# Context-Oriented Knowledge Management for Decision Support in Business Networks: Modern Requirements and Challenges

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**Abstract.** In many industrial sectors, business networks emerged as collaborative partnerships for tackling challenges caused by globalization and changing market needs. These networks are bundling competence and knowledge of different partners for co-operations in development or manufacturing projects. In such networks and collaborations, management of knowledge, competences and capacities at the different network members is crucial. This paper investigates requirements and challenges to knowledge management for business networks and argues that context-orientation is a key feature of modern approaches. The focus on our work is on decision support.

**Keywords:** business network, context, knowledge management, cyber-physical system, organisational knowledge

## 1 Introduction

In many industrial sectors and manufacturing areas, such as automotive industry, aerospace, wood-related industry or construction industries, globalization and the adaption of supply strategies to global markets resulted in network organization forms. The needs for shorter innovation cycles, lead time reduction or mass customization have stimulated the creation of collaborative partnerships, like networks of suppliers and sub-suppliers, value networks [1] or co-operations in product development or construction projects. In such networks and collaborations, management of knowledge, competences and capacities at the different network members is crucial. Relevant knowledge encompasses production capability, services offered, available resources, product variants and configuration options as well as the organizational competences of the members in the network. In this context, concepts and approaches from knowledge management can contribute to decision support and efficient operations of the network, if these approaches take the individual context and demands of the network members into account.

Furthermore, globalization and digitalization of companies brings to the agenda a number of problems to be solved. Knowledge Management for decision support of efficient configuration of business networks (trends leading to Industry 4.0, Logistics 4.0, and Mobility 4.0) based on customer requirements and preferences, different resources (physical, information, etc.) and their efficient interaction (the Internet of Things and the Internet of Everything concepts), handling cultural differences of making business between representatives (employees and companies) from different countries (organizational behaviour issues related to international dimensions and cross cultural aspects of collaboration and decision making) are among them.

Modern business networks are mainly service-oriented and based on integration of number of networks which supported by using following information technologies:

- Social networks: who knows whom => Virtual Communities;
- Knowledge networks: who knows what =>Human & Knowledge Management;
- Information networks: who informs what => Internet/Intranet/Extranet/Cloud;
- Work networks: who works where => Decision Support based on Crowdsourcing and Recommendation Systems;
- Competency networks: what is where => Knowledge Map;
- Inter-organizational network: organizational linkages => Semantic-Driven Interoperability.

The competitiveness of large companies and organizations heavily depends on how they maintain and access their knowledge. The fast development of transportation and communication means lead to emerging global business network and such a new area of information technologies as Knowledge Management. A widely accepted 'working definition' of Knowledge Management applied in worldwide organizations is available from the WWW Virtual Library on Knowledge Management [2]:

"*Knowledge Management caters to the critical issues of organizational adaptation, survival, and competence in face of increasingly discontinuous environmental change.... Essentially, it embodies organizational processes that seek synergistic combination of data and information processing capacity of information technologies, and the creative and innovative capacity of human beings*."

Knowledge management is defined as a complex set of relations between people, processes and technology bound together with the cultural norms, like mentoring and knowledge sharing. Knowledge management consists of the following major processes: knowledge discovery (knowledge entry, capture tacit knowledge, etc.), knowledge engineering (knowledge base (KB) development, knowledge sharing and reuse, knowledge exchange, etc.), and knowledge mapping (identifying knowledge sources (KSs), indexing knowledge, making knowledge accessible, etc.).

Today an intensive knowledge integration and knowledge exchange between participants of the global business network are required. Currently major Knowledge Management Problems related to business network are:

- Semantic-based Interoperability between network participants;
- Taking into account dynamics of the business environment;

- Use business network participants as knowledge sources.

This paper investigates requirements and challenges to knowledge management for business networks and argues that context-orientation is a key feature of modern approaches. The focus on our work is on decision support. Section 2 shows some examples for business networks in order to illustrate typical constellations and tasks in such networks. Section 3 identifies requirements and challenges to context-oriented knowledge management. Section 4 focuses on theoretical foundations of decision support and section 5 presents selected technological and methodical approaches for knowledge management.

