Context-Oriented Knowledge Management for Decision Support in Business Socio-Cyber-Physical Networks: Conceptual and Methodical Foundations

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***Abstract*—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 describes a scenario tailored to the needs of knowledge management in business socio-cyber-physical networks.**

I. Introduction

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 Things 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” [1]. The Internet of Everything can be defined 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” [2]. Here, the 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 [3]. Networked or virtual organizations [4] exploiting these possibilities are in the following called business socio-cyber-physical networks. Cyber-physical systems (CPS) [5] in general integrate physical systems (physical production equipment, vehicles, devices, etc.) and IT components (e.g. enterprise resource planning, manufacturing execution systems or other information systems) in real-time. Socio-CPS take into account the integration or human actors (e.g. organizational roles and stakeholders) on individual and social network level. Business socio-CP networks (BSCPNet) are networked organization structures of businesses which member organizations intensely use socio-CPS for value creation and digital transformation.

Knowledge management (KM) is a crucial task for successful collaboration in BSCPNet. Distributed work of various partners in product design, manufacturing, and supply management projects require decision support for the involved partners tailored to the actual organizational context of these partners. Modern BSCPNet are mainly service-oriented and based on integration of number of networks supported by the following information technologies [6]:

- 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.

BSCPNets belong to the class of variable systems with dynamic structures. Their resources are numerous, mobile with a changeable composition. BSCPNets are expected to be context-aware. The context is defined as any information that can be used to characterize the situation of an entity, where an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves [7].

This paper investigates conceptional and methodical foundations of knowledge management for BSCPNets and argues that context-orientation is a key feature of modern approaches. The focus of our work is on decision support. Section II starts with a conceptual schema for role-based knowledge management (II.A) which forms the foundation for context-orientation. It continues in II.B with a framework for context-oriented KM discusses in II.C how to capture profiles and best practice descriptions for BSCPNet, members based on the conceptual schema and the framework. Section II.D describes a scenario for using the overall approach including a method for determining context. A summary concludes the paper (section III).

II. Context-oriented knowledge management approach

A. Conceptual schema of role-based knowledge management

Knowledge management (KM) in BSCPNets requires interoperability at both technical and semantic levels. The interoperability at the technical level is usually represented by such approaches as e.g., SOA (Service-Oriented Architecture) and is based on the appropriate standards like WSDL and SOAP. The semantic level of interoperability in the network is also paid significant attention. As an example (probably the most widely known), the Semantic Technologies are worth mentioning that rely on application of ontologies for knowledge and terminology description.

Besides, the dynamic nature of the BSCPNet, it is necessary to consider the current situation in order to provide for actual knowledge or information. For this purpose, the idea of context is used. 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.

The overall schema of the KM would be formed as follows. The schema is based on the idea that knowledge of the BSCPNet and its members can be represented by two levels for the purposes of its processing in information systems. *The knowledge of the first level (structural knowledge)* is described by a common ontology. The ontology forms the core of the KM. In order for the ontology to be of reasonable size, it includes only the most generic common entities. This ontology is used in a number of different workflows. The tools are interoperable due to the usage of the common ontology and database. Knowledge map connects the ontology with different knowledge sources of the company. *Knowledge represented by the second level is an instantiation* of the first level knowledge.

The ontology consist of the upper ontology for general concepts, and domain specific ontology representing knowledge of different application domains. 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. The present research inherits the idea of context ontology usage for modelling context in BSCPNets. In the upper ontology (Fig. 1) proposed for BSCPNets [8], the BSCPNets resources are thought of as the entities whose contexts are to be described. The concept "resource" distinguishing two types of resources (physical devices and humans).

The above ontology is well related to the core ontology of industrial automation (1872-2015 - IEEE Standard Ontologies for Robotics and Automation), which specifies the main, most general concepts, relations, and axioms of the robotics & automation domain (Fig. 2), a robot is both a device and an agent. The standard provides a unified way of representing knowledge and provides a common set of term definitions, allowing for unambiguous knowledge transfer among any group of humans, robots, and other artificial systems, as well as a formal reference vocabulary for communicating knowledge between robots and humans. Robots are an example for cyber-physical systems in the BSCPNet.

The second idea of the schema is to consider the workflows from perspectives of different user roles, which reflect the "socio" aspect of BSCPNet. Role-based approaches have shown their efficiency in competence modelling [9].

