DISTRIBUTED KNOWLEDGE MANAGEMENT IN THE TRANSPORTATION DOMAIN

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ABSTRACT

In the context of e-Business and the global economy, the role and requirements of logistics have risen dramatically. Current theories and methods of logistics as well as available information and management systems are not providing the necessary level of flexibility to meet these requirements. In consequence, new ways of designing, implementing, and managing logistics are needed.

The key challenge here is the adequate management of information and knowledge. We propose a framework consisting of intelligent agents, distributed knowledge management, and risk management for ensuring flexibility and reliability.

INTRODUCTION

Since the last decade, global economy is changing logistics in production and transportation significantly. As a result, production and transportation networks are becoming more dynamic increasing the need for agility and flexibility. The implementation of transportation logistics within these temporal networks is a key for efficient and reliable logistics. The customization of products and distribution of production is boosting the need for additional transportation capacities. The demand is growing super proportional to the expansion of transportation infrastructure, such that – from a market-economy point of view – the prices for transportation will increase within the next decades. Current approaches from operation research are not considering these flexible and dynamic requirements adequately. Consequently, new methods and systems for the coordination and optimization of transportation logistics in competitive environments are needed.

For a long time, most research on computational modelling of transportation processes has put a strong emphasis on the flow of goods, often based on simplified mathematical problem formulations (e.g., Travelling Salesman Problem, Pick-up-and-Delivery Problem), and, hence, neglected the increasing importance of knowledge as a resource in real-world transportation problems [1]. In real-world applications, shortcomings of existing planning and scheduling systems are handled rather implicitly by knowledge and experience of the human users involved in the processes.

Since the early nineties, multiagent systems and Intelligent Agents are of increasing concern within software engineering of large scale distributed systems, and, therefore, seem to be a promising approach if applied to the transportation domain. Supporting the management and integration of planning, scheduling, and controlling processes they can be used as "enterprise delegates" [2]. Various research projects on multiagent transport scheduling have been conducted during the nineties [3]. A survey on agent-based approaches to transport logistics has been conducted by Davidsson et al. [4]. On the one hand, the authors come to the conclusion that agents are an adequate means for the transportation domain and have had a significant impact to the state-of-the-art of traffic management research [4, p. 20]. On the other hand, they point out that relevant applications in the real-world and sufficient evaluation are still missing and that agent-based approaches are not addressing strategic decision making, yet [4, p. 20].

AUTONOMOUS COOPERATING LOGISTIC PROCESSES

The impact of these new requirements on transportation logistics raises the question, whether or not a revolutionary change in logistics management is needed to cope with high level of flexibility and dynamics in these temporal networks. New developments in information and communication technologies, as well as new mathematical and economical models for designing, analysing, coordinating, and managing processes contain high potential for new types of logistics. Thus, the German Science Foundation ("Deutsche Forschungsgemeinschaft") has founded a Collaborative Research Centre (CRC 637) on "Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations" (see: http://www.sfb637.uni-bremen.de/) at the University of Bremen for multidisciplinary research on new and innovative approaches to decentralized logistics. Autonomous cooperation describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems which possess the capability and possibility to render decisions independently. The objective of autonomous cooperation is the achievement of increased robustness and positive emergence of the total system due to a distributed and flexible coping with dynamics and complexity.[1] The autonomy of logistic objects such as cargo, transit equipment, and transportation systems can be implemented by novel communication technologies such as radio frequency identification (RFID) and wireless communication networks. These and others permit and require new control strategies and autonomous decentralized control systems for logistics processes (cf. [6]). In the setting, aspects like flexibility, adaptivity, reactivity to dynamically changing external influences while maintaining the global goals are of central interest. The underlying logistic models include transportation as well as manufacturing logistics.

In a standard approach to logistics, local entities are making decisions on the basis of pre-defined set of rules, short-term objectives of the enterprise, and current information about their environment. Strategic objectives of an enterprise are not considered within this kind of local decision making. The innovative approach of autonomous logistic processes involves even transferring of strategic objectives in decision making to local interacting entities. Thus, the local entities have to integrate strategic and short-term objectives. This leads to a strong need of knowledge within the local decision making process.

SCENARIO

To illustrate the need for novel approaches to knowledge management in logistics, consider a scenario in which a shipping company manages the shipping, intermediate storage, and distribution of paper rolls. The paper is produced by paper mills in North America and sold to newspapers, publishers, and manufacturers of paper products in Europe. In order to help inventory management as well as to reduce the price of paper (e.g., through high volume discounts), the shipping company combines and brokers orders from the consumers to the manufacturers.

Each order typically includes the number of desired rolls, the delivery date (including possible late penalties) and for each roll, the required dimensions and quality (weight and purity) of the paper. To fulfil an order, the shipper locates the appropriate paper rolls in his distributions centres, preferably the one(s) closest to the buyer. Alternatively, the shipper brokers an order to one or more of the paper mills if not enough rolls from the distribution centres are available. In either case, the rolls are shipped to the buyer via ship, rail, or truck or a combination thereof.

