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Roland Zimmermann
University of Erlangen-Nuremberg

Oliver Hofmann
University of Erlangen-Nuremberg

Freimut Bodendorf
University of Erlangen-Nuremberg

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Roland Zimmermann
Department of Information Systems
University of Erlangen-Nuremberg
Roland.Zimmermann@wiso.uni-erlangen.de

Oliver Hofmann
Department of Information Systems
University of Erlangen-Nuremberg
Oliver.Hofman@wiso.uni-erlangen.de

Freimut Bodendorf
Department of Information Systems
University of Erlangen-Nuremberg
Freimut.Bodendorf@wiso.uni-erlangen.de

Abstract

An architecture for tracking and tracing fulfillment processes in inter-organizational supply chains is introduced. The information to be gathered is a basis for controlling activities. The architecture is generic. For illustration it is presented based on a specific supply chain scenario. In addition a multi-agent system is sketched to support the tracking and tracing process.

Keywords: Supply chain, tracking and tracing, software agents

Supply Chain Scenario

The supply chain scenario for illustrating a decentralized tracking and tracing approach is based on a typical "make-to-order" product (see figure 1). Because of specific customer requirements the product is built to order. For instance special seals have to be used for different compressor tasks and the chassis of such a compressor is build individually by specialized suppliers exactly for every order. The scenario consists of a manufacturer who produces compressors and suppliers who are responsible for delivering material, customized parts and standard parts. The chassis can either be made from steal or from aluminum as is depicted in figure 1.

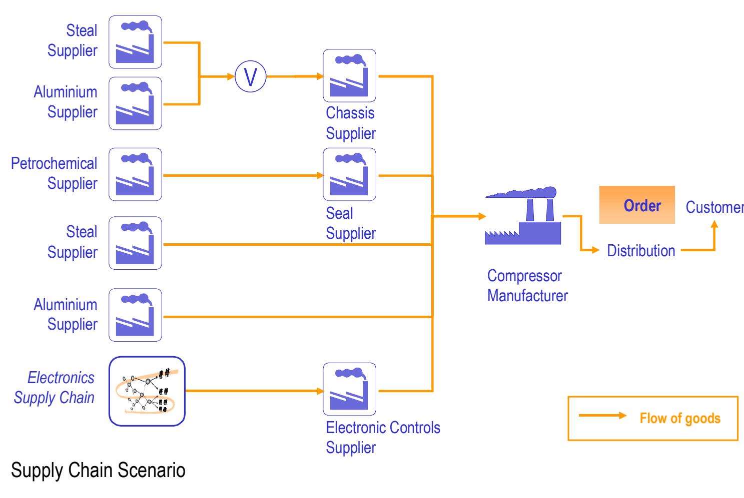

Figure 1. Supply Chain Scenario

The coordination of such a supply chain system - especially the task of planning the processes to fulfill a customer order - can be analyzed on an abstract level using findings from systems theory, especially cybernetics. Cybernetics as "the doctrine of information exchange and control, regardless of whether living creatures or machines are concerned" (Wiener 1967, pp.9) puts planning as an activity into the wider context of system control. A supply chain can be seen as a system with elements and relations among them. Planning in this context is only one process in the whole process of a cybernetic control loop – its result is a plan with detailed data (see figure 2).

The control loop needs information on the ongoing fulfillment of the plan as basis for any further controlling activities. Based on this information, discrepancies between the actually observed values and the planned figures are identified and a search for the reasons is initiated.

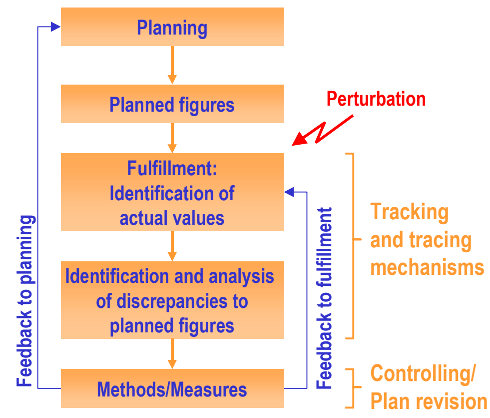

Figure 2. Control Loop

Agent-based Tracking and Tracing

A supply chain is generally formed by multiple enterprises. These enterprises are mostly legally independent and participate in several supply chains. Consequently a central planning and control system for a supply chain is impossible. To reflect this decentralized structural design an agent system is the appropriate system to implement a tracking and tracing mechanism.

The characteristics of a supply chain determine what types of agents are necessary for tracking and tracing. In a supply chain which produces a product "to order", these orders directly control the production processes. For instance in the scenario the manufacturer generates a production plan which schedules the individual orders for fulfillment. Based on such a plan orders for upstream-suppliers are generated to procure material. An architecture which generates controlling information has to reflect this order-driven structure.

Considering the order-focus of the supply chain an agent system is designed according to the existing objects of the supply chain. This approach is favored by Brueckner (2000, p.25) over a design that focuses on different functions of a supply chain.

Based on findings about "holonic manufacturing"[1] a general architecture called PROSA, which is proposed by Van Brussel et al (1998), can be used. It consists of so called "holons", which can be interpreted as agents and software agents in specific. Three types of software agents exist: resource agents, product agents and order agents.

