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SITUATION-AWARE DECISION-MAKING IN AUTONOMOUS LOGISTIC PROCESSES – AN INTERDISCIPLINARY PERSPECTIVE

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ABSTRACT
This paper introduces a decision-making model for autonomous cooperating logistics processes (ALPs) in transport organizations, an emerging technology following the paradigm of self-organisation from an interdisciplinary perspective.

INTRODUCTION
The desire and possibility to have goods available nearly anywhere at any time have contributed to a tremendous increase in transport volume and in delivery frequencies. Customer expectations, the pressure of competition on turbulent global markets, and virtualisation of logistic companies results in complex, dynamic logistic systems, structures, and networks. A promising emerging approach is the use of the self-organisation paradigm for logistic processes (Scholz-Reiter, Windt & Freitag, 2004) to create autonomous logistic processes (ALPs). This approach operates as a direct challenge to central planning as it decentralises control, planning, information, and decision-making in production and transport logistics through the use of innovative information and communication technologies. The main goal of ALPs is to increase a logistic system's robustness, flexibility, and reactivity. Logistic systems are regarded as socio-technical systems with different sub-systems and levels. This paper focuses on the social and technical decision-making systems of ALPs from an interdisciplinary perspective involving insights from an emerging Sustainable Management approach in economics, on the one hand, and multiagent-systems (MAS) research (Wooldridge & Jennings, 1995), a predominant paradigm in distributed artificial intelligence, on the other. Our purpose is twofold: First, we analyse the problem of delegating decisions from a social decision-making system to an agent-based, i.e., technical, decision-making system and offer an interdisciplinary model for autonomous cooperating logistics processes. Second, we present a multiagent-system-based approach which integrates knowledge management and risk management. In the last part of our paper, we offer implications for further research.

SUSTAINABLE MANAGEMENT AS A DECISION-MAKING FRAMEWORK
The concept of sustainability becomes increasingly important for transport logistics organizations (McIntyre, 2003; Wu & Dunn, 1995). The value of a sustainability perspective for transport logistics is to control for unintended side effects, long-term feedback effects, and to ensure an organisation's long-term access to economic, natural, and social resources (Ehnert, Arndt & Müller-Christ,

in press). We understand organisations as resource-dependent socio-economic systems, which consume and supply resources. Sustainability is regarded as a rationale to deal with these resources (Müller-Christ, 2001). In the future, new technologies in ALPs will allow transport organizations to delegate decision-making competence partly from the social technical decision-making systems (e.g. managers, schedulers) to an agent-based, i.e., technical decision-making system (see figure 1). While strategic decisions remain on the social systems level of an organization operational decisions and goal achievement can be transferred to the technical-operational level. This delegation from a centralized social and technical management system to autonomous units (agents) is accompanied by various challenges on both the social and technical levels. For example, it is a difficult task to guarantee the sustainability of decisions, if there is no longer a unique central organisational unit where all the necessary information and experience is available. Therefore, we apply a newly developed Sustainable Management framework for ALPs which encompasses a management of organizational dilemmas (dilemma management), of organizational boundaries (boundary management), and a management of participation (participation management) (see Ehnert et al., in press). This framework provides the basis for the delegation of decisions from the social to the technical systems level and it is influenced by feedback effects of delegation as e.g. higher degree of goal achievement (see figure 1).

