An Organizational Knowledge Ontology for Automotive Supply Chains

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Abstract. The currently completed ILIPT (Intelligent Logistics for Innovative Product Technologies) project was concerned with the concept of the "5 day car" (a customized car that is delivered within five days after its ordering) and encompassed extensive research on the required production and logistics network structures and processes. As car manufacturers in the automotive industry (commonly referred to as OEMs) rely heavily on their suppliers, the major challenge lies in the organization of inter-enterprise cooperation supported by information systems (IS) in an efficient manner. A common understanding of supply chain concepts is indispensable for this. Ontologies as formal representations of concepts can be used as a semantic basis for cooperation. Relevant results from ILIPT are presented followed by a concept as well as a prototype of how to transfer the theoretical findings to a practical implementation, in this case a multi-agent system.

Keywords: Ontology, Supply Chain Management, Multi-Agent System.

1 Introduction

Research concerning ontologies is in most cases embedded in the context of the semantic web. There are, however, several fields of application in the manufacturing industry. The automotive industry is a good example as it consists of a huge network of suppliers and OEMs interlinked by material and information flows. The control of the flow of goods, information, and funds within this network is investigated by the field of Supply Chain Management. The basics of ontologies and Supply Chain Management will be given here along with the motivation of why to bring these two topics together.

The rest of the paper is organized as follows. Section 2 summarizes previous approaches. Section 3 describes the relevant topics from ILIPT in detail. Section 4 lists the requirements that stem from automotive supply networks and how

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ILIPT results can be transferred for a solution. Section 5 gives the results, i.e. the different models that were developed. Section 6 decribes the application in a multi-agent system. Section 7 concludes the paper with an outlook on further research.

1.1 Ontologies

An ontology in general is defined as the "formal, explicit specification of a shared conceptualization" [1]. It is constructed for certain domains and captures the knowledge held therein. Ontologies can be designed as solutions to specific challenges. In the supply network domain, a distinction into organizational ontologies and problem ontologies[1] is reasonable. The former describes organizational knowledge, defined as "the capability members of an organization have developed to draw distinctions in the process of carrying out their work, in particular concrete contexts, by enacting sets of generalizations whose application depends on historically evolved collective understandings" [4], or simply, the knowledge that "helps to understand the domain requirements" [5]. This knowledge contains structures like products and processes and enables organizations to make use of their resources. As opposed to that, problem solving knowledge formalizes the meaning of problems and sets it into relation to the concepts provided in the organizational ontology. A problem solving ontology is the basis for communication and collaborative problem solving. This paper will focus on the organizational aspect as the problem ontology has to be built on top of it and will be subject to further research.

1.2 Supply Chain Management

Supply Chain Management (SCM) denotes a field of research which is concerned with the development of tools and methods for the collaboration within the supply network. More precisely: SCM is the integrated, process oriented design, planning, and control of the flow of material, information, and cash along the whole value chain, ranging from the consumer to the raw material producer, aiming at enhanced customer orientation, synchronization of production and demand, flexible and demand oriented production, and the reduction of inventories along the supply chain [6].

1.3 Motivation

Each enterprise within a supply network holds its own concepts and data models. This is fine as long as collaboration consists of placing orders and receiving goods only. As soon as collaboration becomes closer, the lack of a common understanding hinders efficient inter-enterprise processes. Ontologies can help at that point since they force every participant to formalize their knowledge. Once

[1] The terms "domain ontology" and "application ontology" or "task ontology" can also be found in literature (cf. [2] [3]).

this is done, IS can be built that make use of them. In contrast to that, there is criticism that "literature falls short in defining supply chain knowledge and information, their characteristics and their interdependence" [7]. The reasons why we chose ontologies instead of relational database schemes is that we believe the rich semantics will foster cooperative development and that most concepts can be modeled easier and more straightforward. The aim of this paper is to present an ontology that describes the field of automotive supply chains in sufficient detail so that an IS is able to make use of it. The future goal is to support the design of cooperating IS that will facilitate business processes between companies in order to provide improved production and logistics plans avoiding capacity shortages.

