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Stanisław STRZELCZAK
Wydział Inżynierii Produkcji
Politechnika Warszawska

CORE ONTOLOGY FOR MANUFACTURING AND LOGISTICS

Summary. Ontologies enjoy growing interest as facilitators for intra- and inter-organizational semantic integration of different management activities in the ICT and automation intensive industries. This work provides a proposal of core ontology that addresses the operational level of discrete manufacturing and logistics processes. Although only partial research results are presented, they go beyond published knowledge because they involve such important aspects of complexity as the spatiotemporal transformations, including the mereological one.

Keywords: manufacturing, logistics, ontology, changeability.

ONTOLOGIA RDZENIOWA DLA WYTWARZANIA I LOGISTYKI

Streszczenie. Ontologie zyskują rosnące zainteresowanie jako narzędzie wewnątrz- i międzyorganizacyjnej integracji semantycznej w zarządzaniu tam, gdzie intensywnie wykorzystuje się informatyzację i automatyzację. W artykule przedstawiono propozycję ontologii rdzeniowej dla poziomu operacyjnego dyskretnych procesów wytwarzania i logistyki. Choć zaprezentowano tylko część wyników, to wykraczają one poza publikowaną wiedzę, gdyż ujęto takie aspekty złożoności, jak transformacje chwilowo-przestrzenne, w tym mereologiczne.

Słowa kluczowe: wytwarzanie, logistyka, ontologia, podatność na zmiany.

1. Introduction

Manufacturing and logistics are recently exposed to the rapid growth of openness and complexity. Many innovations in information and communication technologies (ICT) and automation technologies (AT) were developed parallely. Among the key novel technologies there are: Web services, semantic technologies, smart embedded systems and remote mobile terminals, distributed systems technologies, tracking technologies. Enormous opportunities but also challenges have affected manufacturing and logistics. Specifically, frequent changes and shortening life-cycles have pushed up the need for changeability of systems, particularly in terms of re-configurability.

The area of this work concerns operational level management of integrated manufacturing and logistics, assuming discrete type of processes. Particular attention is given to the semantic technologies and distributed systems technologies, which are recognized as facilitators for some aspects of changeability, mainly: re-configurability and interoperability [1]. Although a plethora of publications addresses this research area, and the satisfactory level of maturity of the enabling technologies has been achieved [2, 3], still many important issues stay unresolved. One of them is the research focus of this work: it is to develop the core ontology for the domain, i.e. such one that contains all categories relevant to some range of applications within it [4]. It is expected to be holistic and complete, not like the existing ones that merely provide high level taxonomies of systems and some processes. Apart of such taxonomies, the dynamic transformational aspects should be addressed. It is particularly expected that the ontology would be able to describe to the required extent all complexities that affect performance of operations, and to support different management functions, especially planning and control. It is also desired to make the proposed conceptualization open for novel architectures of systems and processes, which could be eventually developed by bio-mimetic and eco-mimetic imitations, especially in reference to distributed non-hierarchical structures of resources and processes [6].

The importance of the research problem relates to the integrating power of ontologies as possible core of various platforms, for sharing and exchanging knowledge between different applications, used to aid interlinked activities of management and automated control [5]. Apart of the existing research gaps, in terms of both theoretical and methodological foundations, practice gaps exist. They were widely documented in the deliverables of the EU ESCOP project [7, 8]. An essence of the gaps from industrial perspective was briefly defined by Mr. Ermanno Rondi, who is the founder and CEO of the INCAS Group, i.e. one of the major European providers of integrated management and automation turnkey solutions for supply chains and manufacturing. During the panel research led by the author of this paper, Mr. Rondi said that: (1) reducing efforts and shortening lead-times, concerning development and reconfiguration of supply chains or factories, is currently a primary issue in his domain of business; (2) ontology-aided systems management and applications development seem to be the most promising provision to address this issue; (3) his industry cannot fully exploit enabling potential of the available ICT/AT technologies due to shortcomings of centralized hierarchical architectures of existing systems. In reference to the last argument, it is widely demonstrated that tracking technology is able to accurately capture the detailed operational information. However, it still remains a fundamental challenge to transform this abundance of data into accurate and timely control decisions. Finally, the importance of research problem is also somehow reflected by assignments of first patents concerning ontology-aided management and control of distributed industrial systems, e.g. [9].

