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Modelling internal logistics systems through ontologies

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ABSTRACT

Industry is facing an era characterised by unpredictable market changes and by a turbulent competitive environment. The key to compete in such a context is to achieve high degrees of responsiveness by means of high flexibility and rapid reconfiguration capabilities. The deployment of modular solutions seems to be part of the answer to face these challenges. Semantic modelling and ontologies may represent the needed knowledge representation to support flexibility and modularity of production systems, when designing a new system or when reconfiguring an existing one. Although numerous ontologies for production systems have been developed in the past years, they mainly focus on discrete manufacturing, while logistics aspects, such as those related to internal logistics and warehousing, have not received the same attention. The paper aims at offering a representation of logistics aspects, reflecting what has become a de-facto standard terminology in industry and among researchers in the field. Such representation is to be used as an extension to the already-existing production systems ontologies that are more focused on manufacturing processes. The paper presents the structure of the hierarchical relations within the examined internal logistics elements, namely Storage and Transporters, structuring them in a series of classes and sub-classes, suggesting also the relationships and the attributes to be considered to complete the modelling. Finally, the paper proposes an industrial example with a miniload system to show how such a modelling of internal logistics elements could be instanced in the real world.

1. Introduction

Recently companies are facing frequent and unpredictable market changes driven by global competition. A key challenge in such a turbulent environment is for companies to be responsive, i.e. companies must be able to react to all kind of changes rapidly and cost-effectively if they want to remain competitive [1]. In order to achieve responsiveness, manufacturing companies are using novel technologies and redesigning their existing production systems to meet the new requirements: in particular, the rapid configuration of new systems and rapid re-configuration of the existing ones are among the most promising challenges to reach a high level of responsiveness [1].

The rapid (re)configuration of production systems has been studied since many years and great advancements have been achieved in terms of enabling technologies and approaches, that offered a high level of automation and flexibility. A keystone approach for flexibility and rapid (re)configuration is surely the modularity of the production system itself [2], that perceives the system as a composition of single modules. These are recognised as elements that have a specific function and could be controlled autonomously. The modules offer a high level of flexibility, at physical and mechatronic levels with standard interfaces, however the control does not present an equal level of modularity: it is still thought as a whole software system that manages the entire system in all its parts. Different studies [3–5] have suggested that ontologies could represent the needed knowledge base to support flexibility and modularity of production systems, when designing a new system or when reconfiguring an existing one (e.g. to easily update the control software system to be compliant with the specific production system [6], or to share a vocabulary among developers and designers).

The production field, and in particular reference logistics-related aspects, have been studied since many years, so that literature and applications have matured to a great extent offering de-facto standards in the industrial solutions with practical alignment in terms and concepts among academics and practitioners. In fact, numerous research works have proposed taxonomies, classifications and definitions in the field of logistics (e.g. [7–11]). However, their main aim was to classify the available

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solutions (e.g. for material handling, storage, and picking) rather than to address modularity and (re)configurability issues.

The contribution that this paper would like to offer is an ontology of the internal logistics (i.e. warehousing) elements, to be used as semantic support to the modularity of production systems. The objective of the paper is to model internal logistics systems in an ontology that could be used as knowledge base for different applications towards system modularity (to name one, the semantics at the basis of a control systems that flexibly builds on the aggregation of single modules). To this purpose, the authors propose both a taxonomy of the internal logistics elements and a way to model them into an ontology.

To sum up, the drivers that push this research work are:

- The need for a shared and structured definition and modelling of the internal logistics terminology, that reflects the concepts and taxonomies already existing in the scientific community and in the industry;
- The need to build a model to support logistics systems modularity, that is going to increase even more according to the mentioned technological trends;
- The need to develop a model for the internal logics of the logistics system structure that is machine processable and that allows the integration of knowledge within automated systems.

The remainder of the paper will present a literature review and background in Section 2; the research objectives will be explicated in Section 3; the research method is described in Section 4; Section 5 and its subsections present the proposed model; Section 6 is an application example of how to use the ontological model to describe an industrial system. Conclusions are reported in Section 7.

Table 1
Research on ontologies for logistics: examples.

Ontology subject	Reference	Paper	Year	Use of ontology	Main focus		Perspective	
					Supply Chain	Internal Logistics/ Warehousing	Process	Physical resources
Logistics only as minor aspect	[49]	Lemaignan et al.	2006	Distributed manufacturing control (and automated cost estimation)		X	X	x, poorly described
	[2]	Alsafi and Vyatkin	2010	Distributed manufacturing control		X	X	
	[39]	Kiritsis	2011	Product data technology for Product Lifecycle Management (PLM)	X		X	
	[50]	Nadoveza and Kiritsis	2014	Information and data management	X	X	X	
Logistics as main body of the ontology	[56]	Matheus et al.	2005 (1)	Situational awareness (i.e. ontology to represent the relevant rules and relationships to be monitored)	X		X	x, poorly described
	[57]	Matheus et al.	2005 (2)	Situational awareness (i.e. ontology to represent the relevant rules and relationships to be monitored)	X		X	
	[58]	Fayez et al.	2005	Support to supply chain simulation	X		X	x, poorly described
	[59]	Himoff et al.	2006	Information support to logistics scheduler	X		X	X
	[60]	Lian et al.	2007	Information support to event notification system		X	X	
	[61]	Chandra and Tumanyan	2007	Decision support for scheduling in multi-state steel manufacturing processes	X		X	
	[62]	Gonnet et al.	2007	Sharing a precise meaning of the information exchanged during communication among the many stakeholders involved in the Supply Chain	X		X	x, poorly described
	[48]	Leukel and Kirn	2008	Automated data integration along the supply chain	X		X	
	[63]	Ha et al.	2008	Support to Decision Support Systems (DSS)		X	X	
	[64]	Gimenez et al.	2008	Inter-enterprise integration of logistics information flows	X			
	[65]	Ye et al.	2008	Semantic integration among heterogeneous supply chain information systems	X		X	
	[66]	Park et al.	2008	Inter-enterprise integration of logistics information flows	X		X	
	[67]	Tsou	2008	Knowledge sharing and communication	X			X
	[68]	Nie et al.	2009	Mapping of different logistics ontologies for e-commerce	X		n.a.	n.a.
	[3]	Hoxha et al.	2010	Decentralised control and planning of logistics systems	X		X	x, poorly described
	[69]	Zhang and Tian	2010	Logistics information continuity in information platforms	X		X	
	[70]	Bonfatti et al.	2010	Automated logistics document integration among legacy systems	X		X	
	[54]	Grubic and Fan	2010	Inter-enterprise integration of logistics information flows	X		n.a.	n.a.
	[71]	Chi	2010	Tracing of suppliers and inbound freight	X			
	[72]	Grubic et al.	2011	Modelling and quantitative analysis of supply chain processes	X		X	
	[53]	Sakka et al.	2011	Transforming Supply Chain Operations Reference (SCOR) model	X		X	
	[4]	Scheuermann and Hoxha	2012	Support to flexible IT architectures	X		X	x, poorly described
	[73]	Lu et al.	2013	Integrating product information within the entire supply chain	X		X	
	[52]	Yang et al.	2013	Support to Decision Support Systems (DSS)	X		X	
	[23]	Scheuermann and Leukel	2014	Diverse range of applications: support to supply chain modelling, planning, scheduling, simulation, and information integration along the supply chain	X		n.a.	n.a.
	[51]	Gonzalez-Rodriguez et al.	2015	Inter-enterprise integration of logistics information flows	X		X	