Autonomous Logistic Processes: An Application Oriented Approach for Risk Management

Boris Bemeleit[1], Martin Lorenz[2], Jens Schumacher[3], and Otthein Herzog[2]

[1] Bremen Institute for Industrial Technology and Applied Work Science—BIBA
bem@biba.uni-bremen.de
[2] Center for Computing Technologies—TZI {mlo|herzog}@tzi.de
[3] University of Applied Science Vorarlberg - jens.schumacher@fhv.at

ABSTRACT
Autonomous logistics processes are an approach to face the current challenges in logistics by use of modern information and communication technologies (ICT) and novel decision-preparing and decision-making tools. Risk management is needed to make the autonomous logistic processes reliable and robust against suddenly appearing events which were not considered during the planning phase of the logistic processes. This paper introduces a proposed realisation of using risk management by agent based technology for realizing robustness of autonomous control in the domain of logistics.

INTRODUCTION
Changing product life cycles, company structures and information flows constantly change the requirements for logistic processes and impose new challenges. These are results of ever increasing quantities of transported goods, increasing complexity of logistic networks, e.g., by the development of virtual enterprises, and the increasing maturity of new ICTs like RFID and ubiquitous computing. With the reduction of the vertical range of manufacturing and the tendency to globally distributed production, logistics and the design of logistic processes are of particular significance [1]. As a result the importance of logistics rises steadily and new concepts for planning and controlling the logistic processes are needed.
The rising complexity of inter-organizational structures and also a relative shortage of logistic infrastructure lead to an increasing utilization of the existing logistic processes and 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 logistic processes.
The resulting dynamic and structural complexity of logistics networks renders conventional central planning and control structures outdated. As it gets very difficult to provide all necessary information for a central planning and control instance in time during the planning phase and to react on incoming information during the execution phase. 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, i.e., autonomous logistic entities.
These autonomous entities are self-contained and follow their local goals. 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 investigate the opportunities and issues that arise from introducing autonomy into logistic processes on an entity level as defined in [3]. It will be shown that risk management on the level of individuals in an autonomous logistic system can answer questions of robustness, dependability and trust that could arise when autonomous logistic entities are introduced. The requirements for a technical system that can address those will be laid out and a possible application oriented approach will be introduced.

COMPLEXITY AND DYNAMIC IN LOGISTIC SYSTEMS

The main issue that makes modern logistic systems difficult to handle by traditional central process controls is the increasing complexity which is result from the steadily rising number of goods to be transported and a more distinctive intermodalisation. 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 appear to be insufficient for an entire understanding of the term complexity in the context of logistic systems, in particular production systems [5]. Philipp et al. [6] 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 dynamics of a logistic system are characterised by its temporal behaviour. A dynamic system is subject to permanent changes on the micro and meso level but it can also take on a constant perceivable state on the 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 dynamics of the logistic system and is as important for planning tasks and realising logistic processes as the complexity of the logistic system.

However, the complexity of a logistic system and its dynamic as well as the overall behaviour of the system still do not allow for a 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 the complexity (the system is exposed to) [7] we enable the (logistic) system to deal with increased complexity in its environment by increasing the complexity of the system itself and managing this complexity (by means of technology) [8].

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

The new 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 possibly compensate a temporary or unlimited malfunction of an entity or a relation between two or more entities. A consequence of the autonomous nature 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 a specific logistic entity. This has to be taken into account by developing a management concept of autonomous logistic objects given the complexity of the total system.

CONTROL OF A DYNAMIC SYSTEM BY ONLINE RISK MANAGEMENT

In classical logistic systems a malfunction of the centralized decision instance is the main danger for the success of the logistic processes involved. Other problems are constituted by the fact that central systems are only suitable to a limited extent to react to changing local conditions as a local lack of information affects the complete system. With the introduction of autonomous 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 the interaction between them which leads to non-predictable states on the local and global level. It is also important to consider that contradictory information generated from different objects are another source of risk for the logistic processes in relation to their specific goals and that an optimization on the local level can compromise the goal of the complete system.
These flexible characteristics of disturbances can be categorized in three types of risks:

- 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 or 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 of the different characteristics of risks which may influence the logistic objects is given in figure 1.