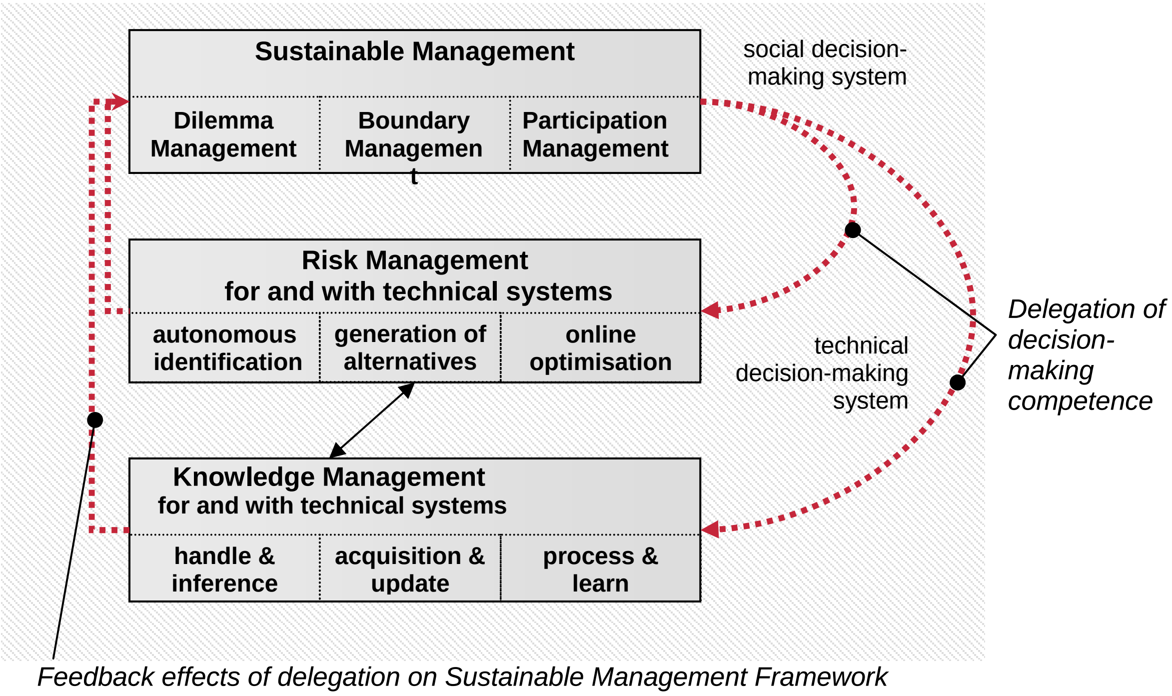

Figure 1: Interdisciplinary model of delegating decision-making for autonomous cooperating logistics processes

The objective of a Sustainable Management is to provide logistics managers with a frame to analyse and design the particular management situation in their organization, to profit from the full potential of ALPs, and to support a sustainable development of the organization. Specified solutions are not provided in this approach due to the contextual differences between organizations. A dilemma management is needed for ALPs as transport logistics organizations have to reconcile the dilemmas of 'central versus autonomous control' and of 'efficiency versus sustainability' (see Ehnert et al., in press). Dilemma situations require a choice between two equally important and contrary alternative actions (Neuberger, 2002). Reconciliation strategies for ALPs encompass temporal, spatial, and spherical separation and synthesis of dilemmas (Ehnert et al., 2006). In this paper, we suggest to mix different reconciliation strategies. For the dilemma of central versus autonomous control, we suggest to combine spatial and spherical separation because of the nature of ALPs. ALPs separate the dilemma of central versus autonomous control spatially, shifting the decision-making to different locations in and between organizations. The result is a tension between the social and technical decision-making systems. This tension can be used constructively by spherical separation, i.e. by addressing the poles of the dilemma simultaneously in the same subsystem. On the social decision-making level, the dilemma of central versus autonomous control could be addressed by an agent decision mechanism which incorporates both, the ability to act autonomously based on the proposed risk- and knowledge management framework, and to interact with a central authority whenever appropriate and possible. The level of autonomy an agent can achieve or may exercise is subject to further research (see Timm, 2006 and conclusions). For organizations striving for sustainability, ALPs offer the advantage of collecting data with the help of an agent-based knowledge and risk management and thus reducing the danger of unintended feedback loops on the transport organization. The purpose of a boundary management is to support the regulation of boundaries within and between organizations that implement ALPs. This is important, because ALPs presuppose new relationships in and between transport logistics organizations requiring them to open their boundaries. These relationships have to be long-lasting if logistics corporations want to achieve their goals efficiently and at the same time secure their long-term success and continued existence. A boundary management has to address relevant organisational decision premises (cp. Luhmann, 2002) in order to manage the process of boundary opening (Ehnert et al., in press). For example, reflecting, negotiating and implementing collective strategies (cp. Astley & Fombrun, 1983) can be an important aspect of managing boundaries between transport logistics organisations which cooperate via ALPs. As boundary openings come along with an increased vulnerability (e.g. towards competitors using shared information for their individual benefit), the linking of cooperation and strategic intent may motivate organisations to refrain from short-sighted opportunistic behaviour and provide the necessary basis for the willingness to open organisational boundaries. In further research, this dilemma and boundary management is going to be complemented by a participation management because ALPs require that all important stakeholders (e.g. employees, transport logistics partners) are actively involved in the process. Maintaining a Sustainable Management in a highly dynamic and distributed environment presupposes complex social mechanisms of coordination in order to enable a flexible and proactive knowledge management, and an elaborated risk management for identifying and assessing risks as precisely as possible in dynamic and complex environments. This objective can be achieved with the help of a multiagent-system-based approach.

