sciendo RIGA TECHNICAL UNIVERSITY

Applied Computer Systems

ISSN 2255-8691 (online)
ISSN 2255-8683 (print)
December 2018, vol. 23, no. 2, pp. 81–89
doi: 10.2478/acss-2018-0011
https://content.sciendo.com

Context-oriented Knowledge Management in Production Networks

Kurt Sandkuhl[1*], Alexander Smirnov[2]
[1] *Institute of Computer Science, University of Rostock, Rostock, Germany*
[2] *St. Petersburg Institute for Informatics and Automation of Russian Academy of Sciences, St. Petersburg, Russia*

***Abstract* – Production networks have been established in many industrial domains with globalized supply structures, sourcing strategies or cooperation environments. Knowledge management in such networks requires a context-oriented approach in order to accommodate for individual and organizational needs when providing relevant knowledge for complex tasks, such as value creation. The focus of this paper is on the procedure by which to determine what actually has to be taken into account as part of the 'context' for establishing context-oriented knowledge management, how to capture this context, and how to use it. The variability of organisational and individual tasks both at design time and at runtime is essential for understanding context in production networks. The main contribution of the present study is a context modelling method, including variability identification. The application of this method is demonstrated by using an example of a production network from automotive industries.**

***Keywords* – Context computing, context modelling, enterprise modelling, knowledge engineering, knowledge management, production network, variability.**

I. Introduction

Networked organisation structures have been established in many industrial domains with globalized supply structures, sourcing strategies or cooperation environments. Examples are value networks [1], SME networks [2], and production networks [3]. A common challenge observed is that it is difficult to identify who can provide what kind of resources, services or knowledge for a given task or application context [4], i.e., 'who can do what?' and 'who knows what'? As a consequence, the formation of new collaborations among network members and the establishment of operation support take more time and resources than necessary. Furthermore, the recent research has shown that manufacturing organisations see a need of sharing information and promoting collaboration in the manufacturing industry [5].

Knowledge management is supposed to contribute to solving this challenge by providing organisational and technical components for the systematic capturing, integration, supply, and maintenance of relevant knowledge [6]. In particular, context-oriented knowledge management systems (KMS), which are supposed to provide the exactly right knowledge for a given context, are expected to contribute high quality and efficiency in knowledge supply [7]. The importance of context orientation in knowledge management is largely undisputed [8]. Context orientation basically aims at understanding all relevant information required for knowledge use of an organisation or an actor (the context) and applying this understanding to organisational and technical knowledge management solutions (cf. Section II).

The focus of this paper is on the procedure by which to determine what actually has to be taken into account in the 'context' for establishing context orientation in knowledge management, how to capture the relevant context elements in a model, and how to use this model. The work builds upon an earlier proposal for context modelling, which so far has not taken into account the specifics of networked organisations. We argue that general context modelling methods are too broad for the purposes of production networks and should be specialised. From our perspective, the variability of organisational and individual tasks both at design time and at runtime is essential for understanding context in production networks and thus form the key aspects of a method specialisation. Thus, the paper aims at investigating three main questions:

- What are the specifics of 'context' in production networks?
- How can the elements of context for an actual production network be identified?
- What benefits can be expected from context-oriented knowledge management?

The main contribution of the present study is an improved context modelling method, including variability identification. From an application perspective, the work is positioned in production networks, i.e., we will use an example of a network to demonstrate the use of the method and we expect the method to be applicable in networked organisations. The remaining part of the paper is structured as follows: the next section briefly discusses the theoretical background for our work. In Section III, the research method and the research process performed are presented. Section IV introduces the context modelling and analysis method with its specialisation towards production networks. An example on how to put this context model into operation is covered in Section V. Expected benefits and a summary of the work conclude the paper.

II. Theoretical Background

The theoretical background for the work presented in this paper originates from production networks as an application field and enterprise modelling, context modelling and knowledge management as disciplines within information

[*] Corresponding author's e-mail: kurt.sandkuhl@uni-rostock.de

systems engineering. All four areas will briefly be presented in this section.

A. Production Networks

Production networks in general are a cross-enterprise organisation structure implementing and managing distributed value creation and product/service delivery in a coordinated and often geographically distributed partner structure. More precisely, Sturgeon defines production networks as "two or more value-chains that share at least one actor (network linkage)" [9] with a value chain being a "sequence of productive (i.e., value-added) activities leading to end use".

Network-like organisations consisting of a large number of nodes are usually more flexible and robust when compared with hierarchically organised large-scale companies [3]. Distributed production networks have a number of advantages when compared to vertically controlled companies, but they also pose challenges. Partnering on manufacturing and design has increased the need to integrate and share product information, from initial design to manufacturing and engineering changes, including best practices of processes and their integration across company limits [10]. With the aim of achieving value chain integration and dynamic collaboration, knowledge management has become of high importance. Knowledge management frameworks are applied in various industries as a support for implementing knowledge management (see [11] for an example). When dealing with multiple organisations within a network, trying to identify and integrate a member with knowledge in a particular part can be a time-consuming process. Context-based knowledge management is supposed to significantly reduce the time and enhance its effectiveness [12].

B. Enterprise Models as Sources for Context Information

In general terms, enterprise modelling addresses the systematic analysis and modelling of processes, organisation structures, product structures, IT-systems or any other perspective relevant for the modelling purpose [13]. Research [14] provides a detailed account of enterprise modelling approaches. Enterprise models can be applied for various purposes, such as visualization of current structures in an enterprise, process improvement or introduction of new IT solutions. The knowledge needed 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 [15].

In the field of enterprise engineering and knowledge management, there are many reports about the application of enterprise models in industrial practice, e.g., [16] and [17]. Furthermore, many enterprises have been reported to use process models and models of their product knowledge, which can be seen as parts of enterprise models. Thus, our approach is based on the assumption that there is at least a partial enterprise model for each production network member.

