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Risk management in dynamic logistic systems by agent based autonomous objects

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Summary. Intelligent logistic objects with the ability of autonomous control are a possibility to face new challenges in dynamic logistic systems. On the other hand autonomy of logistic entities poses new questions to the underlying logistic system. In this paper we will focus on the possibilities of reducing the objective and subjective drawbacks of autonomy in logistics by an autonomous risk management for the logistic entity. A technical solution based on intelligent agent technology will be presented.

1 Introduction

Within the last years logistics has developed to a key success factor in globally distributed production because of its cross-sectional function. Enhanced product life cycles, rapid changes in company structures and information flows alter the requirements for logistic processes. With the reduction of the vertical range of manufacturing and the tendency to globally distributed production, logistics and the design of logistic processes gain significance [1]. As a result the importance of logistics grows and new concepts for planning and control of the logistic processes are needed.

On the one hand the rising complexity of inter-organizational structures and also a relative shortage of logistic infrastructure lead to increasing utilization of the existing logistic processes. On the other hand a specialization and intermodalisation of the ways of transportation and respective carriers can be observed [2]. These factors combined with changing customer market conditions have considerable effects on planning and controlling of logistic processes in such a dynamic environment.

The resulting dynamic and structural complexity of logistics networks makes it very difficult to provide all information necessary for a central planning and control instance in time during the planning phase and react on incoming information during the phase of execution. A possible approach to face these challenges is the development of autonomous logistic processes which have the ability and capabilities for decentralised coordination and decision making.

The autonomous entities are self contained and follow an individually rational goal. In the basic assumption they are individually rational decision-makers in the sense of game theory, each aiming at maximizing their individual utility function.

In the remainder we will further investigate the issue of complexity and dynamics in modern logistic systems and the possibilities that arise from introducing autonomy (Sec. 2). Section 3 will show that risk management on the level of individuals in an autonomous logistic system can answer questions of dependability and trust that could arise when making logistic entities autonomous. We will furthermore investigate the requirements for a technical system that can address those answers in sect. 4 and sketch it's implementation in sect. 5. An Outlook in sect. 6 will wrap up over results. An approach to face the challenges on existing and upcoming problems in logistics is the concept of autonomous logistic processes represented by autonomous logistic objects. Autonomy in logistic processes is defined by "Autonomous control in logistics systems is characterized by the ability of logistic objects to process information, to render and to execute decisions on their own" [3]. The autonomous control of logistic processes can be realized through decentralized control systems, which select alternatives autonomously or logic based semi-autonomously and decide within a given framework of goals.

2 Complexity and Dynamic in Logistic Systems

Complexity can be understood as interaction between complicatedness and dynamics [4]. Due to the fact that the described approaches of complexity only refer to single aspects of complexity, as for instance the structure of a considered system, they seem insufficient for an entire understanding of the term complexity in the context of logistic systems, in particular production systems [5].

Different approaches aim at explaining the complexity of systems that also apply to logistic systems. We subsume those under two main categories, the *element-* or *relation complexity* approaches like Bar-Yam [6], who names (1) elements (and their number), (2) interactions (and their strength), (3) formation/operation (and their time scales), (4) diversity/variability, (5) environment (and its demands), and (6) activity(ies) (and its[their] objective[s]) as the characterizing properties of a complex system, whereas Ottino [7] as a representant of the class that defines complexity by its property of *emergence* states: "A complex system is a system with a large number of elements, building blocks or agents, [...] that [...] display organisation without any external organizing principle being applied."

The dynamics of a logistic system is characterised by its temporal behaviour. A dynamic system is subject to permanent changes on micro and meso level however it can take a constant perceivable state on macro level. The number of possible states resulting from events influencing the system and the interaction between the embedded entities of the system is a representative factor for measuring the dynamic of the logistic system and is as important for tasks of planning and realising logistic processes as the complexity of the logistic system.

Philipp et al. [8] believe that it is essential to define different categories of complexity and to refer them to each other to obtain a comprehensive description of complexity. They divide complexity into three categories *Organisational complexity*, which resembles element- and relation complexity, *Time-related complexity*, thus redefining dynamics as a form of complexity, and *Systemic complexity*, which introduces the border between system and environment. The emergence aspect of complexity is not present in this approach.