2 Ontologies in Supply Chain Management

Little research exists on this topic. Chandra [5] [8] [9] [10] has frequently published in this field. One of his papers [8] presents a framework for the development of a taxonomy along with an example for a production system. It is constructed by concretizing a general structure and enriching it with more specific information. No hints are given on if and how reoccurring structures such as the bill of material (BOM) are represented. In the follow-up paper [5], the distinction between problem knowledge and organizational knowledge is introduced. The resulting ontology is presented as an extension of the taxonomy. The latest work points out the integration with IS, especially multi-agent systems, where agents can be used to interact with other agents based on their knowledge to plan and execute a supply chain. A proof of concept has yet to be delivered. Ye et al. [11] claim that interoperability on the semantic level is the key for successful business process integration. They construct an ontology that consists of different parties that play a certain role within a supply chain. Parties can perform activities which require resources. Moreover, each party has objectives and realizes an individual performance. Processes are not explicitly contained but can be described as complex activities. Blomqvist et al. [12] developed an ontology aimed at small and medium sized enterprises. Their approach is deductive, i.e. they split up a supply chain into its constituent parts. The paper focuses on the task of supply chain configuration. Problem solving ontologies are mentioned but not further examined. The authors bring up the problem that domain specific ontologies are not only implementations of a general ontology, but that they often contain data in much more detail so that mapping is not sufficient and a refinement has to be made. Mollaghasemi et al. [7] [13] state that until 2004 "there has not been a lot of use of ontologies in supply chain management research or in enterprise engineering research in a broader sense". They describe an ontology based on the Supply Chain Operations Reference Model (SCOR). The result is a process centric ontology that does not capture facilities, BOMs, or other entities and their attributes. Umeda and Lee [14] analyze what processes and data are necessary in order to conduct cooperative planning processes in a supply chain, thereby taking the first step towards a problem ontology. Fox et al. [15] [16] have developed the TOVE ontology which is limited to a single enterprise and has been discontinued since 2001. All authors acknowledge the fact that members of a supply chain must agree on a common vocabulary in order to work together efficiently. The way to formalize this vocabulary has so far been a top-down approach where first a generic supply chain ontology is devised which in turn serves as a basis for domain specific specialization. This paper will present a bottom-up approach where a supply chain ontology is developed based on specific domain knowledge. A potential loss of generality is accepted in exchange for a hands-on ontology.

3 ILIPT

ILIPT (Intelligent Logistics for Innovative Product Technologies) [17] is a project sponsored by the European Union. Its objective is to find methods, structures, and technologies that make it possible to produce a customized car within a few days after being ordered. Besides research institutions also OEMs, suppliers, and logistics service providers are part of the consortium.

The ILIPT project is working on the requirements to move the European automotive industry from the "stock push" and "mass production" thinking of the last century to a stockless "build-to-order" (BTO) production strategy. It therefore aims at an order-specific final assembly and component production in the network as far as this is feasible regarding drastically reduced delivery target dates and cost effectiveness in respect to the aspired massive reduction of inventory in expensive cars and components. ILIPT investigates all relevant influencing factors enabling built-to-order production and logistics processes in the network. For this reason, ILIPT is working in the three major thematic areas of product structures, planning and execution processes in the production network together with the supporting IT systems and the methods for modeling and evaluating supply and distribution networks.

The target of a short order-to-delivery time under the requirement of a customer specific production requires highly capable processes for controlling the supply and distribution network. In the design of these processes, ILIPT follows the idea of planning and executing the network operations on the basis of final customer orders. The planning processes of ILIPT focus onto the improvement of the flexibility and the ability to respond to the supply and distribution network. Guiding principle is the decentralization of the planning processes on a collaboration basis, leaving the planning autonomy with the respective company, an indispensable requirement in the highly interwoven supply structures in the automotive industry. Network partners are only loosely coupled through the exchange of demand and capacity information. Decisions are made through iterative negotiation-based co-ordination of the different network partners within the boundaries of strategic general agreements. The execution processes of ILIPT include the order management, the order sequencing, and the control of the material flow. The latter processes take care for the monitoring of the material supply through build-to-stock suppliers and the handling of breakdowns and exceptions. Within the order management, the feasibility of delivering the requested car in a few days is already checked at the moment the order is entered in a configurator or ordering system. To allow this, the capacity situation of the whole network is continuously monitored. The realization of the described planning and execution processing is only possible with the development of supporting IT systems. To enable the communication among the network partners for the planning and execution processes, a so called Virtual-Order-Bank (VOB) has been developed in the ILIPT project. The VOB is an integrated order management and scheduling system which connects customers, dealers, OEM, suppliers and logistics service providers across the whole network. Basic idea of the VOB is the direct connection of customer demands and the capacity offers in production and logistics of the network companies, thus allowing the real-time synchronization of the network. Therefore, all incoming customer orders are balanced with the available capacities of the final assembly of the OEM, the suppliers, and logistics service providers in the built-to-order part of the network. The VOB manages and updates the capacity agreements and restrictions of all relevant companies. The amount of allocated capacities by accepted orders in relation to the agreed capacities is thus transparent for every built-to-order producer. On this basis, it can be checked directly with the entry of an order in how far it is satisfiable and the orders are booked to the necessary capacities at each plant and assembly period. If the requested delivery date is not feasible, the VOB determines an alternative date, communicating it to the customer, or informs the customer about the selected vehicle options delaying the delivery. In periods of under-utilization, the VOB determines in how far long-term or fleet orders can be postponed or brought forward to achieve the desired level of utilization in the considered time period. The special characteristic of the planning support given by the VOB is the fast and straightforward connection of the local planning systems used in the network in order to balance demand and capacity across several tiers in the network. The development of interoperability concepts and standards for the seamless information flow between the VOB and among the heterogeneous information systems is also a field of activity in the ILIPT project and is described in the following.