C. Context Orientation and Context Modelling

'Context awareness' has emerged from a special and innovative feature of niche applications to a characteristic of many IT systems. Dey's seminal work defined context as information characterising the situation of an entity [18]. Nowadays, groupware systems, knowledge portals, and other information systems adapt to the users' situation on demand.

However, design and development of context awareness still require substantial engineering work, i.e., there is no general development methodology for context-based systems. One reason is probably a variety of interpretations of the term 'context' in the area of engineering ([19], [20]). An essential part of developing context-based systems is to analyse and conceptualise the elements of the specific context required for the application under development, including their dependencies and mechanism of use.

Approaches and methods for context modelling (CM) were analysed extensively by [21], [20], and [22]. Based on these works, four major scientific work streams can be identified: foundations and essential features of CM (for example, the work of [19]), approaches to represent context models (e.g., [23]), application cases for context models (e.g., [24]), and, most relevant for our work, methods for context modelling. In the field of CM methods, some work has been done with a focus on process context [1], context modelling in digital enterprises [25], and context in decision support [26]. Some of these works have also investigated variation as a contribution to context modelling, but none of them includes all perspectives represented in an enterprise model. In particular, the importance of the product perspective is neglected in all approaches. Furthermore, there is no approach addressing networked organisations, which supports our proposal for a specialised CM method.

D. Context-oriented Knowledge Management

The field of knowledge management attracts researchers from diverse disciplines with different perspectives, theories, and interest in the field. Knowledge management in manufacturing and collaborative organisations also has been addressed in previous research, for example in [8], [27], [28], and [29]. At least two perspectives on KMS have to be differentiated:

- KMS from an organisational perspective. These systems describe how to establish systematic knowledge management in an organisation in terms of activities and organisational structures. Well-known approaches in this area are the 'building block' model [30] and the SECI model [31],
- KMS from a technology perspective, i.e., IT systems supporting organisational knowledge management. In this area, the architecture proposal of [32] is often applied. Maier distinguishes several layers in a KMS architecture (access, personalization, knowledge service, integration, and infrastructure layer) and four basic services (publication, search, collaboration, and learning) in the knowledge service layer of the architecture.

In both perspectives, it is acknowledged that context plays an important role, either for the process of individual knowledge generation from information, the process of understanding [31], or the creation of new knowledge [33]. IT systems supporting knowledge management often explicitly include components for ‘contextualization’ (e.g., in knowledge portals) or contain personalization features, which aim at adapting to a certain user and the actual context of use [32].

III. Research Method

The research paradigm used for the work presented in this paper is the design science research (DSR) framework for information system research proposed by [34]. Design science is a problem-solving paradigm that starts from identified business problems or demands by developing and validating IT artefacts. In this context, IT artefacts are a means to solve the identified problem and can be, e.g., prototypes, models, methods, or conceptualizations. DSR projects usually include several design-evaluate iterations of the IT artefact under consideration in search for the best solution to the problem.

In the case of our research, the DSR focused on the research questions presented in the introduction, while the IT artefact in focus was the method for context modelling in production networks (PN). The need for such a method emerged in the first DSR cycle from the industrial demand in production networks of implementing knowledge management solutions addressing both the individual member company and the overall network needs. Figure 1 illustrates the first DSR cycle, which is described in more detail in the following two sections. We started with a problem investigation in the automotive supplier production network (Section “Context-Model Use in Knowledge Supply”), then developed a method to solve the identified need (Section “Method for Context Modelling and Analysis”), then validated it, and investigated expected benefits (Section “Context-Model Use in Knowledge Supply”).

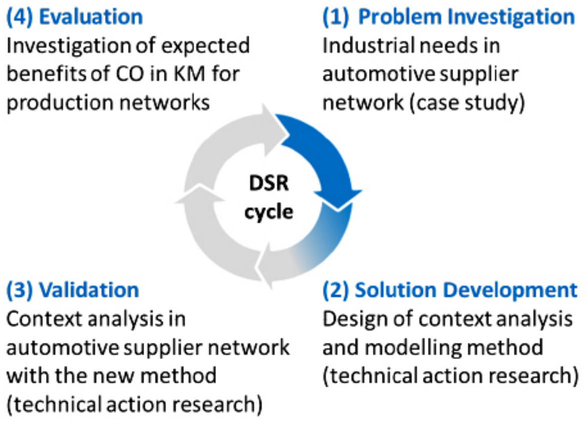

Fig. 1. First Design Science Research (DSR) cycle performed in our work.

Within a DSR cycle, different research methods can be applied. In our case, most of the work in solution development and validation consisted in technical action research using the approach by [35]. In technical action research, an innovative artefact or technique is validated and improved by applying it in a real-world setting. The researcher is part of an (industrial) development team and actively contributes to developing a solution or to solving a problem by using the new technique or artefact. At the same time, the researcher collects data and draws lessons learned from the work in the team, which helps the team to improve. In our case, the new artefact was the method specialised for production networks.

IV. Method for Context Modelling and Analysis

This section describes a proposal for a context modelling and analysis approach, which is tailored to the needs of knowledge management in production networks. It starts with an overview of the method idea and related approaches. Furthermore, the actual approach is described with its different method steps.

A. Overview

The overall idea of the method is to derive contextual information relevant for knowledge management from enterprise models, capture this information in a machine-readable context model, and use the model for configuring knowledge management solutions. Figure 2 illustrates the overall approach. The top of the figure shows the member organisations of a production network (middle) with their employees (right), and the application domain (left) of the production network. The objective of the context modelling method is to determine the relevant variation points in process and products of these enterprises, which are relevant for knowledge supply and the required support for the employees based on their work context. As a starting point for context modelling, we assume the existence of enterprise models for those parts of production network member organisations relevant for knowledge management. If enterprise models should not exist, a variety of methods are available for developing them (see Section II.C).