The research approach of this work is founded on systemic and multi-agency paradigms. The methodological grounding of the research encompasses:

- literature review of existing ontologies for manufacturing and logistics (section 3).
- empirical research of issues related to the research problem as viewed by practitioners; the obtained results were a side effect of semi-structured interviews led by the author within the EU ESCOP project; industrial needs and requirements; in addition, gaps between them and existing practices were identified [7, 8]; due to a limited space of this paper they are presented to a very limited extent herein, but a separate publication is in preparation; nevertheless conclusions from this research were thrived on by the conceptual research.
- conceptual research on the core ontology for manufacturing and logistics (section 4).

2. Ontological foundations

As it was argued before, ontologies can be used as core conceptualizations for different applications, to be utilized by various management and control activities in the manufacturing and logistics domain. Aiming at re-configurability, interoperability and integrability, as the important attributes of organizationally and spatially distributed resources and processes, ontologies provide significant advantages, namely:

1. Ontologies can be used as common conceptualizations for modelizations, development, re-configuration and operation of resources and processes, hence increased potential can be provided for cross-layer, cross-functional, cross-domain and cross-process integrations, including intra- and inter-organizational integrations. This way some further effects may emerge, like improved: openness, interoperability, integrability, convertibility, scalability.
2. Sharing and exchanging distributed knowledge between humans and smart applications is enabled and easy, hence distributed intelligence is facilitated. This way improvements of performance, robustness and dependability of resources and processes, can be obtained.
3. Knowledge is described and maintained in a human-friendly way; typically ontologies are expressed in semi-natural languages and can be visualized.

The concept of ontology was adopted in 1980s from philosophy by artificial intelligence and computer science communities. Then in 1990s after publication of the seminal work of Gruber [10] it was widely disseminated. Independently in mid 1980s Krupa developed a complete conceptual framework for manufacturing and logistics[1], rooted in the theory of sets, theory of graphs, formal linguistics, theory of automata and theory of artificial

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[1] Krupa has mostly published in research reports of limited circulation. His contributions were summarized in a later publication, i.e. [11].

intelligence. It uses two basic categories to describe the domain: resources and tasks. It is distinctive by many features, of which some were never addressed by the literature. The key of them are:

1. Semiotic interpretation of resources, namely, in terms of classes, objects and denotations.
2. Distinction of transformation-informative, structural and functional relations of resources.
3. Distinction of transformation operations on the resources.
4. Various collectivities of resources, i.e. mereology.
5. Distinction of mereo- and systemic transformation operations on the resources.
6. Mereo-functional and automata interpretation of the dynamic behavior of resources.
7. Distinction of global and local a priori and a posteriori discrepancies between properties.
8. Distinction of tacit (procedural) and explicit (structural) representation of tasks.
9. Distinction of different forms of representation of tasks: procedural, predicate, operator, space of states, hypergraph, logistical model, mixed representations.
10. Use of scenarios of tasks, logistical models of tasks and reasoning about tasks, by graphs.

Although the term “ontology” was never used by the framework of Krupa, it evidently meets common definitions of ontology: i.e. it is a formal explicit description of concepts in a domain. It is descriptive in the Seidewitz's sense [12], and also prescriptive. It is interesting to note that the dyadic construct of tasks and resources introduced by Krupa preceded the Service-Oriented Architecture (SOA) paradigm, as services and tasks are dual concepts. Unfortunately the framework was never tooled, nor widely disseminated. Its only limited implementation was by development of shop floor control system for flexible manufacturing systems, which was headed by the author[2].

Ontology engineering has been intensively developing in recent years, particularly due to the Semantic Web initiative, driven by the World Wide Web Consortium (W3C), which has been targeting an open infrastructure for intelligent agents and Web services. It is based on ontologies as domain formalizations, linked on the Web. W3C defined the Ontology Web Language (OWL), as the standard for representing ontologies. Using of Semantic Web tools is not restricted to the Semantic Web or Web services [2]. The Semantic Web initiative and other developments in ontology engineering provided principles, methods and tools for activities that support creation, exploitation, management and maintenance of ontologies.