The role-based approach assumes the following main steps for KM implementation:

1) Structural information about workflows and the problem domain is collected and described in the common ontology.
2) User roles are identified and their relevant parts of the common ontology are defined.
3) Tasks assigned to the identified roles are defined.
4) Knowledge required for performing identified tasks is defined.
5) Based on the identified roles, tasks and knowledge, new knowledge-based workflows are defined.
6) Corresponding role-based knowledge support of the workflows is provided based on the usage of the common ontology and knowledge / information storages.

This process repeats for each particular role, with some knowledge being reused between roles. The conceptual model of the role-based knowledge management is presented in Fig. 3. The ontology forms the core of the model. It describes common entities (objects, facilities, products, processes, etc.) of the BSCPNet members and relationships between them. In order for the ontology to be of reasonable size, it includes only most generic common entities of the participating companies.

For modern decision support systems, personalized support is important. Each user (human or an information system) works on a particular problem or scenario represented via a context that may be characterized by a particular customer order, its time, requirements, etc. Usually it is based on application of the profiling technology. For organization of multi-tier BSCPNet, a company profile structure including description of company's responsibilities and competences is proposed.

B. Major elements of context-oriented knowledge management framework

During the life cycle phases of BSCPNet, potential network members are registered in KM framework or excluded. For these purposes, the following elements of the KM framework are suggested:

- The ontology describes common entities of the BSCPNet members' knowledge and relationships between them. The ontological model contains a formalized description of the subject area, includes a list of synonyms for concepts included in its structure

