharing implicit knowledge. This impression is supported by the reuse situation found in these cases which is "shared work practitioners", i.e. the practitioners exchanging knowledge face-to-face without explicating it. The reuse situation commonly supported by template or pattern as reuse technique is "shared work procedures" – which also was the case in the industrial case study.

Regarding the capacity of the knowledge reuse approach, there is no clear picture from the analysis of the papers: vocabulary, conceptual model and problems solving (like in the industrial case) can be found. The most frequent addressee of the knowledge in the literature cases is the organization, but also individuals are seen as addressee. This confirms the hypothesis from the industrial case but also indicates that individuals should be added. The scope of the knowledge in all cases includes processes and in all but one case also includes organization structures, which confirms the hypothesis from the industrial case. When it comes to the phase of development, design always is included and in most cases all phases are relevant.

Table 14 summarizes our analysis on what kind of knowledge reuse approaches are of specific relevance for production networks and SME networks: templates or patterns capturing processes and organization structures for sharing of work procedures on the level of an organization or an individual role. This knowledge should be validated in a real-world application

context and is required for all phases of solution development with specific focus on the design phase.

7. Summary and Future Work. Starting from an existing classification approach for knowledge reuse techniques and a review of literature on knowledge reuse in SME production networks, the paper evaluated the classification approach for knowledge reuse techniques regarding its suitability for use in SME networks. The criteria included in the approach are reuse technique, reuse situation, capacity of knowledge representation, addressee of knowledge, validation status, scope and phase of solution development.

Table 14. Kinds of Knowledge Reuse relevant for SME production networks

Criterion	Classification of knowledge reuse approach used in SME network
Reuse Technique	Template and pattern
Reuse Situation	Shared work procedures
Capacity of knowledge reuse approach	All are relevant (no specific preference)
Addressee of knowledge	Individual, Organization
Scope of the knowledge	Knowledge about processes and organization structures
Phase of solution development	All phases (with specific importance on Design)
Validation status of the approach	External, in application context

The most important finding regarding knowledge reuse in SME production networks is that there is not much research available on this topic. The published approaches focus on framework or module development, which in most cases have not entered the validation phase yet. The dominant scope of the existing approaches is product knowledge. An application for this product-centric view could be that mainly physical products have been in focus of such networks whereas product-service combinations mostly are considered internally by enterprises. With an increasing number of service networks, this aspect might change which would result in an increased importance of the process view. Future work to this end should develop practice oriented reuse techniques for combined product and process knowledge ready-made for adaptations in SME. Even knowledge reuse approaches covering a combination of product, process, organization and systems perspective at the same time have to be considered, as these perspectives are mutually dependent.

Suitability and applicability of the classification approach for knowledge reuse techniques were evaluated by applying them on different knowledge reuse studies reported in research papers which by intention were selected from different areas of SME networks and by using them as part of

an assignment in different seminars in university education on PhD and master student level. The classification approach was perceived applicable, suitable and useful for the intended purpose. By analyzing the industrial case and the literature published about such cases, we also presented our view on those kinds of knowledge reuse in particular relevant for SME production networks.

One part of future work will be to perform various refinement and improvement activities of the classification approach:

– The criteria receiving criticism during application in the seminars need improvement

– The categorization for each individual criterion should be checked one more time for completeness. For this purpose an extensive literature study will be performed

– The way of how to perform the classification for a given knowledge reuse approach should be described in more detail as a guideline

Another important part of the future work will be to revisit the initial motivation for developing the classification: to support practitioners in finding and selecting the right knowledge reuse approach for a given problem or application scenario. For this purpose, much information included in the classification is supposed to be useful and required, like the reuse situation and the technique. However, it will be crucial to better understand the drivers and frame conditions of knowledge reuse in organizations. Probably, typical motivations like automation for higher efficiency or standardization as means to raise quality will not be sufficient. New application domains, such as internetworked e-work, are considered as promising fields for knowledge reuse. New case studies in this field are expected to provide first insights [47].

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УПРАВЛЕНИЕ ЗНАНИЯМИ В ПРОИЗВОДСТВЕННЫХ СЕТЯХ: КЛАССИФИКАЦИЯ И ТЕХНОЛОГИИ ДЛЯ ПОВТОРНОГО ИСПОЛЬЗОВАНИЯ ЗНАНИЙ

Зандкуль К., Смирнов А.В. **Управление знаниями в производственных сетях: классификация и технологии для повторного использования знаний.**

Аннотация. Многие исследования в области управления знаниями указывают на то, что предприятия и организации, поддерживающие систематический обмен, передачу и повторное использование знаний, могут рассчитывать на значительные выгоды. Однако не так много исследований выполнено в рамках анализа технологий для повторного использования знаний, которые применяются в организациях. Исходя из классификации подходов к повторному использованию знаний, в статье рассматривается состояние в этой области применительно к производственным сетях (с уделением особого внимания сетям малых и средних предприятий - МСП). Цель статьи двоякая: для производственных сетей это исследование того, какие виды повторно используемых знаний (с точки зрения разрабатываемой классификации) наиболее актуальны для таких сетей; для подхода к классификации методов повторного использования знаний это уточнении данного подхода и его обоснование применительно к производственным сетям. Основными результатами статьи являются: (1) анализ ситуаций повторного использования знаний в сетях МСП, (2) оценка предложенного подхода к классификации методов повторного использования знаний применительно к различным ситуациям и (3) дальнейшее уточнение и валидация предложенного подхода.

Ключевые слова: трансфер знаний, представление знаний, производственные сети, сети МСП.

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