

AGENT-BASED TRACKING AND TRACING FOR CONTROLLING FULFILLMENT-PROCESSES IN SUPPLY CHAINS

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ABSTRACT

Within inter-organizational supply chains decentralized planning spheres lead to new challenges for the tracking and tracing of the fulfillment process. Nevertheless, information about progress and delays for instance in production has to be gathered to plan and to control the supply chain activities. Due to decentralized planning there is a lack of central information about structure and schedule of the fulfillment process. Therefore, a tracking and tracing system has to combine on demand data out of dispersed databases.

We present an approach based on autonomous software agents with reasoning capabilities in order to construct an efficient retrieval strategy. To ensure efficient communication and coordination between the software agents, an ontology will be developed to incorporate the needs of supply chain management but taking already available ontologies into account.

Efficient retrieval on demand in complex systems leads to the need of generating an optimized retrieval plan under the conditions of minimized costs or retrieval time. A concept for this will also be proposed in this paper.

DECENTRALIZED PLANNING IN SUPPLY CHAINS

Decentralized planning-systems are becoming more and more popular. Examples in business administration can be found in all major functional areas, e.g. production (decentralized production planning systems (Corsten 1998)), distribution (decentralized transportation planning (Gomber et al. 1997)) and procurement (e.g. continuous replenishment concepts and supplier/vendor managed inventory concepts (Distel et al. 2000)).

These developments are supported through changing organizational designs which are for instance reflected in the transformation from shop production with large batch sizes towards process-oriented segmentation of the production and smaller batch-sizes for more flexibility. Increased autonomy and responsibilities for the staff-members are the consequences of these organizational changes which in turn lead to a need for more decentralized planning procedures.

Focusing on individual enterprises as is implicitly done above falls short of the expectations which are associated with the concept of "Supply Chain Management", because it neglects the system in which an enterprise is embedded. "Supply Chains" which are at the core of this concept represent a model which can be associated with the traditional economic view of value chains (Klaus 1998) but which reaches beyond the calculation of value added. It is the active configuration and management of a supply chain which is termed "Supply Chain Management". The following figure illustrates an example of a supply chain for textiles (see figure 1).

In this example a company in Hong Kong receives an order from a customer specifying a shipment of clothes.

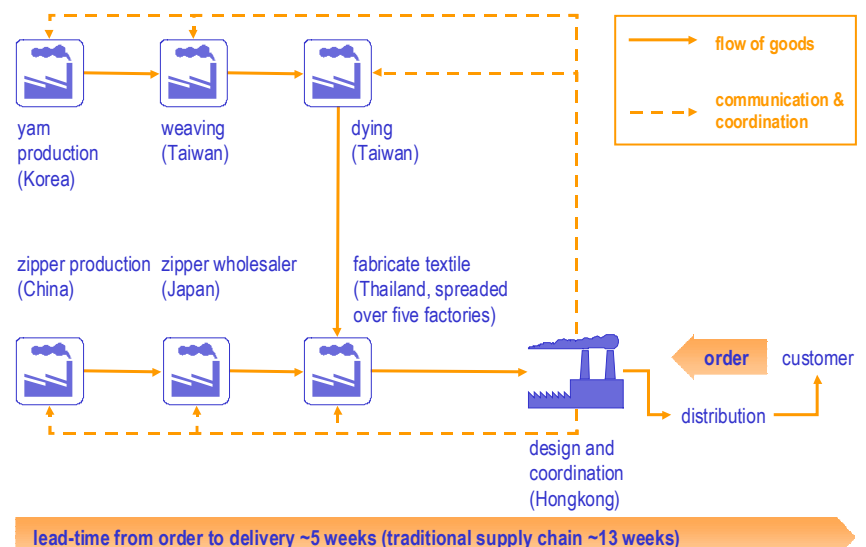


Figure 1: Example of a supply chain for textiles

This company then starts coordinating numerous suppliers at different levels of the supply chain. The coordinating company only sets global dates and guarantees in advance the capacities reserved for this special order. It is important to notice that the suppliers are all independent companies and the Hong Kong based coordinator never uses more than 30% to 70% of the capacity of individual suppliers in order to keep them independent. But still this high-level coordination enables a reduction of lead times from order to delivery for the whole supply chain from 13 to five weeks, which results in a major competitive advantage for the participants of this supply chain (Magretta 1998).

As was mentioned the suppliers are all independent companies. Therefore this supply chain, viewed as a single system, faces major planning tasks which are solved decentralized in each company individually. Only the coordination through the Hong Kong based company can be characterized as central planning but it remains on a very high level without detailed planning and scheduling of the fulfillment processes.