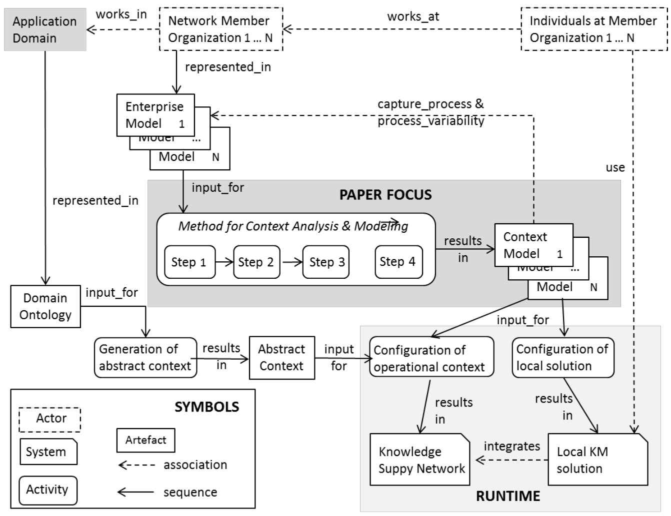

Fig. 2. Overview of the context analysis approach and related work.

How the context model is derived from an enterprise model is described in detail in the next section and illustrated in Fig. 2 as a grey-shaded box ‘paper focus’ in the middle of the figure. The result of the CM method is a separate context model for each individual production network member. During runtime, each context model is used within the production network member organisation to configure the local knowledge management solution for the enterprise and for the individuals working with this solution. This could happen, for example, by configuring the personalization component of a knowledge portal or the different knowledge services in Maier's architecture proposal for KMS (see Section II.D).

Furthermore, the context models are used to configure the knowledge supply solution for the overall production network. Here, we propose to use previous work on knowledge supply networks and decision support systems. This work is based on a domain ontology reflecting the application domain in question. This application domain is used to derive an abstract decision-making context. Decision-making context and knowledge management context both are used to configure the knowledge supply solution for the production network (see lower part of Fig. 2).

B. Method Steps

We propose a CM approach consisting of four steps, which is inspired by a CM approach for e-learning systems [36]. These steps are:

- scenario modelling for context-based knowledge management in production networks;
- variability elicitation;
- initial context model development;
- implementation of context-based knowledge management.

(1) Scenario Modelling

The purpose of the first step is to identify user groups and intended scenarios of use for the context-based knowledge management in production networks. In order to understand which user groups exist and how their ways of using the knowledge management system differ, the processes supported by the system, the information input and output with particular focus in production networks on product models, possible connections to other systems and processes, and the integration of resources have to be made explicit. As indicated when discussing the theoretical background for this work, many enterprises in manufacturing apply enterprise modelling. Existing enterprise models usually include all information required:

- user groups of the context-based knowledge management system (e.g., indicated by organisational roles);
- the tasks the users are supposed to perform with the knowledge management system (e.g., the process model);
- information input or conditions which cause branching in the flow of actions.

Thus, the scenario modelling step for production network members is only required when no previous models with the above information exist.

(2) Variability Elicitation

The second step is probably the most important one. A context model has to capture on which inputs or events what kind of adaptations in the context-based system should be made. Adaptations in general can concern functionality, behaviour, output, or appearance of the knowledge management system. Since the results of these adaptations can be considered as variations of the system use, the behaviour of the system or even its configuration, it is decisive to understand the cause and the kind of variation. For this purpose, two aspects have to be investigated: the variation aspects and the variation points.

Variation Aspects: Variations in behaviour, functionality, or content of context-aware systems can be caused by different aspects, like the user groups, the task performed, the information input, etc. In order to identify these aspects, the scenario models have to be investigated. The analysis of previous CM analysis methods shows that variation usually lies in the work flow and the subject of work. For production networks, we thus argue that the product structures and work processes have to be in focus. Enterprise modelling approaches usually include different model component types for capturing processes and product components.

For each of these model component types, it has to be examined whether different instances of this component type would require an adaptation in the context-aware system. For those component types causing an adaptation, it has to be investigated what characteristic of the component type is actually decisive for the adaptation. If, for example, 'process' component types would cause adaptation, it has to be investigated whether this is due to process input, process output, process duration, or other characteristics. The identified component types and their decisive characteristics are called variation aspects.

Variation Points: Within each variation aspect, the variation points define under which conditions or for which events an adaptation in the context-aware system has to happen. Often, even the kind of adaptation can be identified together with the variation points. In order to identify the variation point, all variation aspects identified in the above procedure have to be examined. It is recommended that this is done based on the scenario models by assuming alternatives in the scenarios regarding the validation aspects under consideration.

(3) Developing Context Model

According to the definition of context, it contains all information characterising the situation of an entity. We assume that this information consists of different elements and that each element has different attributes. An example would be a context element 'product variant' with the attribute of 'related product family' and 'variation target group'. For developing the initial context model, the first task would be to define a context element for each of the identified variation aspects and to decide on the attributes for the context model.

The second task aims at investigating what type of adaptation of the context-based application is related to each context element. For this purpose, we assume that a context-aware application not only has to adapt its own behaviour with respect to functionality or what information is provided (active role) but also needs to provide information to other ‘context-aware’ components outside the context-based application to be developed (a passive role). An example would be a context element ‘product variant under development’, which can be used to adapt the context-based knowledge management to a specific production network member, but which also serves as input for the knowledge management in the overall production network supporting other members working with this variant.

When investigating the type of adaptation related to context elements, this passive vs. active role of the context and the content vs. application orientation of the context can be used as an aid.