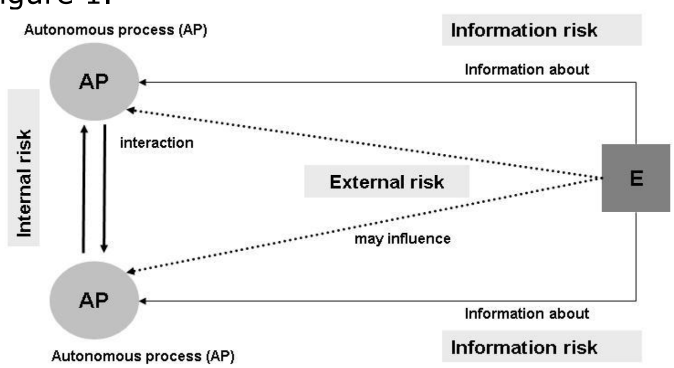

Fig. 1. Risks induced by events; related to [10]

In order to manage different types of risks 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 autonomous objects in decision making and in realizing these decisions considering the risk which is related to the global 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.

RISK MANAGEMENT OF AUTONOMOUS OBJECTS

Goal fulfilment is the defining characteristic of a risk management concept for autonomous logistic entities. In the logistics domain this goal could be to reach a given destination in the shortest possible time, at lowest cost, or with the lowest possible fuel consumption. The autonomous entities aim to maximize their local utility and will usually try to fulfil their primary goals, but aspects like system stability or the contribution to a global utility of the enterprise an 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 then enable the assessment of situations that will be occurring. Such a mechanism has of course to be of technical nature and thus needs to look at possible 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 realisable method to assess risks. The former is simply a matter of the completeness of the design process where the disadvantage of design-time assessment is obviously that unforeseen situations in which risks occur cannot be handled by the autonomous system. In conventional control tasks a human operator will be responsible and thus will be able to intervene in most cases. 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 the 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 fulfil 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 have to

(5) evaluate current plans and predicted states of the environment for their potential of risk.

The main technical challenge of autonomous logistic processes is the realisation of autonomous decision taking in logistic entities that have no reliable connection to a

central control system. Granting such systems a certain level of autonomy may be risky for a principal. Therefore he will ask for reliability or dependability facing the various risks the autonomous entity may be exposed to.
Autonomous software agents, situated in multiagent systems (MAS) are a prototypical realization of autonomous processes [9].
Because the complexity of the local problem is by orders of magnitude lower than a global optimisation approach we are able to model the logistic problem at a much more fine grained level. As such we can give entities quite some reasoning power for themselves. This includes the ability to identify and assess possible risks such as being late (and having to pay a penalty), to let goods rot or thaw, or to be damaged by improper handling. Therefore, planning for a logistic domain is a real-time problem with relaxed timing constraints of hours or even days rather than seconds. Domain actions like loading, delivering, or monitoring goods do not utilise the full computational power of the agents' underlying hardware. Although deliberating can be done concurrently to acting it is constrained by on-board computational resources, which may be very limited regarding computing power and memory.
Risk management as integral part of an autonomous agent's deliberation is realised in three steps. The agent uses a hybrid symbolic and probabilistic planner to generate predictions of future states of its environment given outcomes of its own actions as well as possible actions of others and events that occur. The most probable plan that will meet the goals produces a time-series of states, for which risk can be assessed by matching patterns of dangerous stated against the predicted state. We discuss aspects of risk identification using an internal model of the domain and abstract patterns of situations that induce risk in [10, 11]. The construction of possible future states of the world in which risky situations can occur is subject to current research outlined in [12]. The acquisition of knowledge that might be needed to assess a situation and the integration of novel knowledge into an agent's world model is shown in [13].
Integrating those methods within an autonomous technical system (i.e., an autonomous software agent), which constitutes an autonomous logistic process enables the sort of explainable dependability a logistic service provider as the principal of an autonomous logistic system will ask for.

CONCLUSION

To enable local autonomous decision making in complex and dynamic logistics each entity can be equipped with its own intelligence including a risk management system. In the present paper we analysed possibilities for risk management in autonomous logistic processes and related aspects of complexity and dynamics in modern logistic systems. We showed that autonomous logistic processes, which can serve as a building block for managing the growing dynamics and complexity, will need a mechanism for dealing with risks.
The proposed risk management appears to be an adequate option to be integrated in a MAS as a required and helpful application. This risk management system supports 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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