Contemporary ontologies share many structural similarities, regardless of the language in which they are defined. Basically ontologies include:

- Classes/concepts: sets, collections, types of objects. They may contain individuals, other classes, or a combination of both.
- Individuals: instances, objects.
- Relations: ways in which classes and individuals can relate to each other. Apart of the basic “is-a” (“subclass-of” or “kind-of”), “part-of” (“connected-to”) and “instance of”

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[2] National R&D Program No. 7.5, Flexible Manufacturing Systems, 1988. See also [13].

relationships, ontologies may include other types that further refine the semantics, like: non-binary ones, mereotopological, spatiotemporal, granulating [14]. These relationships are often domain-specific and are used to answer particular types of question.

- Attributes: aspects, properties, features, parameters and other characteristics of classes, relations and objects.
- Events: result in changes of attributes or relations.
- Function terms: complex structures formed from certain relations that can be used in place of an individual term in a statement.
- Axioms: assertions (including rules) in a logical form that all together comprise the overall theory that the ontology describes in its domain of application.
- Restrictions: formally stated descriptions of what must be true in order for some assertion to be accepted as input.
- Rules: statements in the basic form of “if-then” (“antecedent-consequent”) sentence that describe the logical inferences that can be drawn from an assertion in a particular form.

Principally ontologies respect the open-world assumption and are descriptive, hence they are partial descriptions. They accept under-specification as a means of abstraction, also in the terms of grey conceptualization [15]. Ontologies can be encapsulated into application models, or directly into applications, including the run-time mode encapsulation [16]. In such case, if not following the grey paradigm, they have to describe a domain as completely as needed, and they also have to meet some rigid requirements of software engineering. This argumentation exposes a particular side issue: whether ontologies should be standardized for some domains. Possibly, in order to be general enough, ontologies should be negotiated between their stakeholders, and be confirmed by competent institutions, like: standardization committees, professional associations and scientific organizations. A limited range of provisions of such kind that are presented mostly as taxonomies, are recently available e.g. [17, 18, 19].

3. State-of-the-art and gaps

The number of published ontologies for manufacturing and logistics is limited. Many of them target specific areas, and only few address the operational level of manufacturing and logistics. All these are reviewed below (only most representative papers from different research teams are quoted), except [11] that was commented in the section 2.

Lin et al. [20] developed MSE (manufacturing systems engineering) ontology to support intelligent coordination in extended or virtual enterprises. The MSE ontology conforms to a simple taxonomy of various concepts, like: strategy, project, enterprise, extended enterprise and resource.

The ontology of Soares et al. [21] focuses on production planning and control in a virtual enterprise to improve human communication and to support specification of system requirements. It is founded on meta-ontology, whereas the concepts are defined by natural language and object models.

Lemaignan et al. [22] presented MASON ontology (Manufacturing's Semantics Ontology), which is built upon three head concepts: resources, operations and entities. For each class several subclasses were defined.

Dassisti et al. [23] proposed an ontology-based model, following the IEC 62264 standard [19]. It includes: (a) Product Definition Model; (b) Material Model; (c) Equipment Model; (d) Personnel Model; (e) Process Segment Model: it contains process segments that list the classes of personnel, equipment, and material needed; (f) Production Schedule Model: it shall be made up from one or more production requests; (g) Production Capability Model; (h) Production Performance Model. Extended conceptualizations were provided for two classes.

Cândido et al. [24] described the ontology for shop floor assembly. Two categories of concepts were proposed: modules and skills. Modules represent physical processing units or their aggregation and they are compositions of workstations. Workstation is a composition of units (transforming, flow and verification unit). Two common constructs "composed-of" and "is-a" are used to describe compositions and specialization relations. Skills represent abilities to perform operations. The basic element in the system, which uses ontology as a data model for reasoning about objects and their relations, is the Manufacturing Resource Agent (MRA). This agent searches ontology after instantiation for skills it supports, using their serial number and equipment type. Then it registers its capabilities in the yellow pages provided by a special Directory Facilitator (DF) agent, which manages and provides information about services provided by agents. MRA agents can form coalitions to provide combined skills. In such case there is a Coalition Leader Agent, which registers in the DF all complex skills provided by coalition and coordinates execution of elementary actions by particular coalition members.