This would result in a classification for each context element, on the one hand, into locally relevant and updated or (also) relevant and updated network-wide. On the other hand, there is a classification into relevant for behaviour adaptation or relevant for information provision. This classification helps during the configuration of the context-aware knowledge management for deciding on operations regarding context elements, their local/network-wide visibility, and related interfaces.

(4) Implementation of Context-based Knowledge Management

The next step in our approach is the implementation of a context-based knowledge management using the context model from the previous step. In this step, it has to be differentiated between the implementation of the product network-wide knowledge management and the local knowledge management of each partner. Both parts are mutually dependent but they are usually not identical, as – depending on the preferences of a production network member – the ‘local’ implementation can be realised by different IT KMS. In this paper, our focus is on implementing knowledge management support for the overall production network using the context model developed in the previous steps. The proposed approach is to use the approach of knowledge supply networks.

The knowledge supply approach is based on the idea of representing relevant knowledge services via IT services. For the purpose of semantic interoperability, the services could be represented by web services using the common notation described by a common ontology. A detailed overview of the approach can be found in [37].

The context model for each network partner and in particular the information about variation aspects in products and processes can be either provided by a separate service or integrated into one of the above-mentioned services. Depending on the network member, the relevant part of the ontology is selected and forms the so-called ‘abstract context’. The abstract context is an ontology-based model embedding the content of the context model.

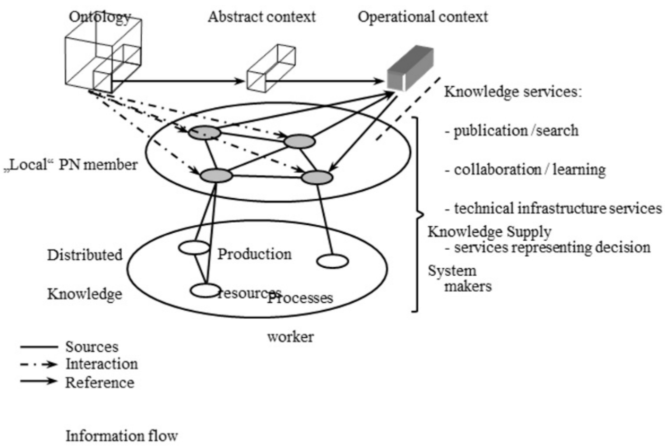

Fig. 3. Generic scheme of knowledge supply system.

When the abstract context is filled with actual values during the use of the knowledge management environment, an operational context (formalized description of the current context) is built. The operational context is an instantiated abstract context and the real-time picture of the current situation. In the considered example, the context creation assumes involvement of other services that can be derived from the enterprise model represented in Fig. 3. In particular, the services include those representing users and different organisational resources and roles. Since the knowledge resources are represented in the service network by services, they can negotiate in order to achieve desired states and, thus, support context-oriented knowledge supply. One of the ways to do it is to use the context variation idea that assumes comparing the current situation described by the context with available context variants describing some ‘pre-set’ situations and assigned with pre-defined rules of actions.

V. Context-Model Use in Knowledge Supply

In order to illustrate the context modelling approach presented in the previous section, this section considers an example from automotive supplier industries. Furthermore, we will discuss expected benefits for production networks.

For the evaluation of methods and other design artefacts, a catalogue of approached has been developed by [34]. This catalogue includes observational (case study in business environment), analytical (focus on structural and static qualities), experimental (focus on dynamic qualities in controlled environment), and descriptive evaluation (detailed scenarios showing utility). The illustrative case study presented in this section provides an analytical and descriptive evaluation: a real-world scenario is used to show that the proposed method steps have the desired results and show the planned functional behaviour. Experimental and observational evaluations are part of future work (see next section).

A. Example: Automotive Supplier Production Network

In order to illustrate the use of the CM approach, we will use a production network in automotive industries focusing on interior components for cars. The production network includes partners producing sub-systems, components for sub-systems, or services linked to these components for seat heating, headrest and armrest as well as door handles. In the production network, many companies are part of several value chains, e.g., cover material for arm rests and its manufacturing can also be used for door panels. For evaluating the proposed context modelling approach, we investigated the collaboration between two network partners concerned with the development of seat heating wire solutions. Both partners have the challenge of knowledge sharing for improving the collaboration concerning development projects, albeit they internally have processes for production and development of new products. For both partners, the existing enterprise models cover the development of new products and the production planning, which are suitable as a substitute for scenario models according to our methodology.

The focus of our example is on a process for developing a material specification for seat heating and its components. Seat heating usually includes parts from different supplies, like, e.g., heating wire from one partner, sensors and controller devices from a second partner, and carrier material for the heating from a third company. Figure 4 provides the top level view of a selected step (material testing) in the process perspective for the example; Fig. 5 shows the product perspective from the same partial enterprise model.

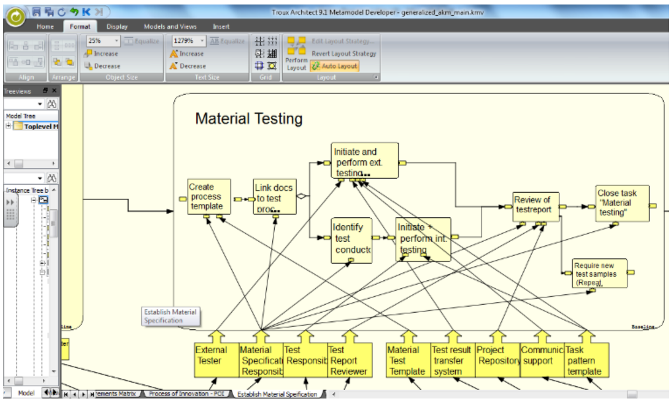

Fig. 4. Excerpt from an enterprise model (i.e., screenshot from a modelling tool) showing the cooperation between two network partners in material testing.