TRACKING AND TRACING IN SUPPLY CHAINS

The Control Loop

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. As a supply chain can be seen as a system with elements and relations between them, cybernetics seems applicable for the planning and control of supply chain activities.

Planning in this context is only one process in the whole process of a cybernetic control loop – it produces the scheduled values as the output of the planning process (see figure 2).

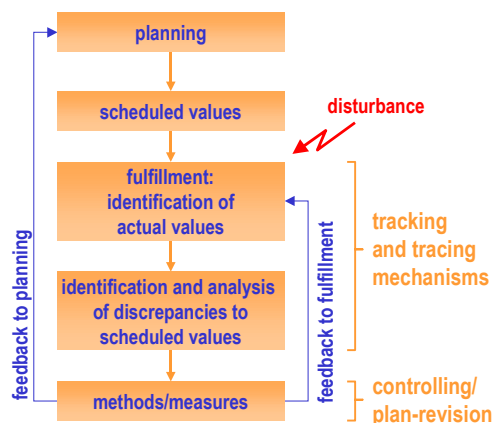


Figure 2: Control loop

A control loop as mentioned implies the necessity of gathering information during the fulfillment of the plan as the basis for any further controlling activities. Based on this information, discrepancies between the actually realized values and the scheduled values can be identified and a search for the reasons can be initiated.

These findings allow a feedback to the fulfillment process as one possible control mechanism. It is further possi-

ble to use this information for forecasting future process-steps in the fulfillment-process. This feed-forward-mechanism allows to recalculate the scheduled values in the light of the new circumstances.

Considering the above example, the necessity for information gathering and control in the control loop demands mechanisms which can achieve these requirements in the complex system of a supply chain. On the level of individual enterprises these are already evident, but thinking in inter-organizational supply chains results in a demand to control this system just as one would control an enterprise and therefore adequate information spanning the whole supply chain as specified above is necessary.

Tracking and tracing mechanisms therefore need to be developed to achieve this task for the supply chain. The already mentioned decentralized planning characteristics are an important factor in the management of a supply chain and therefore have to be taken into account to develop a supply-chain-wide tracking and tracing system for the controlling of the fulfillment processes. But some general thoughts on the costs and benefits of tracking and tracing systems in general seem helpful to underscore the importance of such systems.

Importance and Benefits of Tracking and Tracing

Tracking and tracing is up to now mostly referred to as a means of information gathering during narrowly defined logistic processes, especially in the field of transportation. Parcels, pallets or containers as well as means of transportation like trucks or ships are marked with e.g. barcodes or GPS-devices. During the transportation process these objects are identified at certain milestones, e.g. at a transshipment-point. This information which is for instance gathered with the help of barcode-scanners is typically stored in a centralized database and is used to document and control the transportation process. But they can also be used for sorting-decisions in transshipment-points and for receiving processes on the recipient's side.

Such systems are technically complex systems, which incur costs, that cannot be neglected. The question therefore is, whether the potential benefits of such a system can exceed the associated costs. Beside the already mentioned informational basis for controlling a system, other benefits have to be taken into account.

The literature on tracking and tracing systems discusses questions of costs and benefits only marginally. For this reason a study has to be cited, in which a prototype for a tracking and tracing system especially for small and medium enterprises (SME) was developed and implemented. Based on these findings the calculation of direct monetary effects showed a very fast amortization of about six months and low running costs (Stein 1998, pp.131). As larger companies like the big parcel services have already implemented their systems for quite a few years with such systems becoming standard offerings, similar calculations surely have been done and will have met the expectations (Stein 1998, p.38).

Beside these quantitative measures, there are some more possible benefits of a qualitative nature which cover more than just the small segment of transportation, so that whole supply chains can be taken into consideration.

Especially qualitative improvements through paperless no-touch processes with less process-failures are an important benefit, which may be calculated on an Activity-Based-Costing-basis (Pflaum 1999, pp.80).

Other benefits which relate especially to the marketing-function are the controlled and documented quality of the output and the ability to provide status-information even in real-time. These benefits can result in higher sales, because these services can be used as arguments for differentiation.

Last but not least the information gathered through a tracking and tracing system is useful controlling information for the management of personnel and for optimizing the organizational structure of an enterprise respective on a higher level the supply chain.

And above all, the shown concept of a control loop offers through the intelligent use of such information a vast potential for the optimization of the operative management of any supply chain.

Generic Mechanisms for Tracking and Tracing

Two generic mechanisms can be identified, which both are a way to gather information in the sense of tracking and tracing. To distinguish these types, assumptions have to be made concerning the structure of the supply chain entities.