Obitko et al. proposed ontology for Agent-Based Manufacturing Systems [25]. The basic categories are: (a) customer order, (b) production plan, (c) workstation, transportation and material handling. All of them reuse classes and properties from the proposed Core Ontology that for example separates physical and information resources. There are also other ontologies, such as ontology for the configuration of the system.

Battista and Giordano [26] proposed a modeling framework which incorporates: (1) product and planning data structures (BOM (Bill of Materials), process charts, MPS (Master production Schedule), calendars, etc.); (2) data on operations and equipment; (3) production and inventory management control policies; (4) distinction between physical and information layer. Although the above framework is not named as ontology, the authors advocate for using ontology of manufacturing system including the proposed elements.

Garetti and Fumagalli [27] suggested three layers within their P-PSO ontology: physical (static), technological and control. The main classes are: part; component (system structure); operation; controller (decisional element performing functions of production planning and control; it can be person, PLC or software); operator; subsystem (service class allowing the grouping of objects of classes in a nested way). The primary sub-classes of the component class are: processor, transporter and storage. The secondary sub-classes are: tool, fixture and unit load (entity used to move or handle parts). The ontology includes sound taxonomy of the transporter and storage sub-classes. Apart of the controller class the control aspect of the P-PSO ontology incorporates following classes: rule (logic of decision making for controller; it can be algorithm, heuristic, simple rule or knowledge-based rule); order (part and quantity to be produced or purchased); production plan (set of orders generated by controller for time frame; it can be divided into sub-plans); batch (it does not correspond to a unit load); task (specific action of controller on component, part and operation classes, i.e. the translation of controller actions at the physical level; e.g.: routing, dispatching, process selection).

Table 1

Comparison of ontologies for manufacturing and logistics

Element of ontology		Ontology (by no. of publication)								
		[11]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]
Taxonomy of non-movable manufacturing resources	C	●	•	•	●	●	•	•	•	●
	R	•								•
	A	•								
Taxonomy of movable manufacturing resources	C	●		•	•	●		•	•	●
	R	•								•
	A	•								
Taxonomy of movable logistical resources	C	•			•	●		•	•	●
	R									•
Taxonomy of non-movable logistical resources	C				•	•			•	⬤
	R									•
Mereo- and systemic transformability of resources	C	⬤	•	•	•	●	•	•	•	•
	R	●								
	A	•								
Spatiotemporal representation of resources	C	⬤								
	R	●								
		•								
Transformational representation and operations on resources	C	⬤								
	R	●								
	A	•								
Taxonomy of manufacturing processes	C	●		•	•	•		•	•	•
	R	•								
Taxonomy of logistical processes	C	●						•		
	R	•								•
Taxonomy of operational targets: plans/orders/tasks	C	⬤	•	•	•	•		•	•	•
	R	●								
	A	•								
Mereology of plans/orders/tasks	C	⬤	•				•			
	R	●								
	A	•								

cont. table 1

Element of ontology		Ontology (by No. of publication)								
		[11]	[18]	[19]	[20]	[21]	[22]	[23]	[24]	[25]
Spatiotemporal representation of plans/orders/tasks	C	⬤								
	R	●								
	A	•								
Discrepancies between plans/orders/tasks, processes and resources	C	●						•		
	R	•								
	A	•								
Conceptualization of planning and control of workflows	C	•	•	•					•	•
	R	•								
Conceptualization of planning and control of material flows	C	•		•					•	•
	R	•								
Taxonomy of performance targets for manufacturing or logistics	C					•				
Taxonomy of company targets	C	•	•							
Granularity mappings		•						•		•
Layering		●						•		•
Semiotic mappings		●								
Under-specification										
Paradigm		S	S	S	S	S	S MA	MA H	S	S

Legend: C - Classes, R - Relations, A - Attributes;
Details/ formality level: • - small, ● - medium, ⬤ - high
Paradigm: S – systemic (hierarchical), H – heterarchical, MA – multi-agency;
Source: own work.