The material testing process involves roles from both participating production network members. These roles are shown in the lower left part of the figure and participate differently in the possible work flows shown in the process model. The product model (see Fig. 4) includes, among other aspects, product structure, product variants, and product properties. Both production network members use the same product model but have different views on this model, i.e., they see different but overlapping parts of the model and partly use different instantiations in the model.

Not surprisingly, one variation aspect detected when analysing the process and the product perspective is the organisational role, as many different roles contribute to the process and have different knowledge demands.

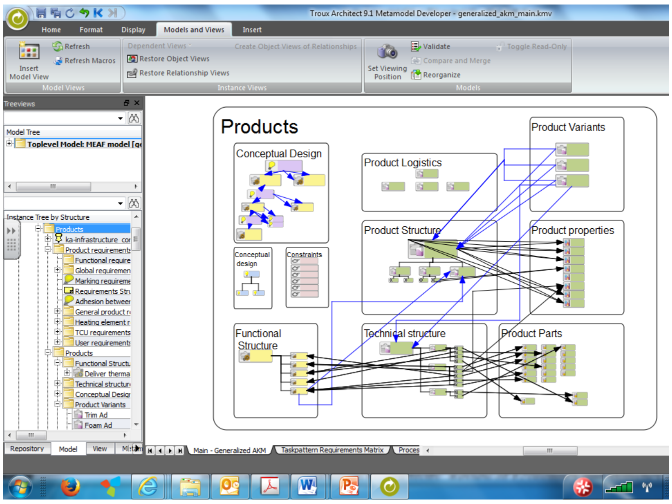

Fig. 5. Product perspective taken from an enterprise model (i.e., screenshot from a modelling tool).

The role is a common variation aspect of processes if the work on the different tasks is performed collaboratively. Furthermore, location turns out to be a variation aspect because the same role needs different knowledge for the same task depending on the country the work is performed in. This is due to different local regulations when it comes to the declaration and reuse of materials. In our example, even the client constitutes a variation aspect as the way of exchanging specification information and engineering changes depends on the client.

When analysing the product perspective, in the simple example, the location also turns out to be a variation aspect as the available manufacturing equipment varies depending on the manufacturing site. Furthermore, the product variant under consideration obviously constitutes a variation aspect. Similar to the organisational role in the process perspective, the product variant is always a variation aspect in case of products with different variants.

The context model should preferably be developed with a suitable modelling tool, which takes care of a computable representation following a defined meta-model. In our example, we used the CDT tool [25], which stores the model in an XML-based representation. CDT also allows for the visual representation of variation points in process models.

Figure 6 shows the context model developed based on the analysis of the scenario models. The local and network-wide perspectives are represented as different context sets (see right hand side of the figure). ‘Context Set 1’ includes the context elements for network-level knowledge management, which are product line, product variant, and production location. In the context set, the context elements are represented with their ranges relevant for the set.

‘Context Set 2’ includes the elements relevant for local knowledge management. The context elements are made explicit in the centre of the figure. Their attributes are shown in the property box at the lower part of the tool.

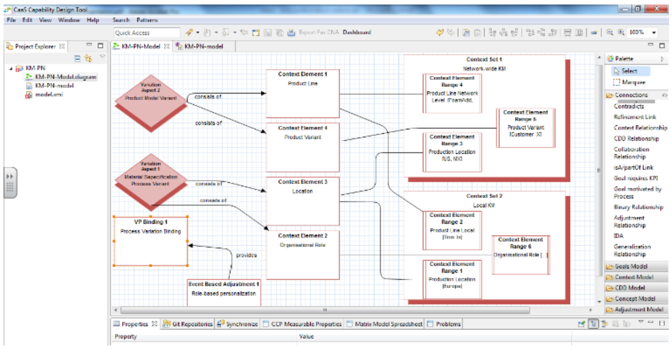

Fig. 6. Screenshot from Context Modelling Tool CDT showing the context model for the example case.

Each context element is on its left-hand side linked to the variation aspect identified in process model or product model.

The use of the context model for 'local' KMS (i.e., KMS of a specific production network member) can be illustrated by using Maier's KMS architecture (see Section II.D). In Maier's architecture, the context model is used to extend what Maier refers to as knowledge structure and enterprise-specific vocabulary. This knowledge structure is stored and maintained in the integration layer (often represented as semantic net or ontology) for the semantic integration of enterprise knowledge sources. Furthermore, it forms the basis for the knowledge services search and publication, e.g., by supporting navigation structures and filter functions in secondary search functions. With the elements of the context model integrated into the knowledge structure, these elements also become available as parameters on the personalization layer, i.e., in our example, the provision of knowledge can be tailored to the organisational role, the localization, the client, the product variant, and the manufacturing equipment as all these concepts and their instantiations become part of the KMS's knowledge structure.

Within the integration layer, even the production network-wide dimension can be addressed. Here, the context elements have to be added to the abstract decision ontology. For each production network member, the operational ontology will include instantiations reflecting their local knowledge sources. As the same context model is used in local KMS and the production network knowledge supply, also the production network-wide knowledge sources can be integrated by the integration layer.

B. Expected Benefits for Production Networks

The benefits of context orientation in knowledge management can be illustrated based on the production network presented in the previous part of this section. Let us assume that the network has M members and member k is looking for specific knowledge in this production network, for example, for knowledge about a certain material for use in a specific product. The use of this material is further specified by context information in the product model (e.g., use for a certain functionality in a variant), and in the model of the manufacturing process (e.g., use in a certain automation step in a specific location or country).

The interaction of the member k with other production network members to select one or more partners for knowledge supply with the help of the knowledge management system is shown in Fig. 7 and Fig. 8. Figure 7 illustrates the situation without context orientation; Fig. 8 – with the use of the context-oriented knowledge management system.