The requirements implied by the methodologies of new collaborative interaction in supply networks are not fulfilled by current information systems and the underlying infrastructure of the automotive industry. Heterogeneity of IS employed by enterprises arises on a large scale - computer environments, hardware and software platforms, programming languages, middleware systems, communication mechanisms and protocols, data formats, etc. For instance, supply chain partners currently depend on software applications exchanging information mostly on basis of proprietary data schemes and interfaces using non-standard transportation and application protocols. This hampers cross-company system integration in the context of ILIPT. Consequently, a common understanding of information exchanged between the partners of an automotive network is a mandatory constituent of collaborative planning and execution processes. Current practice for reaching this understanding is the application of business standards such as Odette or OAGIS (Open Applications Group Integration Specification) [18] which standardize messages - e.g. delivery forecasts or purchase orders - that are exchanged between the network partners. This approach has a major drawback: the semantics of the messages are described in an informal manner and leave room for interpretation. The consequence is that the meaning of a message or a message element is only informally described and not attached to the message itself. As a result, the establishment of an automated information exchange between a customer and supplier is both time consuming and error prone.

4 Design Methodology and Requirements

As was mentioned earlier, this work follows a new and unique approach which is different to previous efforts which tried to devise generic models and customize them for a certain application area in the field of supply chain management. Here, the purpose is known beforehand and the domain has been studied in detail in the ILIPT research project. From that, concepts and relations were already documented and had to be codified. Protégé [19] was used to model the ontology in OWL. Among the requirements for the formal model was the ability to describe different planning entities with different calendars, to have different levels of product descriptions, to make a distinction between built-to-stock and built-to-order suppliers, to reflect capacity information, and to integrate capacity adjustment measures. Although the application domain has been confined to automotive supply chains, scenarios can still differ widely. Certain building blocks might not be required in some scenarios whereas specialized data structures might miss in others, i.e. modularity is very important. Altogether the field of application is well known and the ontologies represent the insights drawn from the ILIPT project which supposedly make them useable in any kind of automotive supply chain project. Last, one important design step is to integrate extensions made in projects to the standard model in order to profit from new insights and to prevent forking.

5 Results

Based on the findings from ILIPT, five different models have been designed from which a planning entity can be built: sourcing model, resource model, adjustment measure model, demand constraint model, and time model. According to the bottom-up approach, these models are the least common denominator for the examined network. Specific implementations might need more structures and relations which can be added to this framework. The function of the models will be explained in the following. The ontology is available upon request from the authors. Only a brief summary of the models can be provided here.

5.1 Sourcing Model

The Sourcing Model (cf. figure 1) gives information about the products sold to customers and the parts procured from suppliers as well as the bilateral contracts

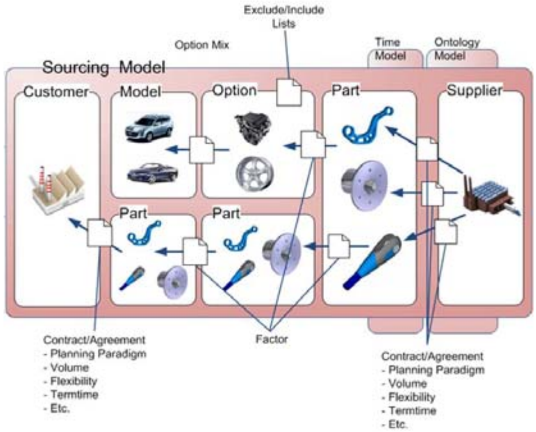

Fig. 1. Sourcing Model

made with each partner in the supply chain. Contracts encompass information on volumes and accepted deviations, term time, agreements on flexibility, and more. In order to create a connection from the customer to the supplier, products have to be split up in their constituent parts. The Bill of Materials (BOM) link contains factors for their calculation. There are two different ways to model BOM relations. First, there is the technical view, i.e. the afore mentioned conventional hierarchical decomposition. In addition to that, the definition of options is possible. Options combine several parts that in combination form a specific feature of the car, e.g. a sunroof. This can be used to express that some options cannot be combined with other options or that options require other options to be included.