The first mechanism is a decentral one. Each entity's knowledge is limited to its predecessors and its successors. To track for instance an order in such a system, the inquirer asks his counterpart to whom he sent the order. From this point each entity checks first if it can supply the requested information and if not it refers the information request to its predecessors. After the information is found it is forwarded until the original inquirer receives his requested information.

The second mechanism implies a central entity which has knowledge about all other entities in the system (e.g. the supply chain). The inquirer always refers to this central entity when he requests information. This central entity uses its knowledge to generate a detailed plan to gather the necessary information while considering constraints (e.g. research costs or answering-time) at the same time.

Both of these generic mechanisms have their weaknesses considering their use in a realistic supply chain. The first one which gathers information step by step can lead to a very inefficient search for information, depending on the search mechanism and the structure of the supply chain. A supply chain with many relationships between entities results in a complex searching graph, which can be searched according to a depth-first search or a breadth-first search. For instance, to identify in a wide-spread supply chain the point where the requested information is situated within the supply chain, either each production path has to be sequentially checked up to the raw material suppliers (depth-first search) or horizontally on each level of the supply chain (breadth-first search). Both mechanisms can only be efficient if the supply chain is simply structured, which in reality cannot be assumed for most supply chains.

The central model as the second generic mechanism is not appropriate to cover inter-enterprise relationships in a supply chain at all. The fact that enterprises are independently owned and controlled organizations would be contradicted by a system which would hold important internal information centrally for a whole supply chain. In fact that would mean enterprises would have to partly give up their independence which clearly seems to be a knock-out-criterion for the success of such an inter-organizational system.

Congruency of Tracking and Tracing Mechanisms with the Organizational Structures of a Supply Chain

As both of the generic models for tracking and tracing are not ideal for a supply-chain-wide system, the question is how to design a tracking-and-tracing-system that can meet the requirements and constraints of a supply chain. It was shown, that the organizational structure of a supply chain which consists of independent enterprises, is one of the major constraints for a central system. On the other hand a fully decentralized system may be inefficient in its searching performance. The solution for both problems lies in the intelligent combination of both mechanisms, thereby realizing efficiencies through partly centralized searching-spheres and allowing for flexibility of the independent enterprises through decentralized mechanisms as the connections between the centralized spheres (see figure 3).

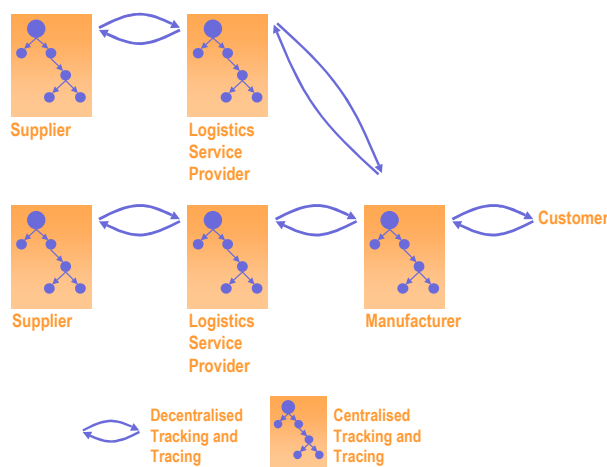


Figure 3: Congruency of Tracking and Tracing Mechanisms with the Organizational Structures of a Supply Chain

According to the organizational structure of a supply chain it seems feasible to implement central systems for tracking and tracing within the borders of individual enterprises. Between these enterprises only decentralized mechanisms can be implemented in order to preserve the necessary independence of the enterprises as was shown above. As a result a flexible system for tracking and tracing has to be designed which is congruent to the underlying organizational structure of the analyzed supply chain.

These findings correspond with the findings concerning decentralized planning in supply chains which state that

naturally each enterprise as part of a supply chain plans mainly on its own - in other words decentralized planning occurs anyway in every supply chain.

AGENT-BASED APPROACH TO TRACKING AND TRACING

Software Agents

In recent years, software agents have been increasingly applied in Electronic Business, especially in the field of Electronic Commerce (i.e., sales transactions). The term "software agent", which was formerly introduced in Distributed Artificial Intelligence (DAI), is now being transferred to information system development. Thereby, software agents become abstractions for real world actors (e.g. customers, suppliers etc.). This development enables the use of software agents in supply chain management problems, where real world actors are the entities of a system which interact heavily to provide goods or services to consumers.