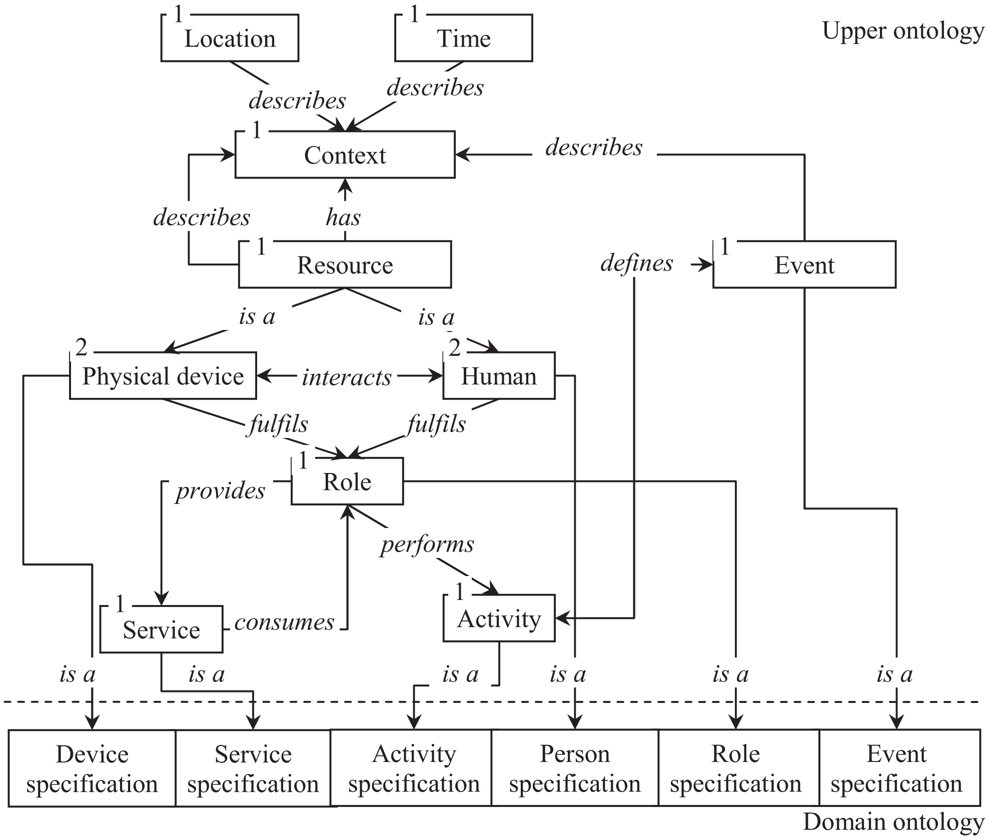

Fig. 1. Upper ontology for socio-cyber-physical networks

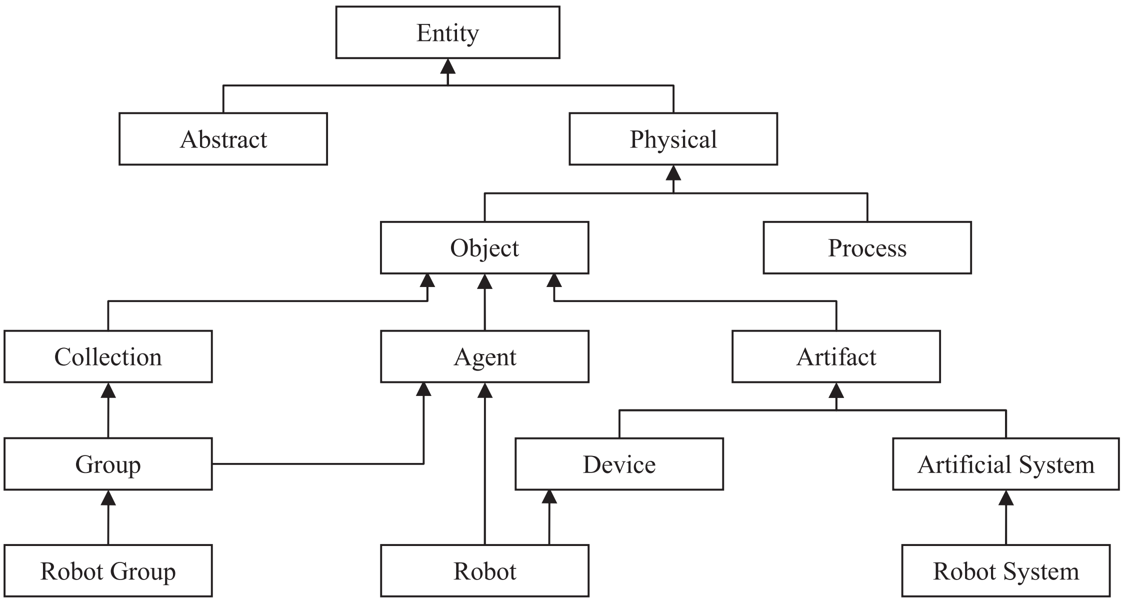

Fig. 2. IEEE 1872 Ontology for robotics and automation

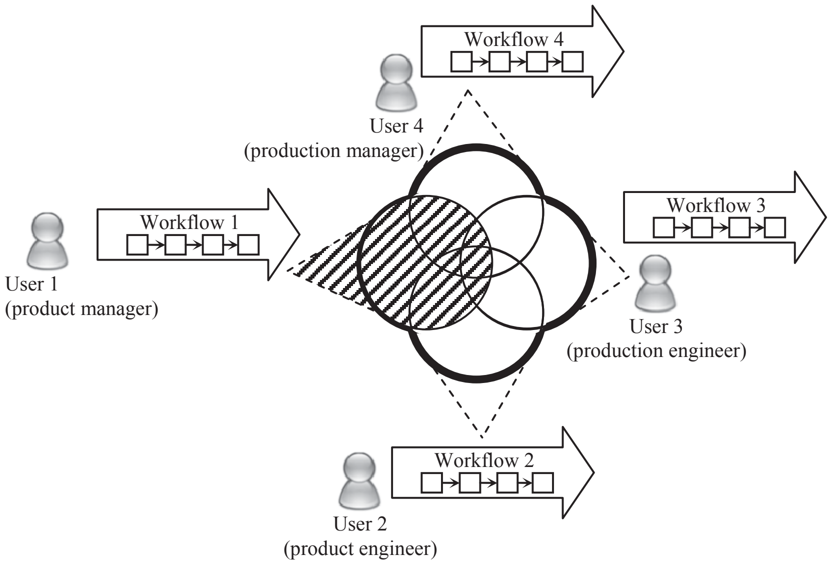

Fig. 3: Role-based perspectives of the common ontology

that allows for unification of members using different terms for the same concepts. The ontological domain model is used for "understanding" of what the user needs and what other BSCPNet members can provide.