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[1] Current working definition for "Autonomous Cooperation" (Selbststeuerung) with the CRC as summarized by K. Windt and M. Hülsmann in 2005.

What makes this scenario interesting from a logistics point of view is the fact that despite their weight (e.g., a roll typically weighs between 1,000 and 2,000 lbs.), paper rolls are very sensitive to shock, temperature changes, and moisture, and thus require special handling and care during loading and transport. For example, an accidental scrape by one of the forks from a fork lift during unloading at the dock can easily tear several inches of paper on a roll. In the best case, the damage can be controlled by unrolling and discarding the torn layers. In the worst case, the contact could have caused the paper to misalign on the core of the roll. This renders the roll unusable for a high-speed printing press, which unrolls paper at speeds in excess of 200 km/h during the printing process. Other problems include water damage caused by rain, e.g., during loading/unloading, or excessive moisture in the storage rooms, e.g., as a result of a sudden temperature change. Considering the cost of a roll which ranges from €1,300 to € 2,000, delivery schedules that are specified down to the desired hour of the day, and the fact that rolls have to be handled several times on their way from the mill to the consumer makes for a very challenging transportation problem that requires careful planning and on-the-fly re-planning. For example, in case of a damaged roll, the shipper needs to decide whether to sell the roll at a reduced price, or if it is not usable by the intended recipient, re-route it to a different customer who uses less sophisticated printing presses.

In addition, many decisions are made based on incomplete knowledge, for example, whether or not a roll sustained damage during transport even though no visible marks exist[2]. Furthermore, many decisions require communication and possibly negotiations among customer, buyer and possibly the manufacturer, for example, to establish a new price for a damaged roll or a new delivery time for a shipment that cannot be unloaded due to bad weather. In the following we outline our framework for agent-based, distributed knowledge management and briefly illustrate the approach using some examples from the scenario introduced here.

DISTRIBUTED KNOWLEDGE MANAGEMENT

Our vision of the overall architecture which integrates the process level, risk management, and distributed knowledge management is depicted in Figure 1 and will be described in the following sections. Starting at the center of the triangle in Fig. 1, we state that in order to support or enable autonomous processes in logistics one must deliver the right knowledge to the right consumer at the right time (just-in-time delivery of knowledge). Thus, the performance measures of information and knowledge management are comparable to standard logistics. In heterogeneous logistic networks, interacting process participants may be competitors such that simple sharing of knowledge is not feasible. As knowledge is more and more a process relevant part, it becomes an essential resource of logistic processes. Next to the aspects of knowledge as resource or tradable good, there are further requirements as the knowledge sources are not part of a static but part of numerous ad hoc networks, such that resources are not continuously available. Thus, the paradigm shift in logistics is inducing a paradigm shift in knowledge management, which is described as "Emergent Knowledge Management" in our current research (cf. [5]).

Assuming that management and just-in-time availability of information is possible, additional research is needed to investigate whether it is possible for logistics networks consisting exclusively of autonomous agents to function reliably without centralized control. As we have stated repeatedly, an important goal of the proposed paradigm shift in logistics is to help the enterprise gain flexibility without loosing any of the reliability of traditional business practices. For example, one important aspect of reliability is whether or not participants are successful in making decisions in such a way that the strategic boundaries of the enterprise are taken into account correctly. In consequence, knowledge management is just the first step

[2] There are plans to outfit rolls with sensors that can detect certain damage during transport and store the information for later usage.

in autonomous decision-making. A comprehensive approach has to consider also reliable management of autonomous processes. Therefore, our framework includes risk management for identification of risk factors as well as multidimensional evaluation of risks for supporting autonomous and situation-aware decision-making.