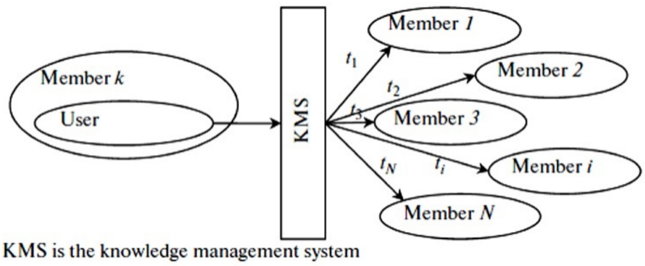

Fig. 7. Interaction without context orientation.

In the first case (without context), to select the partner(s) the member k interacts with all the production network members who offer required material knowledge. The knowledge management system provides the information on who can provide this knowledge, but the product model or process model context is not taken into account. In this case, the time T_k of partner selection by member k consists of the interaction time with the production network members offering knowledge about the specified material. This is illustrated in Fig. 8 where t_i is the time of interaction of the members i and k and N is the number of production network members offering the knowledge.

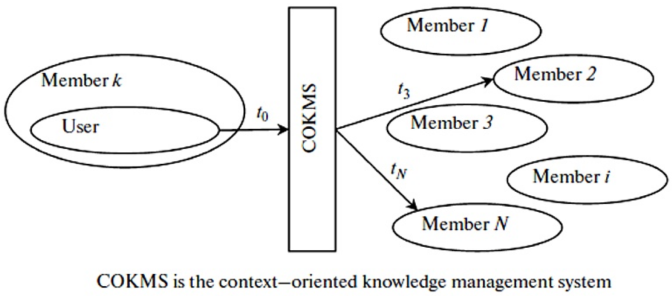

Fig. 8. Interaction with context-oriented knowledge management.

When using context-oriented knowledge management, the context sets and context elements derived from the product and process models can be used to identify partners who not only have required knowledge about the material but also match product variant and manufacturing process knowledge. This additional knowledge can be provided in the KMS, e.g., as a contextualized knowledge profile. The time required for the partner selection by member k consists of the time for analysing these knowledge profiles of possible production network members plus the interaction time of member k with the partners selected on the basis of this analysis: This is illustrated in Fig. 9 where t_0 is the time spent by the user k on the analysis of the profiles of possible partners, t_i is the interaction time of members i and k, and N' is the number of selected partners.

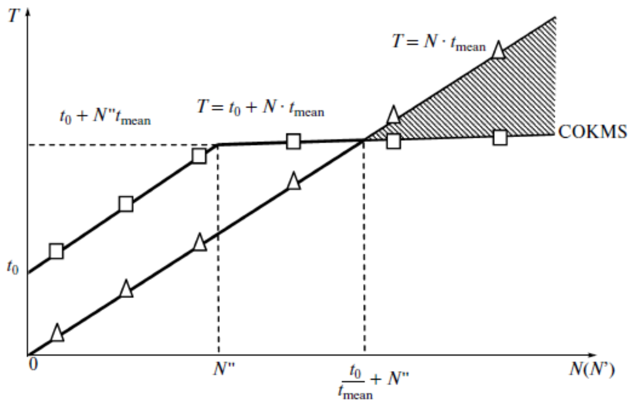

Fig. 9. Benefits of context-oriented knowledge management.

When member k needs complex knowledge, which can only be provided by combined efforts of several production network members with knowledge in this context, N is equal to N'. Then the time of supplier selection without the use of context in the knowledge management system will be less than with its use.

Figure 8 shows the dependence graphs of the time of supplier selection on their number with and without the use of the context in the knowledge management system. For descriptive purposes, the assumption has been made that the interaction time with each supplier is the same, and it is t_{mean}. Then, the interaction time of members when selecting partners for the member k without the use of the context in the knowledge management system will be $T = t_{mean} N$.

When using the context-oriented knowledge management system, member k will select N' suppliers during the time t0 and communicate only with them. In this case, $N' \in [1, N'']$, where N'' is the number of the inquired alternative partners, which usually does not exceed 5–6. It should be noted that the more precisely the context describes the current situation in the production network and outside, the smaller the value of N'' will be. When the current situation is described poorly, the user of member k does not get the required overview of the necessary number of suppliers, and the value of N'' will be high (i.e., the user will have to interact with a large number of suppliers). If the current situation is described fully and without errors, the value of N'' will be low, and the user will be able to choose their supplier at the stage of the analysis of the knowledge management system. Then, the interaction time of members with the help of the knowledge management system will be determined for $N' < N''$ according to the formula $T = t_0 + t_{mean}N'$, and for $N' > N''$ it will be determined by the formula $T = t_0 + t_{mean} N''$.

VI. Conclusion

The goal of the paper has been to develop a method for context modelling and analysis specialised for the need of production networks and the use in context-oriented knowledge management. The approach presented in the section "Method for Context-Modelling and Analysis" has been derived from the previously developed generic context modelling method and has gone through an initial validation in an industrial use case from automotive industries. The approach is based on scenarios and can be run in different manners. One example is to start with one initial scenario, and build a context following this one scenario only. Another example would be to add further scenarios, which makes the context more complex from the beginning, but certainly allows for a more extensive validation.

Our experience during the validation of the method by application in the industrial production network has shown that the differentiation between variation aspects and points turned out to be most difficult for the creation of the context model. Furthermore, the transfer of the context model to an explicit data structure suitable for implementation is labour-intensive using the style of modelling with Troux Semantics as shown here.

Future work will have to include theoretical and practical aspects. From a theoretical perspective, we are aiming at further formalizing the concept of variation points and variation aspects and how the variation has to be reflected in the context model. The classification in content and behaviour aspects and in internal and external effects seems useful, but is not yet clear enough. Furthermore, the transition from the context model into the implementation of the model has to be further investigated with the objective to support the design of software components implementing the context concept and the envisioned behaviour captured in the context model. Furthermore, the integration of the context modelling approach and configuration processes of knowledge supply environments and KMS should be further investigated. Since a model representation of the context can be part of the early design of the information system to be developed, it might also influence the architecture of the overall system. Here, it could be worthwhile to investigate an integration of structures, processes, knowledge representation and technologies into the enterprise architecture of the member organisations of PN. Furthermore, the model carries requirements, which need to be taken into account during the development process. These aspects need further exploration.