KNOWLEDGE MANAGEMENT IN A MULTIAGENT-BASED APPROACH

In our framework, agents are used to represent real world logistic entities such as trucks and containers, abstract objects such as weather or traffic services, or even human decision makers, such as a ramp agent at a loading dock. Our approach to knowledge management consists of three main components: conceptual knowledge, roles, and parameters (Langer et al., 2005). The conceptual knowledge is represented as an OWL (Web Ontology Language, cf. http://www.w3.org/2004/OWL/) ontology. For the purpose of our logistic application domain, this ontology includes a representation of the transportation or production network, the basic types of agents and their properties (e.g., for a vehicle, its average and maximum speed, the types of routes in the network it can use, and its load capacity), and the properties of 'inactive' objects, such as highways, depots, etc. In contrast to previous approaches to agentbased knowledge management, we do not presuppose a one to one correspondence between agents and knowledge management functions, such as providing knowledge or brokering knowledge. In our approach these functions are implemented as roles. A knowledge management role includes certain reasoning capabilities, a visibility function on an agent's beliefs, a deliberation pattern (i.e., a plan how to accomplish the knowledge management task), and a communication behaviour with interacting roles. The aim of knowledge management roles is to provide a formal description of knowledge management tasks that eases the development of agents and reduces computational complexity by means of a minimum set of processed knowledge and applied reasoning capabilities. One agent can assume different roles and may change them over time. In (Langer et al., 2005) we introduced an extended role model of eight roles. It incorporates for instance a translator between different knowledge representation formalisms. Another important aspect of distributed knowledge management is to support social mechanisms enabling the agent to find cooperative and trustworthy partners considering organisational boundaries and confidentiality policies. A model of complex social mechanisms, adapted from sociological research (Mayntz, 2004; Hedström & Swedberg, 2002), overcomes the discrepancy between self-organisation, in the sense of simple interactions between single agents, and complex but static MAS organisations. In contrast, social mechanisms of coordination are not static and enable different organisational structures dynamically adapted to the environment. Exactly in this sense, social mechanisms allow to model self-organisation in MAS (Schillo et al., 2004). Thus, a new kind of boundary management is needed that identifies and considers the variable boundaries of organisations (companies) in the logistics domain.

RISK MANAGEMENT IN A MULTIAGENT-BASED APPROACH

Decisions are subject to changing conditions or changing goals after process initiation. The dynamics of the environment requires a number of short- and mid-term goal-oriented decisions to be taken during every process. In order to fulfil a given goal an autonomous entity will have to use the knowledge of its environment to generate a plan and if possible some alternative plans. Thus, planning is a required capability for autonomous systems. Dynamic environments, however, may endanger the success of an agent’s goals although properly planned. Therefore, the logistic objects have to consider uncertainty and possible risk to make it robust against suddenly appearing events and drifting changes in the environment. The complexity of a planning task increases with the amount of uncertainty in the environment and the amount of essential decisions. In a simple and static world the autonomous entity can formulate a complete model and thus calculate definite plans. With increasing complexity the model on which a plan can be based must be more abstract thereby introducing a source of risk namely incomplete knowledge about the development within the environment. Furthermore the dynamics of the environment interferes with the attempt to execute a plan. Thus, the autonomous entity will have to possess the capability to observe events occurring in the environment and extrapolate their impact on the logistic object into the future. The planning capability therefore depends on the accurateness of the model not only of the world and its entities but also of the processes the entity can trigger, observe or endure. A pro-active risk management system is being implemented to tackle this issue. This risk management system incorporates an autonomous identification of possible risk based on the knowledge of the domain. The initial task and most important assumption for successful risk management is its ability to identify risk and evaluate its potential consequence. Risk identification in an autonomous knowledge-based system can be achieved by matching fractions of the current or predicted model of the world with patterns. In the situation analysis phase of an agent's deliberation cycle incoming perceptions are integrated with the current beliefs. Subsequently the agent generates a list of options that are reachable given the current situation (for details and a formal specification of this process we refer to recent work by Timm (2004). Risk identification will than work on the set of beliefs relevant to one option and the option itself to search for incidents that may impact the options execution. Following the approach presented by Lattner and colleagues (2005), we define a risk pattern as a formal description of a situation where certain occurrences may be dangerous for the agent. Decision-making hereby has to consider not only the primary risk of (partially) failing the given goal of, e.g., reaching the destination intact and within a certain time frame but also needs to take into account side- and long term effects of a decision to ensure perpetuation of the system (i.e., the logistic service provider) and thus contributes to sustainability on a technical basis.