5.2 Resource Model

The Resource Model contains all manufacturing resources that are relevant for planning (machines, workers, etc.) including their capacities. Regarding flexibility, this model also describes uncertainty concerning availability.

5.3 Adjustment Measure Model

The Adjustment Measure Model provides the necessary structures to represent network adaptivity. Network adaptivity also refers to local manufacturing and reflects in the division of measures into resource measures and network measures. They are identical except that the resource measures reference local resources whereas the network measures reference supply relationships. The rest are common attributes that describe measures by lead-time, effect, costs, availability, external approval, and pursued goal. The latter establishes a relationship to the overall goal model as it allows choosing that measure which supports the currently pursued goal best. The goal model is beyond the scope of this paper. Roughly, it is a decision support model for choosing alternative plans.

5.4 Demand Constraint Model

The Demand Constraint Model is the implementation of the entity's capacity and demand planning and realizes a central ILIPT requirement, viz. the direct connection of demand and capacity to allow real time capable-to-promise processes. It consists of three layers. Incoming demand is mapped to the Incoming Demand Layer where it is aggregated with existing demands. The Constraint Layer brings together demand and capacity. The Outgoing Demand Layer contains the demand that is forwarded to the suppliers. The model for coordination entities is set up a little different. It includes the Network Constraint Model and the Supply Demand Model. The former is like a Sourcing Model for the entire network and contains all supply relations between entities. No internal planning data is stored in this model. The latter is constructed in analogy to the Demand Constraint Model and maps the development of supply and demand on the network level.

5.5 Time Model

Companies employ calendars for their internal planning which are usually different from the Gregorian Calendar. Those calendars normally just number the workdays in ascending order starting at some arbitrary point in time. The Time Model provides structures for different calendars in order to create a common understanding of dates between customers and companies. It also introduces different planning horizons.

6 Application in a Multi-agent System

The models outlined in the previous section have been modeled as OWL ontologies using the editor Protégé. To make them available to the agents, source code had to be generated from the ontologies. Protégé makes use of the Eclipse Modeling Framework (EMF) for this. During code generation, each concept found in the ontology was translated to a corresponding Java interface. Each of the interfaces must now be implemented by a Java class. This means implementing the according interface and adding get and set methods as well as constructors. However, the semantic richness of ontologies cannot fully be translated to classes. This loss can be compensated by using a framework such as Jena to retain this knowledge for semantic checks. The resulting classes were then included in the agents which are constructed according to the BDI architecture.

Accordingly, the system is based on the Jadex platform. Each agent uses the models presented in this paper to manage its beliefs. Actual data comes from a MySQL database which currently serves as an ERP system simulation. Plans were programmed to give the agent control over its production planning. For the time being, no goals in the BDI sense were defined.

A proof of concept was designed which makes use of the models. The scenario encompasses an OEM producing cars and procuring parts from two suppliers.

Inter-enterprise planning is monitored by an instance called VOB according to ILIPT terminology. The planning process works as follows. First, the OEM receives an order and starts a requirement analysis. After performing a BOM explosion based on the data stored in the Sourcing Model, information on demands for each supplier is sent to the VOB. The VOB saves and forwards this information to the suppliers. Triggered by the incoming messages, the suppliers start capacity planning runs and check if the available workforce and machine time (and potentially other resources) are sufficient to comply with the request. This information can be accessed in the Resource Model. An answer is sent to the VOB which combines this with the OEM's demand in the Demand Constraint Model and sends an alert if a shortage is detected. In that case, the Adjustment Measure Model provides information on how the supplier's capacity can be increased at short notice. The Time Model is used to ensure consistency of dates.

The system can execute this process which is sufficiently backed by the presented data models. Further efforts have to be made to model bigger examples from practice to give substantial evidence for completeness or to detect shortcomings.

7 Summary and Outlook

In this paper, an ontology was presented that is able to model the domain in question, i.e. organizations in automotive supply chains, on a level of detail that allows for the use by IS, e.g. a multi-agent system. It was constructed bottom-up, starting from research on the domain and subsequently generating the abstract model, whereas previous works tried to come to applicable ontologies by iteratively refining a generic model. It was shown that this is a feasible way to come to models that are capable of being a semantic foundation for IS. The next step is to enhance the underlying communication processes by defining a fitting problem solving ontology. Then, the data formulation within planning entities can be detached from the general model and a comprehensive description of supply chain organizations and processes will be available for a certain field of application. We will use the resulting framework for further research, e.g. studies in supply chain cooperation.

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