## 2 Business Networks: Selected Examples

In order to illustrate the concept of business networks and the need for knowledge management and decision support, this section will briefly introduce three examples of such networks originating from real-world cases. These cases are taken from collaborative engineering in automotive industries, flexible supply network in manufacturing and production networks in electrical engineering.

### 2.1 Collaborative Engineering

Collaborative engineering aims at supporting a distributed group of engineers sharing a common collaboration objective in jointly performing an engineering task, like product design, production planning, engineering change management or development of specifications. These engineering tasks are usually knowledge-intensive activities involving different specialists in collaboration processes tailored for the engineering domain under consideration.

One example for collaborative engineering in a business network is the case of distributed product development with multi project lifecycles in a networked organization from automotive supplier industry. Main partner is the business area seat comfort of a first tier supplier, which main products are seat comfort components (seat heater, seat ventilation, lumber support and head restraint), gear shifts and commercial vehicle components.

The case is focused on development of new products in collaboration of the first tier supplier and its sub-suppliers for heating wires, seat sensors and carrier material. Development of products includes identification of system requirements based on customer requirements, functional specification, development of logical and technical architecture, co-design of electrical and mechanical components, integration testing, and production planning including production logistics, floor planning and product line planning. This process is geographically distributed involving engineers and specialists at several locations and suppliers from the region. A high percentage of seat comfort components are product families, i.e. various versions of the components exist and are maintained and further developed for different product models and different customers. General requirements regarding infrastructure and methodology are:

- to support geographical distribution and knowledge sharing between changing partners,
- to enable flexible engineering processes reflecting the dynamics of changing customer requirements,
- to coordinate a large number of parallel product development activities,
- to allow richness of variants while supporting product reuse and generalization.

More information about this case is available in [3].

### 2.2 Flexible Supply Networks

Automotive production networks are an example for collaborative partnerships aiming at increasing flexibility and lead time reduction (see also [4]). Typical car manufacturers that made 75% of product components 25 years ago now make only 25% of those components. 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.

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 over company limits. With the aim of achieving global distributed processes, value chain integration and dynamic collaboration, knowledge management has become of high importance.

Together with the above advantages flexible supply networks raise a number of problems. The most important problem is coordination of the large amount of independent members of the large network. When dealing with multiple organizations and multiple processes within a complicated supply network, trying to identify and locate a member that has responsibility and/or competence in a particular part of the network can be a laborious, time-consuming process. Developing and maintaining a competence directory of all the relevant parties associated with troubleshooting and solving potential problems can significantly reduce the time. Further, linking this directory to key decision points and frequent problems can further enhance its effectiveness [5].

In flexible supply networks it is important to derive and process knowledge from various sources including best practices, technology forecasting, products in the marketplace (who is buying them and why?), what competitors are selling now and what they are planning to sell in the future. The knowledge supply as a part of knowledge management in a flexible supply network requires interoperability at both technical and semantic levels.

The approach described in [6] relies on the ontological knowledge representation for its sharing. The ontology describes common entities of the enterprise systems and relationships between them. The dynamic nature of the flexible supply networks requires considering the current situation in order to provide for actual knowledge or information. For this purpose, the idea of contexts is used. Context represents additional information that helps to identify specifics of the current transaction. It defines a narrow domain that the user of the knowledge management platform works with. One more important aspect covered by the approach is the competence profiling. Profiles contain such information as the network member's capabilities and capacities, terminological specifics, preferred ways of interaction, etc.

### 2.3 Production network

A supply network aggregates independent companies based on the principle of co-operation within a defined application domain and capable of coordinating their activities for production and delivery of the desired product. Organizations of this form use information and communication technologies to extend their value creation possibilities [7] and form multiple links across the boundaries to work together for a common purpose [8].

In order to illustrate the concept of supply networks, we consider a case from distributed product engineering in a networked organisation from automotive supplier industry, which originates from the MAPPER project [9]. The main partner is the business area "seat comfort components" of a first tier automotive supplier from Scandinavia, working with development and manufacturing of products for the automotive business world-wide. The main products are seat comfort products, like seat heating, seat ventilation, lumber support and head restraint. Development of products in this business area includes identification of system requirements based on customer requirements, functional specification, development of logical and technical architecture, co-design of electrical and mechanical components, integration testing and production planning including production logistics, floor planning and product line planning.