Resource agents represent a single resource. A resource can fulfill distinctive activities on products (e.g. a machine can press metal into forms or a truck can transport a pallet). The product agent has specific knowledge about the details of all product variants. It holds information about needed components (bill-of-material) and process-knowledge (what activities to perform in which logical order using what type of resource). Order agents possess knowledge concerning a specific customer order (scheduled dates, cost, encountered problems during fulfillment). Based on the information delivered by product agents the order agents direct themselves through the network of resources. This network is established through logical links between resources. These links represent possible routes which an order has to follow to be fulfilled. Such a route is another way to look at a process. But the focus of this view is more on objects whereas activities are the operations which use resources and transform intermediate products. The route for an individual order is represented in the process-knowledge. After the resource has fulfilled the process in which the intermediate product is transformed the order is sent to the next resource (or group of resources) (see figure 3). The decision where to go next can be delegated to the order itself. [2]

For tracking an order in this system it is necessary to locate the order agent which represents the specific order. This agent has all the knowledge concerning the order's state (see above). To locate the order agent a tracking agent has to be introduced in the architecture. Its task is to optimize the search for the requested instance of an order agent (see figure 3) and to query it for information concerning the order.

Locating the order agent might not be the only task in tracking the actual state of an order. As customer orders are linked to supplier orders (e.g. material for production) such logically preceding orders can be a reason for problems during fulfillment in the downstream supply chain. Information on the state of these supplier orders is required if the causes for problems are to be analyzed.

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[1]A „Holon" is an entity which can act autonomously but which is on the other hand part of a higher-level entity. The term was created by Koestler (1967) and is derived from the greek term "holos" which means individual and the greek term "on" which means part. A holon is both an individual and a part.

[2]The PROSA reference architecture is originally designed for manufacturing control. It therefore emphasizes aspects of directing orders through the network of resources (negotiating or scheduling tasks). For tracking and tracing these features are not required. Although the system might be extended in the future into such a direction, the actual intention is limited to a system for gathering information in the supply chain while respecting existing systems for planning manufacturing and other fulfillment processes.

Generic Agent Architecture

A generic agent architecture has been designed, that enables the construction of agents for different problem domains. It will be used to implement the tracking and tracing multi-agent-system. Within this architecture, several components are identified.

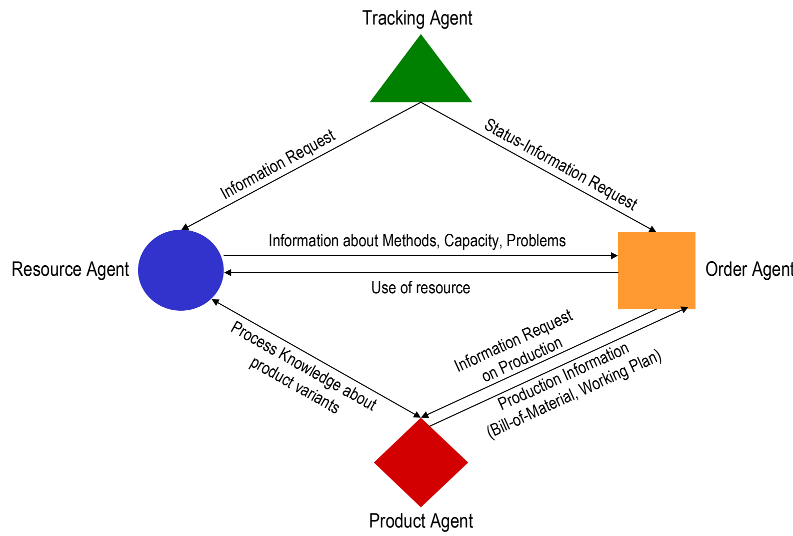

Figure 3. Basic Tracking and Tracing Architecture

Communication between software agents is typically based on an *agent platform* with additional services like ”yellow pages” etc. Communication policies are provided by underlying business process models. These models manage behavior patterns, that determine every step of an inter-agent conversation. Therefore, a *behavior component* provides a runtime environment for behavior patterns stored in a pattern pool. The instantiation of a behavior pattern is either stimulated by messages received from other agents or by the execution of a goal oriented plan. This plan is constructed by a *planning component* which combines predefined behavior patterns to a pattern sequence in order to transmute the physical environment from a starting scenario into a desired status. Both the goals of the user and an image of the relevant part of the physical environment are stored in a *knowledge base*. Consequently, a user interface for entering desires and goals is provided. In addition, changes of the physical environment are transmitted by interrupts or are cyclically polled. During the execution of a behavior pattern, it might be necessary to make certain decisions. For instance performing as an ”order agent” within the tracking and tracing scenario may lead to the question whether to pro-actively publish an identified delay in the fulfillment process. These decisions that are not part of an ex ante planning process, but have to be decided ex nunc based on an evaluation of the given alternatives (e.g. to publish or not), are made by an *evaluation component*.

Conclusion

The proposed tracking and tracing architecture shall be the basis for controlling supply chain processes. The portrayed multi-agent system is currently in the design-phase. An important aspect of future research is to take the characteristics of a supply chain with its independently managed entities and their possibly conflicting goals into account. A first step is to understand the interdependencies of the orders in such a system to reflect these in the inter-agent coordination-mechanisms. For instance an order agent representing a manufacturing order will need knowledge about a preceding order (e.g. due delivery date, process problems) of an important subpart of the product it has to manufacture.

In the next steps of the design process research will be done according to the described generic agent architecture and its main components. Therefore an ontology will be developed to enable the representation of the necessary knowledge concerning the environment of the agents. In order to facilitate the communication and coordination between the agents, the necessary agent behavior will be described in detail. Questions on planning and decision making will be addressed in a later stage of the project and an existing agent platform is to be used as the communicational basis for the multiagent system.

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