Most publications provide a limited description of ontologies and remain abstract. It is to some extent understandable, as papers are normally of limited size. But after closer analysis of details in these publications it is unquestionable that most authors did not target any further development but a rough vision of the ontology. This explains to great extent why the above table is so empty. Most of reviewed papers lack rich formal semantics. Description logic is rarely used, and the limited taxonomies usually lack formal axioms. Decision making and commanding are mostly not discussed. The service-oriented paradigm is often ignored or even neglected. The potential of semiotic interpretation of resources, tasks and some other classes is exceptionally explored. Most publications avoid or bypass important but difficult aspects of the domain, e.g. details of planning and controlling operations, dynamics and behavior of the system etc. The multi-agency and heterarchical paradigms are rarely addressed. Under-specification is never incorporated into conceptualization.

The most important research gap identified refers to the dynamic behavior within the domain, and particularly to the complexities and discrepancies that may arise along planning, controlling or execution of operations. Among them the following are typical: correlations, interdependencies, synchronizations, static and dynamical (temporary) fits and conflicts, blockings, starvations etc. The roots of them are analyzed by the literature to a limited extent, if at all, like e.g.: layout driven limitations to flows; dynamic transformations of temporarily coupled resources and tasks (orders, flows etc.). Only one of the papers considers distinction of enduring and penduring classes of resources and tasks.

Another view at gaps can be derived from the empirical research led by the author within the EU ESCOP project. The main focus of semi-structured interviews run in twenty European companies was industrial needs and requirements, in reference to ICT and automation aided manufacturing and logistics, as well as gaps between them, and existing practices. Although only a minority of interviewees had a prior knowledge on ontology engineering, after the introduction to the topic many valuable feedbacks were provided. Due to limited size of this paper, only key conclusions from the research are presented below in a synthetic way, which does not necessarily address the issues of ontology content directly or precisely:

- the exchange of data between various applications should be accompanied by exchange of knowledge, also in run-time mode; hence the enabling semantics is recognized as crucial;
- to support decision making, intelligence should be added to existing applications; in addition, capacity of local reasoning should provide many new opportunities;
- diagnosability, warning ability or even self-diagnosability of devices and processes are much required; learning from past data could also drive some improvements;
- applications using ontologies could be implemented as bypasses to existing applications, this way easily enabling new important functionalities;

The concise conclusions from the empirical research confirm the crucial role of ontology engineering, as seen from the perspective of industrial practice. Taking all together the practice and literature research the following gaps can be named to be addressed by the work:

- The complete taxonomies are needed in reference to resources, processes, targets, plans, orders, tasks, locations, workflows, material flows, data flows, information and documents flows, knowledge flows, possibly thriving on available standard taxonomies [17, 18, 19].
- The relations between resources and tasks should be fully conceptualized, to enable description of transformations and mereotopological operations, including spatiotemporal.
- Various representations of dynamic behavior of systems and other collectivities, including such aspects and characteristics, as events, states, controls, should be incorporated into the ontology.
- Different complexities and discrepancies that may arise along planning, controlling or execution of operations should be described by the ontology;
- Under-specification of knowledge should be incorporated, in order to facilitate situations of incomplete information, failing processes and unavailable resources.

The next section presents a proposal in order to reduce the above gaps to a possible extent, as it is supported by the current status of the research. The research behind this work is of R&D type and should finalize with industrial implementation. Hence, the ontology for manufacturing and logistics must be holistic and complete.

4. Core ontology for manufacturing and logistics – key features

In this section the proposal of ontology for discrete manufacturing and logistics operations is presented. Its intention is to eliminate or reduce the identified research and practice gaps that were listed in the preceding section. These gaps have defined the starting point for the ontological developments described underneath.

Referring to ontologies and model integrated application development, this work respects the distinction between meta-, core and application ontology. The core ontology describes all categories (classes) for some range of application domains. The application ontology is a conceptualization of the problem to be serviced by a particular application. The meta-ontology provides an ontological foundation for all categories of both core and application ontologies.