Within the first tier supplier, this process is geographically distributed involving engineers and specialists at several locations and SMEs from the region. A high percentage of seat comfort components are product families, i.e. various versions of the components exist and have to be maintained and further engineered for different product models and different customers. In this context, fast and flexible product engineering and integrated management of concurrently performed forward-engineering processes is of crucial importance. Smooth collaboration and information sharing is a key success factor to meet these basic needs.

Figure 1 shows a typical collaboration set-up for collaborative engineering. The customer for a new variant of a seat heating is an Original Equipment Manufacturer (OEM), e.g. for trucks. The first tier supplier receives the order for engineering and manufacturing the seat heating and involves several sub-suppliers and partners. These partners are responsible for specific components, like the carrier material or the copper wires, or for specific services, like the controller design or manufacturing of the control unit. The first tier supplier controls the overall design process, contributes own components and services, and performs the system integration.

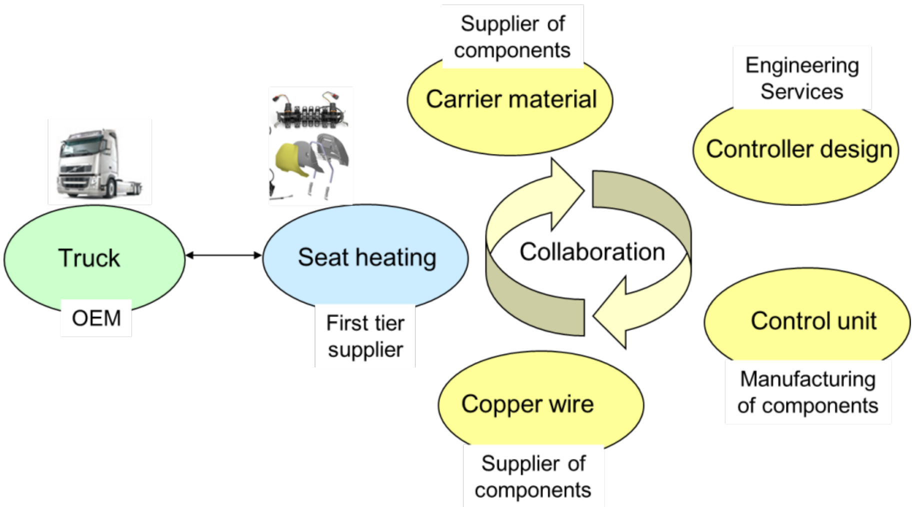


**Fig. 1.** Example supply network in collaborative product engineering

## 3 Requirements to Knowledge Management in Business Networks

Due to the rapidly changing business environment, increasing global competition and wide acceptance of information technologies, knowledge-based systems are currently highly demanded in the area of business network management including the cases presented in section 2. However, there still exists lack of systems that work with knowledge at the level of semantics. This is especially important for knowledge sharing when it is necessary to process knowledge stored in distributed heterogeneous sources in different terminology, languages, etc.

For knowledge sharing the systems operating in these areas have to provide efficient knowledge integration and sharing between multiple participating parties. This knowledge must be pertinent, clear, and correct, and it must be timely processed and delivered to appropriate locations. Thereby, such systems have to meet a number of requirements including (i) support of knowledge sharing, (ii) distributed architecture for collaborative work, (iii) interoperability with other information systems at both technological and semantic levels, (iv) dynamic (on-the-fly) problem solving, (v) ability to work with uncertain information, (vi) constraint satisfaction notation for real-world problem description, and other.

The knowledge sharing problem in the presented approach (detailed description of the approach can be found in [10]) is considered as a configuration of a network including end-users, knowledge resources, and a set of tools and methods for knowledge processing located in the network-centric environment.

Furthermore, modern business networks are based on Industry 4.0 concept using the Internet of Thing and the Internet of Everything paradigms. The European Research Cluster on the Internet of Think defines it as "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network" [11]. The Internet of Everything which defines as "a complex, self-configuring, and adaptive system of networks of sensors and smart objects whose purpose is to connect all things, including commonplace and industrial objects" [12]. Here major innovations driven by advances in the mobility, cloud computing, crowdsourcing, and big data analytics increase the number and kinds of networked connections, as well as the opportunities for people and machines to derive unpredictable value from these connections [13].