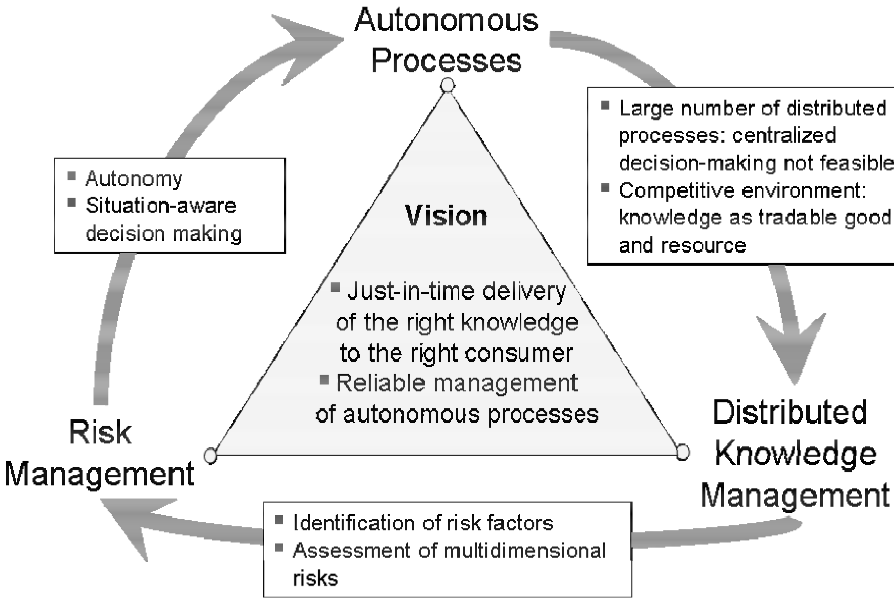

Figure 1. Framework for Risk and Knowledge Management

Our framework for distributed knowledge management consists of three main components: autonomous agents, knowledge, and roles. The aspects of the logistic scenario include paper rolls, trucks, as well as relevant service providers such as weather, traffic, or news services are represented as **autonomous agents**. Each of them is associated with specific *beliefs* and *intentions*, which may differ significantly from one agent to another.

Their beliefs, together with their reasoning capabilities, make up the **knowledge**, which they use to fulfil certain intentions. For example, agents representing vehicles typically share the basic intentions of a *logistic service provider* and have specific knowledge about the origin and destination of a shipment as well as how soon it must get there. Their intention may be to optimize freight consolidation and route planning in order to fully exploit their individual load capacity. In contrast, an agent representing a package (e.g., a paper roll) represents the intentions of a *client* and aims to minimize time spent in transit or shipping cost. In some cases, different agents might also *share* some of their intentions, e.g., in the case of the vehicle and client agents the just-in-time delivery or special handling of the paper

Classical knowledge management as applied to the management of organizations is decomposed into **roles**. A minimal knowledge management scenario involves two such roles: the *provider* who offers information and the *consumer* who requests information. For more complex scenarios we use the following knowledge management roles:

1. *Knowledge consumer role:* acquire new or missing knowledge from another agent (e.g., the loading agent on the dock acting as a knowledge consumer needs information about the paper rolls that are to be unloaded.)

2. *Knowledge provider role:* make information available, either on demand of another agent (in consumer role) or as part of pro-active behaviour (e.g., a paper roll acting as a provider may inform the loading agent about specific details of its handling en route to its destination.)
3. *Knowledge acquisition role:* interface to external data sources (e.g., an agent controlling allowing the retrieval of data from a specific moisture sensor in the cargo hull of a ship)
4. *Knowledge output role:* interface to external environment (e.g., a role representing and implementing output profiles for users, which are not part of knowledge management system)
5. *Knowledge brokerage role:* collect meta-knowledge from providers and point consumers to appropriate sources (e.g., agent providing consumers with specific weather bulletins from different weather services relevant to a geographical area of interest).
6. *Knowledge translator role:* translation between different knowledge communication languages, optionally be engaged in every communication (e.g., in the presence of different sensors measuring temperature either in degrees Celsius, Kelvin or Fahrenheit, respectively, a translating agent may provide all temperatures in degrees Kelvin for further processing)

Depending on their functionality and task in the logistics domain, agents may assume any one of the roles, listed above. For example, the same agent may be a knowledge consumer in one situation and a knowledge provider in the other. For example, an agent representing a ship may assume the role of a knowledge provider reporting weather information to other ships. At a different point in time, the same agent may also assume the role of a knowledge consumer requesting information about new cargo and its destination from the dock agent after taking on additional paper rolls in another port. In contrast to conventional knowledge management approaches, our framework does not depend on centralized knowledge repositories. Communication among the roles is carried out over the already existing agent communication infrastructure. We are tacitly assuming the existence of standard information technologies to provide the proper support such as networking, document storage, retrieval, metadata annotation, etc. In a sense, knowledge management *emerges* from the interaction of agents by virtue of implementing specific roles autonomously and in dynamic change.

As mentioned in the beginning of this section, an important aspect of our approach to knowledge management is the assessment and management of risk (cf. [7] for a more detailed discussion). Specifically, we are referring to the risk that is associated with an agent's decision making (e.g., should the docking agent in our scenario decide to unload paper rolls risking water damage from an impending rain storm or wait and pay a penalty for late delivery) as well as the risk that is associated with acquisition of knowledge as part of the knowledge management process described here (e.g., what is the risk that the weather/traffic information a knowledge consumer is acquiring from another agent acting as provider has been deliberately falsified to achieve a competitive edge).

CONCLUSION

Autonomous processes are seen as a promising approach for logistics. It can be argued that autonomy is supporting flexibility as well as reliability. In this context, the relevance of information and knowledge is increasing rapidly and they become mandatory resources in transportation logistics. In response, we are introducing an integrated approach for enabling autonomous processes in logistics. Our framework, which we have outlined in this paper, is considering knowledge management in a distributed way. Knowledge management is supported by risk management in order to aid autonomous processes, which are represented by agents, in their decision-making.

We have conducted an initial feasibility study of the concepts proposed here using a well-defined portion of our logistic scenario. Currently, we are investigating the effects of different degrees of autonomy on the flexibility and robustness of logistic processes. Other important research challenges include the development of a formal representation that is powerful enough to represent agents, roles, and the underlying knowledge, as well as an efficient implementation of agents to allow experimental validation.

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