The key concern of the ontological development was to address complexities that arise when performing operations. The complexities along manufacturing and logistics operations can be rooted in:

- Opacity – many interdependencies.
- Mereotopology – structural overlaps and connections, layering and granularity.
- Diversity – various aspects and perspectives.
- Divergence and latitude - of properties, of choice.
- Discrepancy – inconsistent or conflicting requirements and objectives.
- Spatiotemporal couplings – indispensable fits along the time dimension.
- Volatility - variability, unpredictability, unforeseeenability, turbulent behavior.

As regards to the conceptualized domain, the following common factors of complexity were identified in reference to operations planning and control:
(1) limitations to material flows, in terms of paths.
(2) limitations to workflows, in terms of routings.
(3) limitations to various flows due to logical structure of decision making and control.
(4) functional fits of operations and resources.
(5) aggregations/splits and fusions/partitions of resources and flows.
(6) spatiotemporal (loading) and durability related fits of operations and resources.
(7) discrepancies (trade-offs) of operational and performance targets.
All complexities caused by the above factors can be represented in terms of: classes, attributes and properties, relations, predicates, function terms, axioms, restrictions and rules.

Due to limited size of this work, the ontology is presented in a limited way. Taxonomies are discussed only to indispensable extent, as they do not cause major issues along ontology development or use; in addition, standard taxonomies are also available. Instead, conceptual and logical aspects are centered below, as they determine the most important capabilities of the ontologies, especially in reference to the gaps. The original description of the ontology was developed in the OWL Full language, using the Protegé tool and the HermiT reasoner.

The two fundamental categories (classes) within the core ontology are: resources and tasks. Resources are used during performance of tasks. Tasks are outcomes of services. These consist in primary and support processes, as well as manage processes. All of them are executed along fulfillment of tasks. Resources and tasks can be viewed from transformational, i.e. processual perspective, or from manage perspective [Fig.1]. Transformations encompass: functional, spatiotemporal, mereological, and mereotopological ones.

Resources can be real and abstract. Real resources are: human resources, items, facilities, devices, auxiliary equipment, ICT hardware, data, databases, documents, visualizations, knowledge (ontological resources), information processing agents, controlling agents et al. Abstract resources are mereological or mereotopological constructs of them, with possible layering and granularity. They may encompass existing resources (e.g. layout, container with inside items, assembly kit) or demanded (hypothetical) resources, which are described in terms of composition and properties (e.g. demanded composition of workstation, in terms of auxiliary equipment). Both may compose dynamic structures and collectivities, including hierarchical and heterarchical (e.g. two workstations may command each other, assuming that both include intelligent agents). Movable resources are distinguished, i.e. those that may change locations, including data, information and knowledge. Followingly, spatiotemporal relationships of resources can be handled. Further distinctions of resources may follow their taxonomies and other properties. The semiotic interpretation of resources can encompass: objects, classes, denotations and locations. Oppositely, semiotic interpretation of locations can encompass: physical locations (e.g. GPS address), objects, classes, and denotations.