As a conclusion, several requirements to modern knowledge management systems for business networks can be stated:

- Flexibility. The system must be ready for sudden changes in the target problem requirements. It maintains its flexibility by keeping minimal information volume in the sources.
- Learning from the user. If the user declines a suggested solution or believes that it is not optimal, it is necessary to provide for an ability to include required changes into the system behavior rules.
- Integrity. During development of the system it is necessary to perform monitoring of information environment KSs for their availability and changes. If KS becomes unavailable it is necessary to remove all the references to it and check knowledge, synthesized while using this source. When the source content changes it is also necessary to perform checks for knowledge consistency.
- Velocity. The system permanently seeks for the ways to reduce and/or compensate the variability in customer/user demand and suppliers/sources.
- Open Connectivity. Ontologies and KBs built during the process of system utilizing must be available for shared access by external users. Besides, database and KB developers can represent the sources in the required form to expand the set of available KSs.
- Reasoning. The system must have clear plan of actions to achieve its goals and reasoning for proposed solutions.
- Customizability. The system must be ready to build any possible configuration of knowledge domain model that a customer (user) requests. Besides, it must be able to motivate the suggested solution.
- Hard' real-time. The system must have features that guarantee a response within a fixed amount of real-time.

## 4 Context-Aware Decision Support: Theoretical Foundations

Decision support in the business environments has to take into account constant environmental changes. In the present research, resources of the environment provide information of any changes to the DSS. These resources are referred to as information resources. The information resources perform the needed computations and solve problems, as well. The collection of information resources comprises various kinds of sensors, electronic devices, databases, services, etc. Besides information resources, the research distinguishes one more type of resources that is acting resources. These resources include physical resources, people and /or organizations that can be involved in the joint actions.

The research follows the knowledge-based methodology to building decision support systems (DSSs). The idea behind the research is to represent the application knowledge by means of constraints. This knowledge is described using two independent sorts of reusable components: domain ontology and task ontology. The domain ontology represents conceptual knowledge about the application domain. The task ontology describes problems occurring in the application domain and methods for achieving solutions to these problems (problem-solving methods). The both components make up the application ontology, which is represented as a set of constraints. This ontology specifies non-instantiated knowledge.

The resources' representations are supposed to be compatible with the ontology representation. The application ontology and the resources' representations are aligned. The alignment indicates what information resource(s) instantiates the given property of the given object specified in the ontology.

In the research, context model serves to represent the knowledge about a decision situation (the settings in which decisions occur and the problems requiring solutions). Context is suggested being modeled at two levels: abstract and operational. These levels are represented by abstract and operational contexts, respectively (Fig. 2).