In addition to conventional software systems, software agents provide mechanisms to cope with the needs of Electronic Business in supply chains:

- The semantics of agent interactions can be formally described using agent communication languages, that are based on the speech act theory. The embedded message content has to correspond to a domain ontology (see below). Companies, which have committed themselves to a common ontology, are enabled to use software agents for inter-organizational coordination.
- As opposed to business objects, software agents are set in charge to fulfil a mission. Thus, agents do not compulsorily answer any request but reflect on their goals ("Objects do it for free, agents do it for money" (Jennings 1998, p. 15)). This behavior meets the needs of encapsulation of secret data, as is requested by independent enterprises in a supply chain to control outgoing data (e.g. for tracking and tracing reasons) to other enterprises.
- Further, software agents provide reasoning capabilities that can be used to plan cooperation, for instance during production processes, but also for other purposes like gathering tracking and tracing information, analyzing this data with respect to the plans and using these findings to control the underlying fulfillment processes of a supply chain.

The evolving multi-agent-system for tracking and tracing the fulfillment processes of a supply chain will consist of agents which represent the individual enterprises of the supply chain(see figure 3). In the borders of their enterprise they can search centrally for requested information using other intra-enterprise agents with detailed knowledge about fulfillment processes or traditional ERP-databases. As soon as it becomes clear that the requested information can only be found in another enterprise of the supply chain, the predecessor or the successor agent of the company is contacted. At this stage the decentralized mechanism for tracking and tracing is used.

In order to avoid repetitive development effort, a generic agent architecture has been designed, that enables the construction of agents for different problem domains.

Within this architecture, several components are identified (see figure 4).

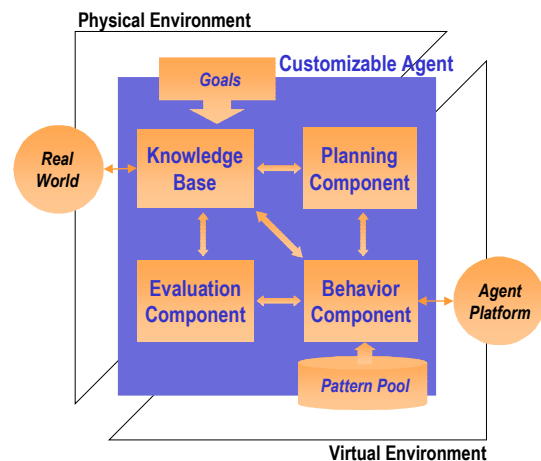


Figure 4: Agent Components

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 conduct 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 "information provider" within a tracking and tracing scenario may lead to the question whether to publish a potential delay in the fulfillment process and at which time. 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, are made by an *evaluation component*.

Ontology

Inter-organizational communication as it is necessary in a supply-chain-wide tracking and tracing system raises the question of agreements on syntax and semantics of the communicated information. Only if such agreements can be established any automated communication is made possible. As software agents are to be used for the implementation of such a tracking and tracing system, the agreements must enable them to communicate with each other, to reason about the communicated information and

plan and act upon it according to their individual goals. The agreements have to be flexible enough to satisfy these needs in order to allow the multi-agent-system to function properly.

Such an agreement is often referred to as an "ontology". An ontology explicitly specifies a topic through the use of different specific terms and the definition of existing or possible relationships between these terms. Therefore an ontology enables two or more agents (human or software) to discuss this topic while assuring that every participant has the same understanding of the communicated terms and their relationships.

For a supply-chain-wide system an ontology must cover all necessary terms related to this system which e.g. covers terms like products, resources, processes, costs, times, etc. A second precondition for the usefulness of an ontology especially in the context of software agents is the ability to formally define it and make it useful for automated processing. Both preconditions – the content and the formalization have already been addressed by scientists, so that a first guidance for future work can be found through analyzing related work.

On the content-level several ontologies in regard to enterprises are analyzed. Especially the so called "Enterprise Ontology" (Uschold et al. 1997) is a solid basis for future research. As it is very generic in its approach, an application to the larger supply chain system seems viable, although this extension over the borders of a single enterprise will add new features to the ontology. Other ontologies have not yet been evaluated but the intention is to blend the best and most common ontologies already available, to extend them where necessary for the purpose of supply chain management but to focus the extent of the ontology where possible to keep it from becoming unnecessary complex. This forthcoming ontology will be named the "Supply Chain Ontology".

For formalization two possible concepts are of scientific importance. On the one hand exists the ontology interchange language Ontolingua ((Gruber, 1993), (Farquhar et al. 1997)), which represents an extension of the Knowledge Interchange Format (KIF) (Genesereth, 1991). It offers high expressive power but no reasoning support (Horrocks et al. 2000, p.7).

On the other hand the Ontology Inference Layer (OIL) (Horrocks et al. 2000) has been developed which for the beginning only offers a simple core language but already proposes a fast reasoning mechanism (FaCT (Horrocks 1998)) Both approaches are beginning to experiment with web languages, especially XML.