- *Profiles of BSCPNet members* are created during registration in the KM framework. The profiles of BSCPNet members describe the members, their production capabilities, preferences, and other information as required by other BSCPNet members to communicate with that party. The profile is described on the basis of the ontological model of the BSCPNet and is divided into two main components, ontological and archiving. The ontological component of the member profile includes categories that are mapped on the ontological model of the BSCPNet, i.e., the information about the member, the unit, and member's preferences. The archival component of the member profile includes the request history. Consequently, the set of ontological components of profiles of BSCPNet members is mapped in the ontological model.
- *User profiles* describe the users of the KM framework, i.e. the human actors in the BSCPNet member organizations. User profile included two main parts: preference profile and demographic profile [10], the first part is based on using behavior modelling, interest modelling, and intention modelling [11].
- *The context* is a formalized description of a user's task in terms of an ontological domain model taking the current situation (the situation at the current time in BSCPNet and beyond) into account.
- *The knowledge map* binds BSCPNet members with the ontological domain model, through which it becomes possible to use these members as sources of knowledge. The knowledge map is based on the context. It allows offering BSCPNet members and knowledge sources to the users for solving their problems.

C. Profile and best practice description

BSCPNet member profiles contain «general information about the company», which includes the attributes "member identifier," member name," "foundation date," and "web site," as well as information about each of the member's divisions, which should include the attributes "division ID," "division name," "languages," "phone/fax," and "email."

The following attributes that characterize the division (a member of a BSCPNet) are suggested:

- The attribute "role" reflects the possibility of problem identification, which may be solved by a member at a given time.
- The attribute "access level" reflects the confidentiality of certain knowledge in the system and determines the information and knowledge, to which a member has access to a given time.
- The attribute "group" determines the user's membership and provides the selection from the members with the same role the one, who is more suit able for solving the problem.
- The attribute "user location" which contains the information about the current geographical location of the member and serves for transportation planning.
- The attribute "time zone" determines when the working day of the production network member starts.

- The attribute "production possibilities" describes the range of products.
- The attribute "production capacity" characterizes the free production capacity for each unit of production.
- The attribute "price list" contains the prices of products.
- The attribute "production cycle" describes the duration of production for each product unit.

Profile BSCPNet member consists of the following categories:

- "Information about the member", which includes the attributes such as the ID of the member, the name of the member, the date of foundation, and the website.
- "Information about the unit", which contains information about the division of the member of a BSCPNet and includes the attributes such as the division ID, the name of the division, the location, the time zone, languages, the access level, the group, the role; and subcategories, such as the contact information (phone number and email, the competences of the divisions (production possibilities, production capacity, pricelist, production cycles), feedback (efficiency).
- "Request history", which contains the history of the division activities within the system and includes the attributes such as the request of a member of the network, the context, the information about the division, the preferences of the division at the time of the request initialization.
- "Member preferences", which contains the preferences of a member of the network concerning the products they supply and includes the subcategories such as decided preferences (run time, the amount of work, technological constraints), and the implicit preferences (output, product attributes).

For example, when decision making process related to the BSCPNet configuring is implemented, the following information from profiles of BSCPNet members is taken into account:

- Production possibilities describe the range of products and services offered by the member. This information is used to determine the capacity of a member to produce the desired products.
- The production capacity is used by the system to determine the workload of the member to produce the necessary products in the required time.
- The price list is used by the system for deter mining the price of the products or services and, consequently, for minimizing the costs of the member initiating the request.
- Production cycles are used to determine the time required for the implementation of services or production.

In addition, the following preferences of the member acting as the source of knowledge are taken into account:

(a) Execution time (user may prefer long-term or short-term projects).

(b) The scope of work (a member may prefer small scale or mass production).

(c) Technological constraints (the member may prefer to produce item B while producing item A).

The information on the location of the BSCPNet member is used to determine the time of product delivery. A member may also be unavailable depending on the current situation (time of the year, abundant rainfall, snow drifts, local holidays, etc.).

The information received from the knowledge sources is transmitted to the user. It should be noted that at this stage, the user profile is used for ranking the reported results on the basis of their relevance to the user's request and preferences.

Furthermore, the concept of task patterns (as a best practices) is very popular in the area of collaborative decision making. Task pattern is defined as "self-contained model template with well-defined connectors to application environments capturing knowledge about best practices for a clearly defined task" [12].

Example of the task pattern "*A generic method to weight criteria is the pairwise comparison"* (which is used for comparing and evaluating several alternatives) presented below:

Pairwise Comparison Method (task pattern):

Description: Derivation of factors for a multitude of criteria by direct pairwise comparison of single criteria. When comparing the question is answered: Is criterion A (row) important than criterion B (column), of same importance or less important? All criteria are listed and span a matrix.

Situation:

- A solution has to be selected. Several alternatives are given.
- Evaluation by the degree of fulfillment of criteria.
- Criteria do not have the same importance (weight).

Problem:

- More than 7 ± 2 criteria cannot be compared mentally at the same time.
- Criteria weighting must be comprehensible and documented.