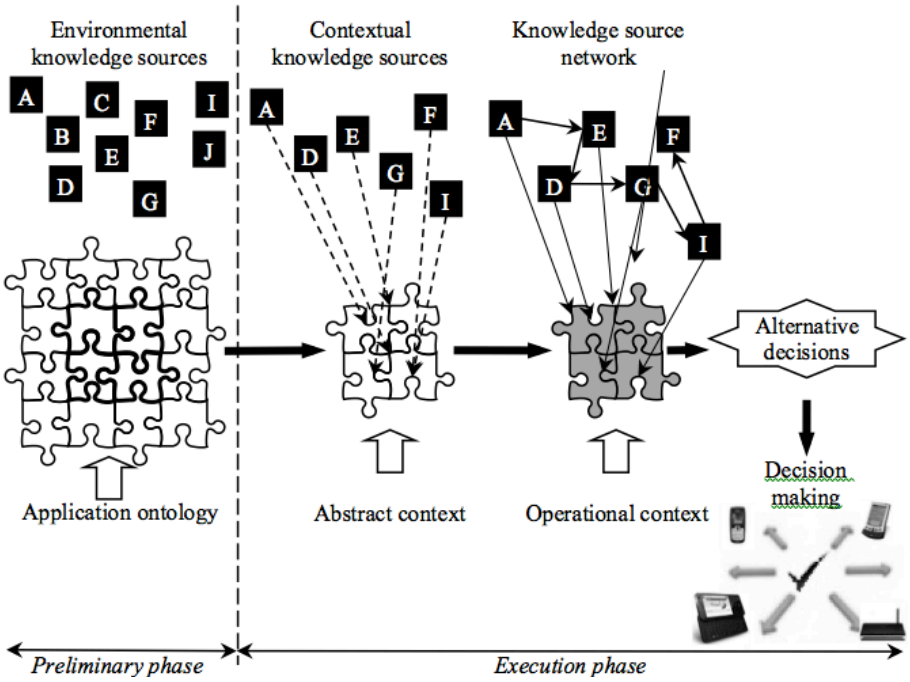


**Fig. 2** Context aware decision support

Abstract context is an ontology-based model integrating information and knowledge relevant to the current decision situation. The DSS's user (the decision maker) in his/her request to the DSS indicates the type of the current situation or smart sensors provide this type to the system. The relevant information and knowledge are extracted from the application ontology. As the two components make up this ontology, the abstract context specifies domain knowledge describing the current situation and problems to be solved in this situation.

The abstract context reduces the amount of knowledge represented in the application ontology to the knowledge relevant to the decision situation. In the application ontology this knowledge is related to the resources via the alignment, therefore the abstract context allows the set of resources to be reduced to the resources needed to instantiate knowledge specified in the abstract context. The reduced set of resources is referred to as contextual resources.

Operational context is an instantiation of the domain constituent of the abstract context with data provided by the contextual resources. This context reflects any changes in environmental information, in this way it is a near real-time picture of the current situation. The operational context embeds the constraint-based specifications of the problems to be solved. Those input parameters of the problems, which correspond to properties of the objects specified in the domain constituent, are instantiated. The embedded in the operational context problems are processed as a constraint satisfaction problem in its enumeration form. As a result, a set of feasible alternative 'satisfactory' solutions in the current situation is produced.

Each solution is a plan of joint actions for the acting resources in the current situation. Decision making is regarded as a choice between the alternatives.

If one or more efficiency criteria are applied to the set of feasible solutions an efficient solution can be found. The efficient solution is considered as the workable decision. The acting resources included in the efficient plan communicate with the DSS in the person of the decision maker on acceptance/rejection of this plan, i.e. on the plan implementation.

In order to enable capturing, monitoring, and analysis of the implemented decisions and their effects the abstract and operational contexts with references to the respective decisions are retained in an archive. As a result, the DSS is provided with reusable models of decision situations. These models, for instance, are used to reveal user preferences based on the analysis of the operational contexts in conjunction with the implemented decisions.

## 5 Technological and Methodical Approaches

Implementation of decision support and context-oriented knowledge management for business networks requires an orchestrated set of technologies. Some of these technologies will be described in this section: self-configuration of resource networks in order to establish flexibility with respect to sources integrated at the different network partners (section 5.1), an ontology as means to structure the network's knowledge for context-oriented knowledge management (section 5.2), and task patterns as a means to capture organisational knowledge in a reusable way (section 5.3).

### 5.1 Self-configuration of resource networks

The section presents theoretical and technological foundations of an approach addressing the requirements presented in section 3. The approach is based on the idea of self-configuration of resource networks (detailed description of the approach can be found in [18]). The process of self-configuration of a network assumes creating and maintaining a business network on top of the dynamically changing physical network topology formed by its resources. This business network then can be used as an infrastructure for various business operations like scheduling, routing, cargo delivery, etc. The context-based self-configuration can provide a new, previously unavailable level of flexibility via finding compromise decisions taking into account proposals of various network resources and task solving preferences.

The approach addresses the problem at three levels: the level of physical and information resources (machines, robots, cars, trains, trucks, services, etc.) responsible for their digitalization and intellectualization; the level of business networks integrating the resources and responsible for the network self-configuration; and the level of human beings – decision makers addressing the organizational behaviour aspects (differences in culture, norms, and rules). The first two levels form the cyber-physical network integrating the physical and IT dimensions, and all three form the socio-cyber-physical network integrating physical, IT and social dimensions.