From the practical perspective, the implementation of the operational context in a knowledge supply system, using it in selected production networks and collecting improvement potential, and experiences during the usage will be an important future activity. In accordance to 4 steps of our context modelling approach, we are aiming at finishing the first complete iteration of the system development and its implementation before starting an improvement cycle, and we expect to collect sufficient experience from internal practical validation to be able to continue with the external validation.

Acknowledgment

The present research has partly been supported by Russian Science Foundation and Grant No. 15-18-30048.

References

[1] J. Peppard and A. Rylander, "From Value Chain to Value Network: Insights for Mobile Operators," *European Management Journal,* vol. 24, no. 2–3, pp. 128–141, 2006. https://doi.org/10.1016/j.emj.2006.03.003

[2] E. Esposito and P. Evangelista, "Knowledge management in SME networks," *Knowledge Management in SME Networks*, vol. 14, no. 2, pp. 204–212, 2016. https://doi.org/10.1057/kmrp.2015.18

[3] D. Ivanov, "DIMA – A Research Methodology for Comprehensive Multi-disciplinary Modelling of Production and Logistics Networks," *International Journal of Production Research*, vol. 47, no. 5, pp. 1153– 1173, 2009. https://doi.org/10.1080/00207540701557205

[4] K. Valkokari and N. Helander, "Knowledge management in different types of strategic SME networks," *Management Research News*, vol. 30, no. 8, pp. 597–608, 2007. https://doi.org/10.1108/01409170710773724
[5] W. H. Quik, N. Wright, A. Rashid and S. Thiruchelvam, "Influential factors of collaborative networks in manufacturing: Validation of a conceptual model," *Interdisciplinary Journal of Information, Knowledge, and Management*, vol. 10, pp. 1–19, 2015. https://doi.org/10.28945/2120
[6] D. Hislop, *Knowledge management in organizations: A critical introduction.* Oxford University Press, 2013.
[7] A. Smirnov and K. Sandkuhl, "Context-Oriented Knowledge Management for Decision Support in Business Networks: Modern Requirements and Challenges", BIR 2015 Workshops, vol. 1420, pp. 9– 23, 2015.
[8] R. Bosua and R. Scheepers, "Towards a model to explain knowledge sharing in complex organizational environments," *Knowledge Management Research & Practice*, vol. 5, no. 2, pp. 93–109, 2007. https://doi.org/10.1057/palgrave.kmrp.8500131
[9] T. J. Sturgeon, "How Do We Define Value Chains and Production Networks?", IDS Bulletin, vol. 32, no. 3, pp. 9–18, 2001. https://doi.org/10.1111/j.1759-5436.2001.mp32003002.x
[10] Z. Y. Wu, X. G. Ming, L. N. He, M. Li and X. Z. Li, "Knowledge integration and sharing for complex product development," *International Journal of Production Research,* vol. 52, no. 21, 2014. https://doi.org/10.1080/00207543.2014.923121
[11] A. Calitz and M. Cullen, "The application of a knowledge management framework to automotive original component manufacturers," *Interdisciplinary Journal of Information, Knowledge, and Management*, vol. 12, pp. 337–365, 2017. https://doi.org/10.28945/3897
[12] E. Lesser and K. Butner, "Knowledge and the Supply Chain," Inside *Supply Management*, vol. 16, no. 4, 2005.
[13] F. B. Vernadat, *Enterprise Modelling and Integration.* Chapman & Hall, 1996.
[14] K. Sandkuhl, J. Stirna, A. Persson and M. Wißotzki, *Enterprise Modelling: Tackling Business Challenges with the 4EM Method.* Springer Verlag, Heidelberg, 2014.
[15] F. Lillehagen, "The Foundations of AKM Technology". *10th International Conference on Concurrent Engineering (CE) Conference*, Madeira, Portugal, 2003.
[16] J. Wortmann, H. Hegge and J. Goossenaerts, "Understanding enterprise modelling from product modelling," *Production Planning & Control*, vol. 12, no. 3, 2001. https://doi.org/10.1080/095372801300107725
[17] F. Lillehagen and J. Krogstie, *Active Knowledge Modelling of Enterprises.* Springer, 2008.
[18] A. K. Dey, "Understanding and Using Context". *Personal and Ubiquitous Computing.* vol. 5, no. 1, pp. 4–7, Feb. 2001. https://doi.org/10.1007/s007790170019
[19] T. Ben Mena, N. Bellamine-Ben Saoud, M. Ben Ahmed, and B. Pavard, "Towards a Methodology for Context Sensitive Systems Development," B. Kokinov, D. C. Richardson, T. R. Roth-Berghofer, L. Vieu, Eds. Modeling and Using Context. CONTEXT 2007. Lecture Notes in Computer Science, Berlin, Heidelberg: Springer, vol. 4635, pp. 56–68, 2007.
[20] H. Koç, E. Hennig, S. Jastram and C. Starke, "State of the Art in Context Modelling – A Systematic Literature Review". Advanced Information Systems Engineering Workshops, CAiSE 2014, vol. 178, pp. 53–64, Springer, 2014. https://doi.org/10.1007/978-3-319-07869-4
[21] H. Koc, "A Capability-based Context Modelling Method to Enhance Digital Service Flexibility," Ph.D. dissertation, Faculty of Computer Science and Electrical Engineering, Rostock University, 2017.
[22] M. Baldauf, S. Dustdar and F. Rosenberg, "A survey on context-aware systems," *Int. Journal of Ad Hoc and Ubiquitous Computing*, vol. 2, no. 4, pp. 263–277, 2007. https://doi.org/10.1504/IJAHUC.2007.014070
[23] R. Hervas, J. Bravo and J. Fontecha, "A Context Model based on Ontological Languages: a Proposal for Information Visualization," Journal *of Universal Computer Science*, vol. 16, no. 12, pp. 1539–1555, 2010.
[24] E. Serral, P. Valderas and V. Pelechano, "Context-Adaptive Coordination of Pervasive Services by Interpreting Models during Runtime," *The Computer Journal,* vol. 56, no. 1, pp. 87–114, 2013. https://doi.org/10.1093/comjnl/bxs019
[25] S. Bērziša, G. Bravos, T. Gonzalez, U. Czubayko, S. España, J. Grabis, M. Henkel, L. Jokste, J. Kampars, H. Koç, J. Kuhr, C. Llorca, P. Loucopoulos, R. Pascual, O. Pastor, K. Sandkuhl, H. Simic, J. Stirna, F. Valverde and J. Zdravkovic, "Capability Driven Development: An Approach to Designing Digital Enterprises," *Business & Information Systems Engineering*, vol. 57, no. 1, pp. 15–25, 2015. https://doi.org/10.1007/s12599-014-0362-0
[26] F. Schaub, B. Könings and M. Weber, „Context-adaptive privacy: Leveraging context awareness to support privacy decision making", *IEEE Pervasive Computing*, vol. 14, no. 1, pp. 34–43, 2015. https://doi.org/10.1109/MPRV.2015.5
[27] L. Loss, "Concept Maps as a Tool for Supporting Knowledge Management in Collaborative Research Projects," *Journal of Information & Knowledge Management,* vol. 8, no. 3, pp. 201– 211, 2009. https://doi.org/10.1142/S0219649209002336
[28] Y. G. Yao, L. F. Lin and F. Wang, "Multi-perspective modeling: managing heterogeneous manufacturing knowledge based on ontologies and topic maps," *International Journal of Production Research*, vol. 51, no. 11, pp. 3252–3269, 2013. https://doi.org/10.1080/00207543.2012.756152
[29] S. Liu, M. Leat, J. Moizer, P. Megicks, and D. Kasturiratne, "A decision-focused knowledge management framework to support collaborative decision making for lean supply chain management," *International Journal of Production Research*, vol. 51, no. 11, pp. 2123–2137, 2013. https://doi.org/10.1080/00207543.2012.709646
[30] G. Probst, S. Raub and K. Romhardt, *Managing Knowledge – Building Blocks for Success.* Chichester, UK: John Wiley & Sons, 2000.
[31] I. Nonaka and H. Takeuchi, *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation.* Oxford university press, 1995.
[32] R. Maier, T. Hädrich and R. Peinl, *Enterprise Knowledge Infrastructures.* 2nd Edition, Springer, 2010.
[33] A. Newell, "The knowledge level," *AI Magazine*, vol. 2, no. 2, pp. 1–21, 1981.
[34] A. R. Hevner, S. T. March, J. Park and S. Ram, "Design Science in Information Systems Research," *MIS Quarterly*, vol. 28, no. 1, pp. 75–105, 2004. https://doi.org/10.2307/25148625
[35] R. Wieringa and A. Morali, "Technical action research as a validation method in information systems design science", in Int. Conf. Design Science Research in Information Systems. Advances in Theory and Practice, pp. 220–238, 2012. https://doi.org/10.1007/978-3-642-29863-9_17
[36] K. Sandkuhl and U. Borchardt, "How to Identify the Relevant Elements of "Context" in Context-Aware Information Systems?" 13th International Conference on Business Informatics Research (BIR 2014), pp. 290–305, 2014. https://doi.org/10.1007/978-3-319-11370-8_21
[37] A. Smirnov, M. Pashkin, N. Shilov and T. Levashova, "KSNet-approach to knowledge fusion from distributed sources," *Computing and Informatics*, vol. 22, pp. 105–142, 2003.