However, the complexity of a logistic system and its dynamic as well as the overall behaviour of the system still allow no conclusion regarding the sensitivity of the system in relation to the malfunction of individual entities or their relations as well as regarding non-deliberate or malevolent disturbances from outside the system.

Following Luhmanns theory that only complexity (of the system) can reduce complexity (the system is exposed to) [9] we enable the (logistic) system to deal with increased complexity in it's environment by increasing the complexity of the system itself and managing this complexity (by means of technology) [10]. This approach is hereby advanced by the development of novel information and communication technology (ICT).

Fast and ongoing development of modern ICT, e.g., telematics, mobile data transfer, and transponder technology opens new possibilities for the development and emergence of intelligent logistic systems which can fulfil the requirements of autonmous logistic processes. However to maintain a controllable dynamic logistic system, technological development must not only provide short-run autonomous replacements for standard logistic operations but also take into account that introducing autonomy will impact the operational and strategic management of logistic services.

Because the dynamic and structural complexity of logistics networks makes it very difficult to provide all management information, which would be necessary for a central planning and control instance the autonomy of the logistic entities is a promising approach.

This autonomy can be realised by the development of adaptive logistic processes including autonomous capabilities for the decentralised coordination of autonomous logistic entities in a heterarchical structure. Autonomy describes processes of decentralised decision making in heterarchical structures. Autonomy assumes that interacting entities have the ability and possibility to decide autonomously in non deterministic systems [3].

The autonomy permits and requires new control strategies and autonomous decentralised control systems for logistic processes. In this setting, aspects like flexibility, adaptivity and reactivity to dynamically changing external influences while maintaining goals are of central interest.

The integration of strategic and tactical planning combined with an amount of actual data and possible communication between the systems entities enables the system to act autonomously and maybe compensate a temporary or unlimited malfunction of an entity or a relation between two or more entities. A consequence of the autonomous acting of the involved entities is a shift of the responsibility for the realisation of the decisions from a central decision system—be it technical or human—to the single logistic entity.

This has to be regarded by developing a management concept of autonomous logistic objects and the complexity of the total system.

3 Control of a Dynamic System by Online Risk Management

The increased complexity of logistic systems is followed by a more complicated planning and control of logistic systems and of the related processes in combination with an increased sensitivity of the total system to disturbances and malfunctions. The hazard of delayed delivery in transportation, latency in manufacturing and reduced adherence to delivery dates are results of complex system structures and increased customer requirements. All these numerated disturbances and changed conditions clarify that logistic systems and the related logistic processes are very fragile and the contained hazards and chances have to be managed to ensure the success of the logistic processes. These circumstances show that the development of a management system for risks is essential for a successful realization of autonomous logistic objects.

Avoiding, reducing and partly compensating are selected strategies for risk by a proactive autonomous risk management system relies on a a-priory identification and analysis of events, which could be dangerous for the fulfillment of goals given to an autonomous logistic object. Thereby the aim should be to model risks on an abstract level and to integrate operational risk detection into the autonomous system. Such a risk management system will be developed in our sub project.

The consequence of the proposed shift of responsibility from a central instance to an autonomous logistic object is a fundamentally different situation in the face of events or situations, which could endanger the success in terms of reaching the goals of a logistic process.

In classic logistic systems a malfunction of the centralized deciding instance is the main danger for the success of the whole of logistic processes involved. Other problems are, that central systems are suitable to only a limited extent in reacting on changing local conditions and that a local lack of information affects the total system. With the application of autonmous logistic objects this disadvantage can be compensated but for an autonomous logistic object it has to be kept in mind that there are additional risks. These risks result from the required communication between the involved objects and that the interaction between them which leads to non calculable states on local and global level. It is also important to consider that contradictory information generated from different objects is another source of risk for the logistic processes in relation to their specific goals and that an optimization on object level can compromise the goal of the total system.

Direct disturbances of the processes caused by risks which exist impartial from the logistic objects and risks which result from the interaction of the logistic processes.

These flexible characteristics of disturbances can be categorized in 3 types of risk: *External risk*, which is caused by an event, that exists independently from the autonomous processes and may affect them, *Internal risk*, which is a result of the interaction between autonomous processes, the reasoning within an autonomous process and *Information risk*, which is related to the information which are available but may be inconsistent, contradictory fuzzy, incomplete or unreliable. An overview about the different characteristics of risk which could influence the logistic objects is given in figure 1.