Currently, there is a significant amount of research efforts in the area of cyber-physical networks and their applications, e.g., in transportation [19], production [20], and many other. Configuration of cyber-physical networks is a complex task, which is currently researched intensively [see, e.g.,21]. Even though such systems often only one stakeholder (e.g., a production system), the centralized control is often not possible due to the complex interactions in the physical world. The situation becomes even more complicated when dealing with socio-cyber-physical networks (SCPNet). Such networks go significantly beyond the ideas of the current progress in cyber-physical systems, socio-technical systems and cyber-social systems to support computing for human experience [22].

### 5.2 Upper Ontology for Context-Oriented Knowledge Management

Semantics is the basis to ensure that several resources arrive at the same meaning regarding the situation and data/information/knowledge being communicated. Ontologies provide for a shared and common understanding of some domain that can be communicated across the multiple SCPNet' resources. They facilitate knowledge sharing and reuse in open and dynamic distributed systems and allow entities not designed to work together to interoperate [23].

SCPNets belong to the class of variable systems with dynamic structures. Their resources are too numerous, mobile with a changeable composition. SCPNets are expected to be context-aware. Sharable contexts lie at the heart of the context-aware systems. Ontologies provide means to create sharable ontology-based context models. Such ontologies are referred to as context ontologies. The context ontologies consist of the upper ontology for general concepts, and domain specific ontologies representing knowledge of different application domains (e.g., [24]). The upper ontology is shared by these domains. As a rule, the upper ontology represents concepts that are common for all context-aware applications (Context Entity, Time, Location, Person, Agent, Activity, Device, etc.) and provide flexible extensibility to add specific concepts in different application domains (i.e., Cell Phone can be a subcategory of the category Device). Context is described as an ontology-based model specified for actual settings. Multiple sources of data/information/knowledge provide information about the actual settings. This information is integrated within the ontology-based model. The context model is a result of the integration.

The present research inherits the idea of context ontologies usage for modelling context in SCPNets. According to [25], any information describing an entity's context falls into one of five categories for context information: individuality, activity, location, time, and relations. The individuality category contains properties and attributes describing the entity itself. The category activity covers all tasks this entity may be involved in. The context categories location and time provide the spatio-temporal coordinates of the respective entity. Finally, the relations category represents information about any possible relation the entity may establish with another entity.

In the upper ontology (Fig. ) proposed for SCPNets [26], the resources are thought of as the entities whose contexts are to be described. Resource's context is described by location, time, resource individuality, and event. Resources perform some activity according to the roles they fulfil in the current context and depending on the type of event. On the other hand, the type of activity that a resource performs defines the type of event. For example, the event of a phone call defines the human activity as answer the phone. But, when a person raises the hand at the lecture time, this activity defines an event as, for instance, lecture interruption. This explains bidirectionality of 'defines' relationship between event and activity. The resources have some functionality in result of which they provide services. The services provided by one resource are consumed by other resources.

In Fig. 3, upper indices in boxes representing the ontology concepts indicate the taxonomical level of these concepts. The main concepts of the upper ontology show their share ability in the application area. The concept "resource" distinguishing two types of resources (physical devices and humans) indicated that there is no necessity

in this division. In the application domain the two resource types were merged into one concept. That is, humans are full members of the SCPNets. Sometimes they fulfil role of resources in providing information, knowledge, services, etc. Another time they are users of the SCPNets in consuming information, knowledge, services, etc.

### 5.3 Capturing Organizational Knowledge with Task Patterns

The concept of task patterns is a result of the EU-FP6 project MAPPER. In this project, collaborative engineering was supported by adaptable models capturing best practices for reoccurring tasks in networked enterprises. These best practices were represented as active knowledge models using the POPS* perspectives. Active knowledge models are visual models of selected aspects of an enterprise, which cannot only be viewed and analyzed, but also executed and adapted during execution.

The POPS* perspectives include the enterprise's processes (P), the organization structure (O), the product developed (P), the IT system used (S) and other aspects deemed relevant when modeling (*) [14].