Kurt Sandkuhl, born in 1963 in Germany, is a Full Professor of Business Information Systems at the University of Rostock (Germany) and Affiliated Professor of Information Engineering at the School of Engineering, Jönköping University (Sweden). He received a diploma (Dipl.-Inform.) and a PhD (Dr.-Ing.) in Computer Science from Berlin University of Technology in 1988 and 1994, respectively. Furthermore, he received the title of Associate Professor (postdoctoral lecturing qualification) at Linköping University, Institute of Technology, in 2005. Sandkuhl's research interests include the fields of information logistics, enterprise modelling, ontology engineering, and model-based software engineering. He has published four books in the field of enterprise modelling and electronic publishing, and more than 200 peer-reviewed papers in information logistics, enterprise knowledge management, CSCW, reference modelling, and enterprise architectures.
E-mail: kurt.sandkuhl@uni-rostock.de
ORCID iD: https://orcid.org/0000-0002-7431-8412

Alexander Smirnov is an Affiliated Professor at the National Research University for IT, Mechanics and Optics (ITMO) in St. Petersburg, Russia. Furthermore, he is the Deputy Director of Research at St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS) and Head of Computer Aided Integrated Systems Laboratory at SPIIRAS. Professor Dr. Alexander V. Smirnov (1956) received his PhD in Technical Cybernetics from St. Petersburg University of Electric Engineering (1984) and D.Sc. in Mathematical Modelling from SPIIRAS (1994), a Full Professor in 1998. He has extensive expertise in research, development, and design of computer-aided complex systems, mathematical modelling, knowledge management, decision support, and flexible supply chain management. He has worked on wide range problems such as corporate knowledge management, ontology-driven information integration, context management, operational decision support, virtual enterprises configuration, and dynamic logistics.
E-mail: smir@iias.spb.su