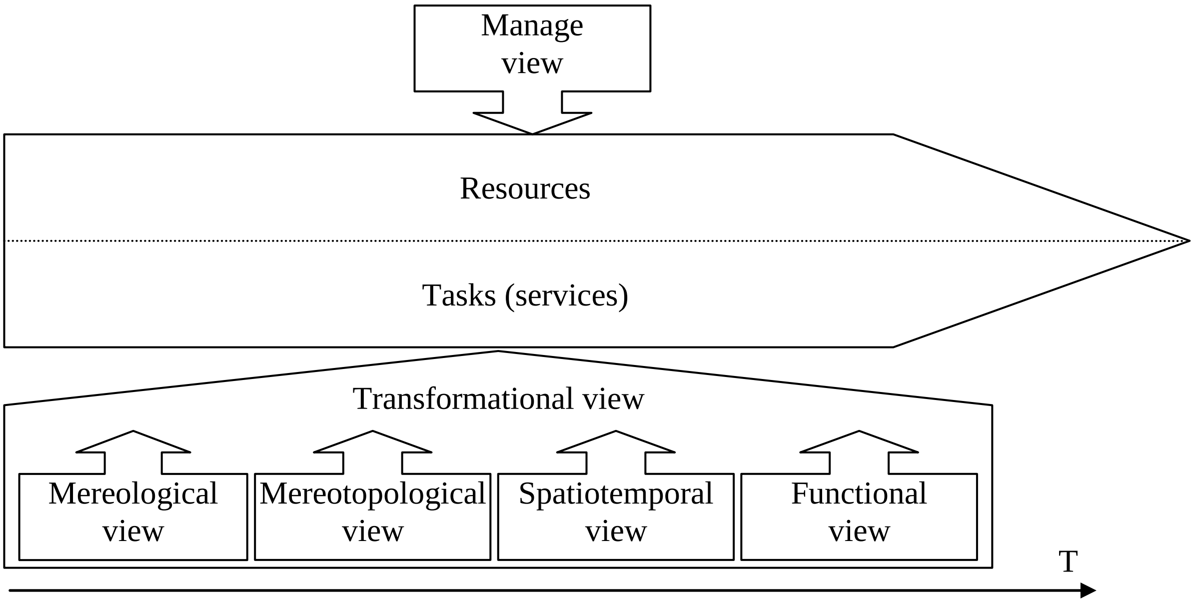

Fig. 1. Fundamental categories and perspectives of the core ontology for manufacturing and logistics
Rys. 1. Podstawowe kategorie i perspektywy w ontologii rdzeniowej dla produkcji i logistyki
Source: own work.

A particular and separate category of resources are items, i.e. those resources that are targeted by primary tasks and are subject of fabrication, assembly or logistical operations.

The processes are run according to tasks, which encompass plans, orders, rates et al. Tasks and their attributes, are subject to mereological, mereotopological and spatiotemporal relations, i.e. like resources. Tasks may follow calendars. Manufacturing orders are composed from operations, and these of tasks. The structure of operations is described in terms of routings or precedence relations. Operations invoke particular resources, which can be described as hypothetical resources (e.g. by collection of properties) or as configured objects.

Logistical and material handling processes may be pre-defined. Normally they are defined in a run-time mode, i.e. they are derived from ontologies by queries, using taxonomically supported classes of elements of logistical processes. In the manufacturing context the destinations are limited by process structures and by eligible paths. These can be derived from the ontology of spatial layout, which describes resources and locations and the eligible flows.

Manage and control activities are run by agents, including human agents and intelligent software agents, and among them: decision making agents and facilitating agents. A human agent would be normally equipped with human-machine interface or smart device. An intelligent software agent should have an encapsulated ontology within it.

The controls, if not performed by humans, are represented inside software agents, i.e. in algorithmic or ontological form, i.e. in terms of axioms, function terms, rules and restrictions, together with ontology queries. The control architecture within ontology reflects all planning, loading, input-output control, scheduling, dispatching, batching and commanding activities. It particularly encompasses all decision making know-how, like rules (e.g. priority rules), control principles (e.g. Conwip, 3C replenishment, kanban), procedures etc.

To illustrate the content of core ontology, a simple example is given below that includes a complexity element within. A particular Product, defined by the ProductCode (attribute of the Product class), is characterized by a particular Routing, that specifies the order and the type of operations that must be performed on the materials to get a finished product. Routing class is composed from Operations (with two basic relations: HasPrecedingOperation and HasNextOperation). The Operation class is then related to itself with a HasNextOperation relationship that allows to know, which is the next operation for a particular product, when queried. Each operation is composed from tasks; in fact it is related to the Task class with the two relationships, HasFirstTask and HasTask. In the same way as Operation class, also Task is related to itself with a HasNextTask relationship, for the same reason as above. To pass from one task to another it may be required to satisfy a specific condition (for this the Condition class is placed between Task and Operation). For each Task of a specific product, additional information should be provided. It is temporarily inserted into the Configuration class that should contain, as values of the attributes, useful information to perform the task: Instructions; Equipment: auxiliary equipment required, such as jigs, fixtures, tools; OperatorSkills required; Input materials; Output material; Control Program etc.

5. Application cases

The core ontology for manufacturing and logistics may provide significant advantages when appropriately merged with novel ICT and AT technologies. This thesis is illustrated and justified by the following four examples.