Information Gathering – the basis for Tracking and Tracing

As was shown in the section concerning the control loop, information gathering is the first step to control systems following the initial planning phase. Information gathering is already an important research topic in the light of the exponential growth of distributed systems in general and the World Wide Web in particular. Findings from this topic can be useful for the task of information gathering in tracking and tracing systems.

Today several systems exist which deal with the collection of information from databases and legacy systems such as *Occam* (Kwok 1996) and *SIMS* (Arens 1996).

- *Occam* is a query planning algorithm that determines the best way to integrate data from different sources. Starting from a library of site descriptions and a user query, *Occam* automatically generates plans that encode alternative ways to gather the requested information. Because most information sources are easily accessible, *Occam's* action language does not support traditional preconditions. Since the operators are requests to information sources there is no need to model causal effects which results in a highly specialized planning algorithm. *Occam* does not model the world state - it models the information state and provides a single unified world model. When no single plan can gather all information, alternatives are generated to collect as much information as possible.
- *SIMS* provides a flexible system for processing queries to multiple information sources. In the process of transforming the domain-level query into an information-source-level query the information sources are selected. Therefore *SIMS* contains a model of its domain of expertise as well as models of all information sources. The last mentioned describe both the content of the information sources and the static mapping between these models and the domain model. In a second step the planning system called *Sage* (Knoblock 1995) generates a query plan which specifies all operations to be performed on the data. This system integrates planning and execution, handles new goals as they arrive and recovers from failures that arise, all while continuing to execute actions already in progress.

In the *SIMS* project the largest application domain is a transportation-planning-domain with information about the movement of personnel and material from one location to another using aircraft, ships or trucks. The tracking and tracing project discussed in this paper goes beyond the transportation domain. It considers the whole supply chain of which transportation is only a small sphere which connects e.g. spheres of production (e.g. manufacturers) and distribution (e.g. wholesalers). Contrary to the mentioned projects the information sources in this project will be agents, as was shown above. These agents are nodes in an agent network which is congruent to the organizational structure of the respective supply chain where each entity is dependent on its predecessors and has commitments to its successors. Each agent in this community has a specific effect on its environment. It needs some input to produce some output. For instance in figure 1 the weaving-agent needs yarn to produce cloth for the dying-agent. In other words it has some preconditions that must be fulfilled in situation *S* to produce situation *S'*. This is exactly what actions do in STRIPS-like planning domains. Under these terms the agent network can be reinterpreted as a planning graph. Consequently 'normal' planning algorithms like Graphplan (Blum and Furst 1997) can be used.

In spheres of a supply chain where centralized tracking and tracing is appropriate (e.g. a single enterprise) the responsible agent has knowledge about all the other entities in this sphere. This means that this central agent

can have knowledge about all preconditions and effects of each agent in this sphere. For information gathering he has to look which agent(s) can provide the needed information. If he finds one it is possible that the gathered information is complete. If there is a lack of information the central agent has to find out which agents have commitments to the first chosen agent. On the basis of the arising network the central agent can complete the answer for the inquired information. For instance if one wants to know if a product is already produced, the central agent looks for the producer. If this agent has not yet started with the production, the central agent has to analyze why. In order to build up the commitment network, the inquired information is taken as the initial state and the graph is expanded up to a predefined level. Hence entities can be found out which are involved to produce this network and more information can be gathered. The advantage of this basic approach is that there is no need to manage all dependencies between the agents. Only the agents' preconditions and effects have to be known, and then such a network can be produced on demand. If one agent leaves the community, the dependency network does not need to be updated, which could be very time-consuming and expensive. As a result the system is flexible, which is important for transient centralized spheres of supply chains. Another advantage is that there is no need to query all agents in the network. It is possible to step in at a very specialized node in the supply chain and then search for the information in a very restricted area.

CONCLUSION

It was shown, that the decentralized planning characteristics of any supply chain offer the basis for a combination of decentralized and centralized tracking and tracing mechanisms which generate the informational basis for a supply-chain-wide controlling of the fulfillment processes. At the same time such a system preserves the independence of every enterprise within any supply chain which guarantees easier acceptance in reality than any centralized system can be able to offer.

The software agent technology is the appropriate technique to implement such a system and guarantees flexibility to changing environments. To ensure communication a "Supply Chain Ontology" has to be developed which will be a basis for the multi-agent tracking and tracing system. Intelligent planning for finding requested information in a supply chain will be another issue beside the proactive analysis of information by the autonomous agents in the supply chain, which will activate the controlling processes whenever necessary.

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