CONCLUSIONS

This paper has proposed a new model which seeks to explain the connection between social and technical systems in ALPs. The theoretical basis for this model on the social decision-making system is provided by a Sustainable Management approach. For long-term organizational success and sustainability in ALPs we argued that it is necessary to implement a management of dilemmas, boundaries and participation. Important implications for further research include exploring the dynamics and consequences of interactions between the social and technical systems levels in ALPs. In this work strategic aspects of decision making still remain on the social system's level. In a software system they represent the highest level of decision-making and are conventionally determined by the system's designer in advance or by the user at runtime. Strategic autonomy in the BDI approach of autonomous software agents is introduced in Timm (2006) and will be subject to future research.

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REFERENCES

Astley WG Fombrun C (1983) “Collective Strategy: The Social Ecology of Organizational Environments” Academy of Management Review, 8(4) 576-587.

Ehnert, I Arndt L Mueller Christ G (in press) “A Sustainable Management Framework for Dilemmas and Boundaries in Autonomous Cooperating Transport Logistics Processes” International Journal of Environment and Sustainable Development

Hedström P Swedberg R (2002) “Social mechanisms: An introductory essay” in Hedström P Swedberg R (eds) Social Mechanisms. An Analytical Approach to Social Theory, Cambridge: Cambridge University Press 1-31.

Langer H Gehrke JD Hammer J Lorenz M Timm IJ Herzog O (2005) „Emerging Knowledge Management in Distributed Environments” in Workshop on Agent-Mediated Knowledge Management (AMKM 2005) at the Fourth International Joint Conference on Autonomous Agents & MultiAgent Systems (AAMAS 2005) 14-26.

Lattner AD Timm IJ Lorenz M Herzog O (2005) “Knowledge-based risk assessment for intelligent vehicles" in Proceedings of the IEEE International Conference on Integration of Knowledge Intensive Multi-Agent Systems KIMAS '05 Waltham, Massachusetts, USA (2005) 191-196 URL http://www.tzi.de/mlo/download/1000_lattner.pdf.

Luhmann N (2002) “Organization” in T Bakken T Hernes (Eds) Autopoietic Organization Theory: Drawing on Niklas Luhmann’s Social Systems Perspective, Oslo 31-52.

Mayntz R (2004) “Mechanisms in the Analysis of Social Macro-Phenomena. Philosophy of the Social Sciences” 34, 237-259.

McIntyre K (2003) Delivering Sustainability through Supply Chain Management In D. Waters (ed) Global Logistics and Distribution Planning: Strategies for Management. Kogan Page, London 233-248.

Schillo M Fischer K Fley B Florian M Hillebrandt F Hinck D (2004) “FORM – A Sociologically Founded Framework for Designing Self-Organization of Multiagent Systems” in Lindemann G Moldt D Paolucci M Yu B (eds) Proceedings of the International Workshop on Regulated Agent-Based Social Systems: Theories and Applications, Springer.

Scholz-Reiter B Windt K Freitag M (2004) “Autonomous Logistic Processes: New Demands and First Approaches” in Monostri L (ed) Proceedings of the 37th CIRP International Seminar on Manufacturing Systems, Budapest, Hungaria 357-362.

Timm, I (2004) „Dynamisches Konfliktmanagement als Verhaltenssteuerung intelligenter Agenten“, PhD thesis, University of Bremen, Germany.

Timm, I (2006) “Strategic Management of Autonomous Software Systems” professorial dissertation (Habilitationsschrift) University of Bremen, Germany.

Wooldridge M Jennings NR (1995) “Intelligent Agents: Theory and Practice” in Knowledge Engineering Review 10(2) 115-152

Wu H-J Dunn SC “Environmentally Responsible Logistics Systems” International Journal of Physical Distribution & Logistics Management 25 (2) 20-38.