Solution:

- Weighting of criteria by pairwise comparison.
- Explanation of the method.

Consequences:

- Number of pairwise comparison increase with number of criterion.

Results:

- Criterion weights.

D. Scenario

Fig. 4 illustrates the overall approach. The top of the figure shows the member organisations of a BSCPNet (middle) with their employees – users (right) and the application domain (left) the BSCPNet is working in. The results of the context modelling is a separate context model for each individual BSCPNet member. During runtime, each context model is used within the BSCPNet member organization to configure the local KM solution for the company and for the users working with this solution. This work is based on a domain ontology reflecting the application domain. This application domain is used to derive an abstract decision making context. Decision making context and KM context both are used to configure the knowledge supply solution for the BSCPNet (see lower part of Fig. 4).

A context modelling consisting of four steps [13]:

- Scenario modelling for context-based KM in BSCPNet. The purpose of the first step is to identify user groups and intended scenarios of use for the context-based KM in network. Existing models usually include all information expected from a scenario model: (a) the different user groups of the context-based KM system (e.g., indicated by organizational roles); (b) the tasks the users are supposed to perform with the KM system; (c) information input or conditions which cause branching in the flow of actions during the tasks.
- Variability elicitation. A context model has to include in what situations and on what inputs or events what kind of adaptations in the context-based system should be made.
- Develop context model. The context contains all information characterizing the situation of an entity. 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’.
- Implementation of context-based knowledge management using the context model from the previous step and implementing the self-organization approach [14] .

The context model for each network member and in particular the information about variation aspects in products and processes can be either provided by a separate service. Depending on the network member, the relevant part of the ontology is selected forming a so-called ‘abstract context’. The abstract context is an ontology-based model embedding the content of the context model. When the abstract context is filled with actual values during use of the KM platform, an

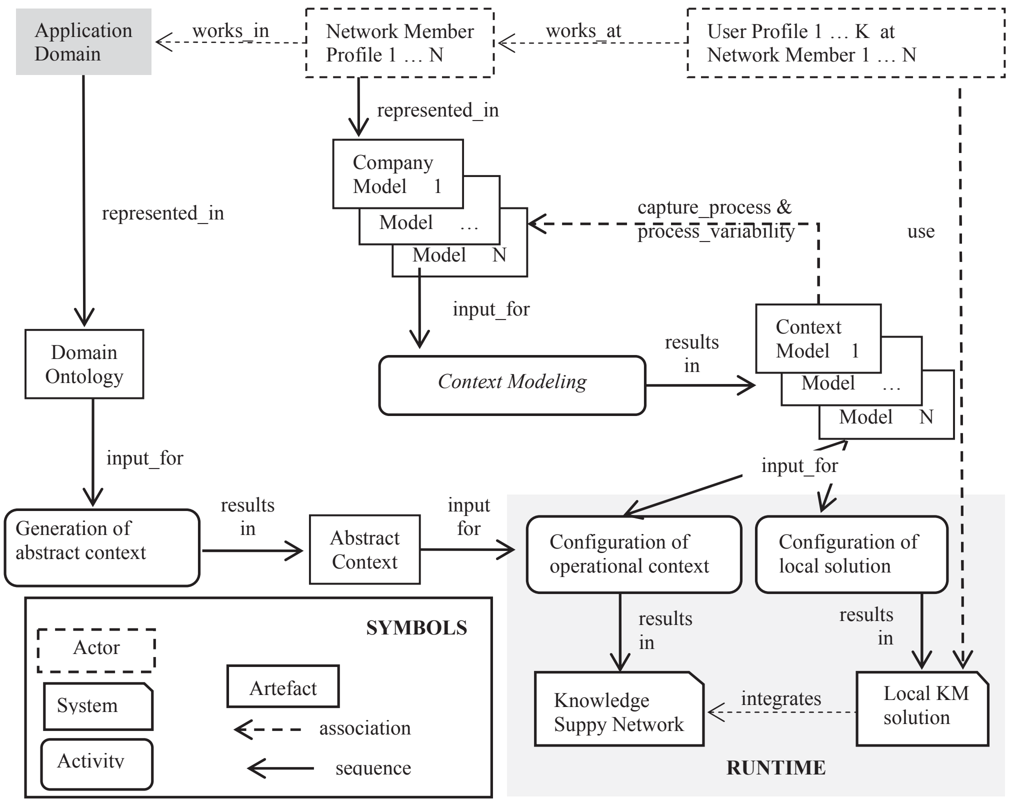

Fig. 4. Context-oriented knowledge management approach

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.