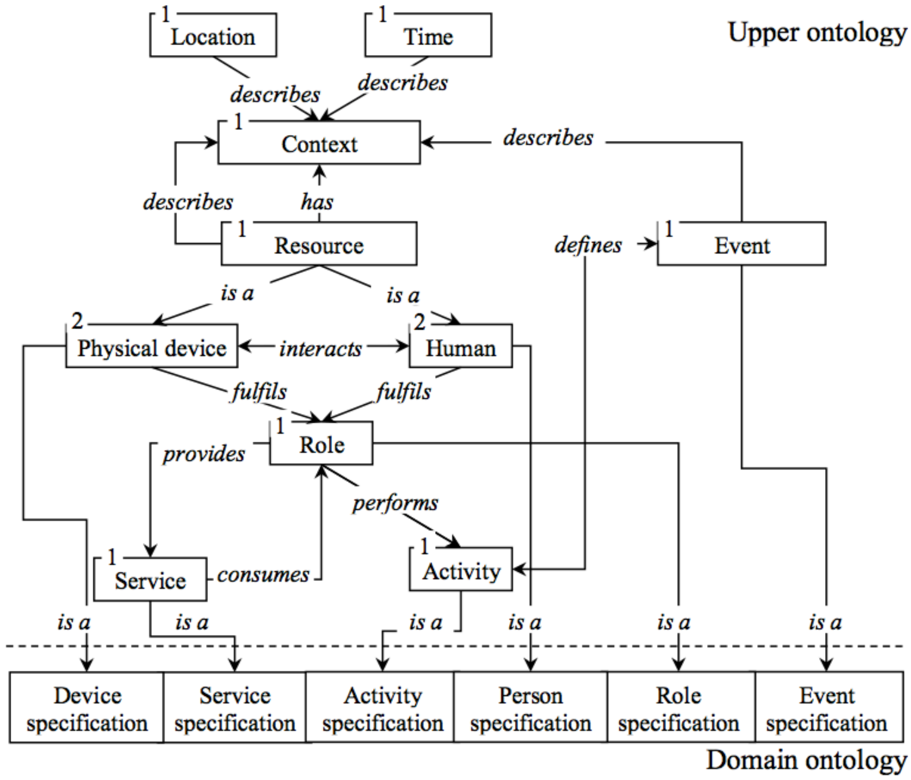


**Fig. 3.** Upper ontology for socio-cyber-physical networks

The term "task patterns" was introduced for these adaptable visual models, as they are not only applicable in a specific company, but are also considered relevant for other enterprises in the application domain under consideration. Task pattern in this context is defined as "self-contained model template with well-defined connectors to application environments capturing knowledge about best practices for a clearly defined task" [15]. In this context, self-contained means that a task pattern includes all POPS* perspectives, model elements and relationships between the model elements required for capturing the knowledge reflecting a best practice. Model template indicates the use of a well-defined modeling language and that no instances are contained in the task patterns. Connectors are model elements representing the adaptation of the task pattern to target application environments.

Reusing organizational knowledge will in practical contexts require a way to store the pattern and retrieve it for a given problem. This requires a representation suitable for use in knowledge repositories or portals. The representation of a task pattern consists of three main elements:

1. description of the problem addressed by the task pattern. Currently, scenario descriptions represent this part.
2. knowledge model proposing a solution for the problem addressed
3. rationale behind the solution, i.e. an explanation about the most important preconditions, principal results and most important work steps. These elements all are included in the model. The rationale is meant as a support for finding and selecting the best suitable task pattern for a problem.

Examples of the 17 task patterns developed so far include: establish material specification, establish product specification, develop test method, perform external testing, or target setting. All patterns originate from automotive supplier or electrical engineering industries. Pattern examples and more information about the development process can be found in [16] and [17].

## 6 Summary

Knowledge management is a crucial task for successful collaboration in business networks. Distributed work of various partners in product design, manufacturing and supply management projects require decision support for the involved partners which is tailored to the actual organizational context of these partners. The paper presented typical cases of business networks, identified requirements and challenges for knowledge management in such networks and presented technological and methodical approaches for context-orientation in knowledge management and for decision support, which are considered suitable not only for specific cases but for a large number of applications.

The use of these methodical and technological approaches in practice will require tailoring of these approaches for the situation at hand and – in most cases – additional technologies depending on knowledge sources to be integrated or collaborative activities to be supported. Future work will address development of additional technological components with the potential to be reused across different application domains or for specific application challenges.

**Acknowledgements**

The present research has been conducted with financial support from Russian Science Foundation grant (project No. 15-18-30048).

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