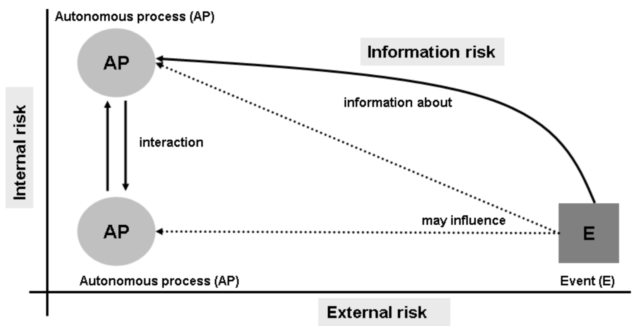

Fig. 1. Risks induced by events

In order to managing different types of risk it is essential to understand the meaning of risk for autonomous logistic objects and their environment. To handle existing and new risks for autonomous processes and autonomous objects a proactive risk management has to be established as a part of the whole system, because it helps to develop logistic processes which are robust and insusceptible to existing and occurring risks: A risk management system supports the autonomous objects in decision making and realizing these decisions considering the risk which is related to the whole logistic processes. For this reason the development of a proactive risk management system can be considered as a relevant success factor for autonomous logistic processes.

4 Risk Management of Autonomous Objects

Goal fulfillment is the defining characteristics of a risk concept for autonomous logistic entities. In the logistics domain this goal might be to reach a given destination in shortest possible time, at lowest cost or with lowest possible fuel consumption. The autonomous entities aim to maximize its local utility will usually subsume primary goal fulfillment but aspects like system continuance or contribution to a global utility of the enterprise the entity belongs to induce different risks. The autonomous system therefore needs to acquire and maintain an internal model of its environment and the processes therein. Using a "foretelling" mechanism can than enable the assessment of situations that will be occurring. Such a mechanism has of course to be of technical nature and thus needs to calculate future states of the world based on probabilities.

In a technical autonomous system one can either employ classical—brainstorming based—methods of risk assessment in advance (the "design time") or find a computer implementable method to assess risks. The former is simply a matter of completeness of the design process. The disadvantage of design-time assessment is obviously that new situations in which risks occur cannot be handled by the autonomous system. In conventional control tasks a human operator will be responsible and able to intervene. In the autonomous decision-making case this task is delegated to the system itself. Therefore enabling autonomous risk assessment is the only remaining alternative.

Thus for a risk management within an autonomous logistic entity we need five technically implementable components. (1) An internal local model of the environment, which will contain static elements that are common to all entities and inherently subjective parts originating from local perception and communication with other entities. To fulfill a given goal it will (2) need to make plans using the knowledge it has and (3) generate hypotheses about future states of the environment. The subjective part of the knowledge needs (4) a mechanism to assign a certainty value to each item and evaluate its contribution to hypotheses, triggering the acquisition of additional information as necessary. Finally it will need to (5) evaluate plans it made and predicted states of the environment for their potential of risk.

5 Technical risk aware decision-making

In conventional research on multiagent systems, it is claimed, that the local interaction of autonomous systems (microscopic behavior) should lead to an optimized behavior on the global level (macroscopic behavior) [11]. However current agent architectures are not designed to model this complex decision-making process which requires agents to process knowledge about internal structures and organizations, show awareness of other agents and communicate or even cooperate with them, and perceive changes in their environment.

An important challenge for this project is to augment the agent's deliberation cycle with the ability to identify and assess the underlying risks that are associated with the options that determine the next course of action. If necessary, the agent must be able to augment its knowledge base with missing or updated knowledge, for example, from other agents, to be able to properly assess and evaluate the feasible options. In [11] we proposed a framework for an enhanced agent deliberation process. This framework is being developed as a common basis for risk- and knowledge-management in agent decision-making [12]. Generally speaking, we use risk management to identify and assess the risks associated with one or more options.

The first step is the identification of potential risks associated with each option. Each identified risk must be evaluated to assess the magnitude of the risk and its probability of occurrence. In the ideal case, the agent has sufficient knowledge to arrive at a meaningful risk assessment. Upon completion, the result of the assessment is returned to the deliberation process which uses the information to aid in the selection of the best possible option.