III. Summary

The paper presented a scenario, which is tailored to the needs of knowledge management in business socio-cyber-physical networks. The use of this scenario in practice will address development of additional knowledge management components with the potential to be reused across different application domains or for specific application challenges.

Currently, the following observations related to context-oriented knowledge management implementation in companies could be made:

- Production engineers and managers are concentrated on their work and cannot pay enough attention to additional tasks related to trying new knowledge-based workflows.
- A potential target expert group related to knowledge management issues has to be formed in the companies. These experts will be involved into the processes of building the initial common ontology and implementing knowledge-based workflows for their role.
- Role-based approach makes it possible to implement knowledge management incrementally, with initiative coming from employees (experts).

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References

[1] IERC - European Research Clister on the Internet of Things, About IoT. Web: http://www.internet-of-things-research.eu/about_iot.htm.

[2] J.R.B. de Marca. Coming Next: The Internet of Everything. *IEEE The Institute.* March 2014; Web: http://theinstitute.ieee.org/opinions/presidents-column/whats-coming-next-the-internet-of-eveything.

[3] Pew Research Center. Digital life in 2025, March 11, 2014; Web: www.pewinternet.org/files/2014/03/PIP_Report_Future_of_the_Internet_Predictions_031114.pdf

[4] J. Browne and J. Zhang, "Extended and virtual enterprises-similarities and differences", *International Journal of Agile Management Systems 1.1 (1999)*, pp. 30-36

[5] I. Horvath and B.H.M. Gerritsen, “Cyber-Physical Systems: Concepts, Technologies and Implementation Principles”, I. Horvath, Z. Rusak, A. Albers, M. Behrendt (eds.), *Proceedings of TMCE 2012*, pp. 19-36.

[6] A. Smirnov and K. Sandkuhl, "Context-Oriented Knowledge Management for Decision Support in Business Networks: Modern Requirements and Challenges", *BIR 2015 Workshops*, vol. 1420, 2015.

[7] A.K. Dey, D. Salber and G.D. Abowd, “A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications”, *Context-Aware Computing, A Special Triple Issue of Human-Computer Interaction*, T. P. Moran and P. Dourish (eds.), Lawrence-Erlbaum, vol. 16 (2001), Web: http://www.cc.gatech.edu/fce/ctk/pubs/HCIJ16.pdf

[8] N. Teslya, A. Smirnov, T. Levashova, N. Shilov, “Ontology for Resource Self-Organisation in Cyber-Physical-Social Systems”, P. Klinov and D. Mouromtsev(eds.), *5th International Conference of Knowledge Engineering and the Semantic Web (KESW 2014)*, Springer International Publishing Switzerland, CCIS, 468, pp. 184-195.

[9] V. Tarasov and K. Sandkuhl, “On the Role of Competence Models for Business and IT Alignment in Network Organizations”, W. Abramowicz, L.A. Maciaszek and K. Wecel (eds.), *Business Information Systems Workshops - BIS 2011 International Workshops and BPSC International Conference*, Poznan, Poland, June 15-17, 2011, Springer, LNBIP 97, pp. 208-219.

[10] M. Amoretti, L. Belli and F. Zanichelli, “UTravel: Smart mobility with a novel user profiling and recommendation approach”, *Pervasive Mob. Comput.*, 2016.

[11] M. Gao, K. Liu and Z. Wu, “Personalisation in web computing and informatics: Theories, techniques, applications, and future research”, *Inf. Syst. Front*, 2010, vol. 12, issue 5, pp. 607–629.

[12] K. Sandkuhl, A. Smirnov and N.Shilov, “Configuration of Automotive Collaborative Engineering and Flexible Supply Networks”, P. Cunningham and M. Cunningham (eds.), *Expanding the Knowledge Econom*, ISBN 978-1-58603-801-4.

[13] K. Sandkuhl U. Borchardt, “How to Identify the Relevant Elements of “Context” in Context-Aware Information Systems”, *13th International Conference on Business Informatics Research (BIR 2014)*, LNBIP 194, Springer, pp. 290-305.

[14] A. Smirnov, K. Sandkuhl and N. Shilov, “Multilevel Self-Organisation of Cyber-Physical Networks: Synergic Approach”, *Int. J. Integrated Supply Management*, 8 (1/2/3), 2013, pp. 90–106.