1. *Overcoming layout rooted limitations*: The job shop layout is normally used for low-repetitive manufacturing, when material flows are typically non-linear. Complexity of internal and external flows is high, hence it is hard to be managed. Internal flows are managed locally. Followingly, low performance occurs, in terms of long lead times and high work in progress. The loading, dispatching and other control activities could be easily managed by an external common agent. An opportunity for better coordination, hence improved performance, would be provided.
2. *Breaking organizational boundaries*: A planning agent at manufacturing site would have a possibility to track the inventories in the distribution center. A daily consumption would establish a new order, following the assumptions of the 3C system [28]. The daily order would be directly transmitted to the planning agent. This way a vendor managed deliveries could be handled. That kind of policy could be in many cases more efficient than vendor managed inventory or other policies.
3. *Self-organization and management*: Manufacturing orders would be parallelized by intelligent agents who would solely manage their execution. The agents would apply for resources in a run-time mode, following completion of consecutive operations. Similarly resources would be equipped with managing agents. A relevant control mechanism would be used by these agents, e.g. auctioning mechanism or prioritizing mechanism. Hence a competition for resources could be resolved this way. The above means that resources and tasks would manage themselves.
4. *Web-based management and control*: (a) Movable resources and tasks within external logistics domain would be tracked and monitored by a cloud coordination service. For example tracks could be re-directed according to current information on pick-ups and pick-offs required, or alternatively according to current traffic information. (b) The resources would report on some process parameters to the cloud, equipped with large analytical capacity. Using the data mining an early warning service would be provided. This way various break downs or other unlikely effects, like blockings or starvations of resources and processes would be avoided.

The above examples briefly illustrate how ontology based management can enable various novelties in the manufacturing and logistics operations. Non-hierarchical, self-organizational and cross-organizational solutions can be easily implemented and merged with various Web-services. The novel organizational structures and management processes can provide significant performance advantages.

6. Conclusions

The presented core ontology for manufacturing and logistics addresses all important gaps, which were identified by the literature review and the empirical research. Unfortunately this aspect of the ontology could not be fully discussed herein. The proposal goes beyond the existing ones in some important aspects, namely: (1) all common interdependencies and discrepancies are addressed, as well as other complexities; (2) transformational perspectives on resources and tasks are considered, including the spatiotemporal and mereotopological perspectives; (3) heterarchical structures of resources, tasks, decision making and controls are taken into account; (4) ontological (knowledge) and control resources, including the control know-how are incorporated; (5) various dynamic fits between resources, tasks, operations, loads are considered, including functional, structural, location (spatial) and sequential fits; (6) novel structures of systems and processes can be supported. The ontology enables handling of re-configurability of manufacturing and logistical systems, namely by updates of some of ontological components. Actually, as the dynamic reconfigurations of movable resources and tasks are serviced by the ontology, the reconfiguration capacity is immanent to its use.

Apart of the shortcomings of its presentation, the ontology requires further refinements and extensions, particularly in reference to the functionality of commanding operations and some other details. Validations and estimations (in terms of its performance) should be also made, to fully proof its viability and soundness.

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Omówienie

Ontologie zyskują duże znaczenie jako narzędzia integracji semantycznej w zarządzaniu produkcją i logistyką w sektorach intensywnie wykorzystujących technologie informatyczne i komunikacyjne (ICT) oraz automatyzację. W artykule przedstawiono holistyczną ontologię rdzeniową dla operacyjnego poziomu produkcji i logistyki, ograniczając się do prezentacji wybranych elementów, głównie taksonomii. Obejmuje ona: zasoby produkcyjne i logistyczne (w ujęciach przestrzennym i funkcjonalnych), zadania, produkty, procesy podstawowe, pomocnicze i sterowania, opisane w ujęciach dynamicznym i statycznym (charakteryzacja i mereologia). Ontologia obejmuje aspekt złożoności – ujmuje różne typy apriorycznych i aposteriorycznych korelacji i sprzeczności (m.in. synchronizacje, kolizje, wykluczenia), co jest istotne dla jej pełnego wykorzystania do automatyzacji zarządzania.