Risk is thereby represented as a set of patterns with an attached "severeness" attribute, which are matched against the current or a predicted state of the world. For example assume the agent knows from a weather forecast, that it might rain within an hour. Together with the knowledge that it carries a paper roll this world state wold match a risk pattern, which states, that water harms paper with a severity of 0.8—where 1 would mean certain total loss.

Due to incomplete or uncertain knowledge, risk management may be unable to decide on risk, e.g., the weather report might be ten hours old. This triggers knowledge management to acquire the missing information or detailed information on the current situation. Knowledge acquisition may retrieve knowledge from other agents or directly from external sources/sensors. In our example a local weather service may offer up-to-date reports on an hourly basis. The agent could then decide to alter its plan from using the direct route across open space to a roofed but much longer way. The tradeof between the risk of loosing the load and choosing the longer, hence more expensive route will make the differnce of success or failure.

6 Conclusion

In the present paper we related different aspects of complexity and dynamics in modern logistic systems to the possibilities that arise from introducing autonomy. We showed that autonomous processes, that can serve as a building block for managing the growing dynamics and complexity, will need a mechanism for dealing with risks.

The concept of risk, as it is known from economics and project management as well as plant and machinery safety, has been re-introduced to fit for assessment and management by an autonomous process, implemented as an autonomous software agent. Risk management on the individual level in an autonomous agent has been introduced.

This risk management system supports the autonomous logistic objects in decision making and realizing these decisions considering the risk which is related to the whole logistic processes.

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References

1. Jens Eschenbächer and Tilman Gühring. Prozeßbenchmarking in der materialversorgung. In *Logistik Management*, pages 31–40. Springer, Berlin, 1999.
2. Tsung-Sheng Chang. An international intermodal routing. In *Operations and Technology Management 2: Complexity Management in Supply Chains*, pages 87 – 103. Erich Schmidt Verlag, Berlin, 2006.
3. Katja Windt, Felix Böse, and Thorsten Philipp. Autonomy in logistics – identification, characterisation and application. *International Journal of Computer Integrated Manufacturing*, 2007. forthcoming.
4. Günther Schuh. *Produktkomplexität managen.* Carl Hanser Verlag, München, 2005.
5. Thorsten Philipp, Christoph de Beer, Katja Windt, and Bernd Scholz-Reiter. Evaluation of autonomous logistic processes analysis of the influence of structural complexity. In Michael Hülsmann and Katja Windt, editors, *Understanding Autonomous Cooperation & Control in Logistics The Impact on Management, Information and Communication and Material Flow.* Springer, Berlin, 2007. to appear.
6. Yaneer Bar-Yam. *Dynamics of Complex Systems (Studies in Nonlinearity).* Westwing Press, 2003.
7. Julio M. Ottino. Complex systems. *AIChE Journal*, 49(2):292 – 299, Apr 2004.
8. Thorsten Philipp, Felix Böse, and Katja Windt. Autonomously controlled processes characterisation of complex production systems. In P. Cunha and P. Maropoulos, editors, *Proceedings of 3rd CIRP Conference in Digital Enterprise Technology*, Setubal, Portugal, 2006.
9. Niklas Luhmann. *Soziale Systeme. Grundriss einer allgemeinen Theorie.* Suhrkamp, Frankfurt/M, 1984.
10. Dirk Baecker. *Organisation als System*, volume 1434 of *suhrkamp taschenbuch wissenschaft.* Suhrkamp, Frankfurt/M., 1999.
11. Hagen Langer, Jan D. Gehrke, Joachim Hammer, Martin Lorenz, Ingo J. Timm, and Otthein Herzog. A framework for distributed knowledge management in autonomous logistic processes. *International Journal of Knowledge-Based & Intelligent Engineering Systems*, 10(4):277–290, 2005.
12. Hagen Langer, Jan D. Gehrke, and Otthein Herzog. Distributed knowledge management in dynamic environments. In Michael Hülsmann and Katja Windt, editors, *Understanding Autonomous Cooperation & Control in Logistics*, chapter B4, pages 215–230. Springer, Berlin, 2006.